Evaluating the Effectiveness of Speed Humps Related to Speed Profile and Noise Profile

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ABSTRACT

Speed humps are an effective traffic calming measure to improve the safety of road users. On the other hand, speed humps have certain drawbacks, such as increasing emergency response time, causing damage to cars, and high noise levels due to excessive traffic. These impacts further vary with different hump profiles. Thus, the primary objective of this research is to investigate how the geometric profile of speed humps affects vehicle speed and noise level. The secondary objective is to find the Level of Service in the presence and absence of a speed hump by using VISSIM microsimulation. In this study, Lake Drive Road, Nawala, was selected with four different speed hump profiles. The Sound Meter smartphone application was used for noise monitoring. A drone camera footage was utilized to capture vehicle flows while speed trajectories of each vehicle were developed using tracking software. The developed speed profiles were used for the simulation purpose. Then, a Multiple Linear Regression (MLR) model was developed and validated to predict the hump height for the desired speed reduction and desired noise level for each selected four-vehicle category. Further, the average noise levels were found to be higher than the Central Environmental Authority's permissible noise level, and it increases with the height of the hump. It was also observed that as the height of the hump increases, vehicle speed decreases. The largest speed reduction, 42.13 %, was observed in passenger cars, while the lowest speed reduction, 23.5 %, was observed in motorcycles. Therefore, speed analysis findings reveal that passenger cars have a significant speed reduction when compared to other categories. However, the average speed reduction for all vehicles was identified as 33.85 %, and VISSIM simulations revealed that the average Level of Service (LOS) drops to LOS C from LOS A due to the presence of the speed hump.

KEYWORDS: *Level of Service, Speed hump profile, Speed hump, VISSIM*

1 INTRODUCTION

Traffic calming devices play a prominent role in the present day. With the rise in the preference of private vehicles, it is necessary to implement traffic calming devices to increase safety of road users. These devices are used to maintain a balance between road traffic and other road users. Placing a traffic calming device in an inconvenient position would not solve the problem of roadways. It can reduce human efficiency and have several negative consequences for road users, such as car damage and wear and tear over time, a delay in emergency response time, and increased road noise (Kiran et al., 2020). Therefore, the main objective of the study is to build two regression models to predict the vehicular speed and the noise level as a function of hump characteristics. Then, using a simulation model, the LOS due to the presence and absence of the speed hump is measured. Since limited research on the impact of hump characteristics on driver behavior has been conducted in Sri Lanka, the created model may serve as a guide for the future development of speed humps.

2 LITERATURE REVIEW

2.1 Literature study of speed analysis

Numerous implementations and attempts at speed analysis for various hump profiles have been made by previous researchers. The main distinguishing feature among these studies is the method used to detect the speed of the vehicle. The findings of the speed analysis literature are summarized in Table 1.

Table 1: Summary of the previous speed analysis studies

Author	Method Used	Gap
Kiran et al., 2020	-A speed radar gun was utilized - Measured speed range: -100m to 80m from the speed hump. -Vehicle categories: two-wheelers, four-wheelers, and multi-axle vehicles, light commercial vehicles, and auto vehicles	Incapable of measuring the speed of the same vehicle at several points.
Mustafa et al., 2019	- A speed radar gun was utilized - Measured speed range: -20 m to 20m from the speed hump - Vehicle categories: motorcycles, cars, buses and lorries.	Incapable of measuring the speed of the same vehicle at several points.
Rosli and Hamsa, 2019	- A speed radar gun was utilized - Six identical hump profiles were selected - Speed measured at the speed hump	Unable to analyse the speed hump effect on vehicular speed whereas it can only be compared with the different speed profile characteristics.
Arthanayake et al., 2020	- A drone camera was used to capture the footage, and Tracker software was used to extract the speed measurements	The study was conducted for only one specific speed hump.
Gupta, 2014	- A speed radar gun was utilized - Measured speed range: 10m, 7m, 5m, and 2m (left and right side of the hump).	Data has been collected for only two vehicle categories.
Kadar et al., 2013	-Only the vehicle count was observed. - Data processing has been done at 30-minute intervals over a 12-hour duration, from 7:00 am to 7:00 pm. - They have collected data for four categories.	There is no speed analysis. Only the traffic volume was considered.
Antić *et al.*, 2013	- A speed radar gun was utilized - Speed measurements were taken before speed bump installation, one day and one month after the installation of the speed bump. - Measured speed range: 40 meters before, after, and at the speed bump.	Installation is more expensive and requires approval from several departments.
Teja et al., 2017	- Video camera technique was used to measure the vehicle speed. - Every 15 minutes, volume counts have been obtained. - Measured speed range: 10 m, 7 m, 4 m, and 1 m before and after the speed breaker.	This approach is ineffective when compared to the speed gun measurement.

Source: (Literature Sources)

2.2 Literature study of noise level analysis on speed humps

Previous researchers have attempted and implemented several noise analysis methods for different hump characteristics. The technique they utilized to determine the vehicle's noise level is the primary feature that differentiates them from one another. The findings of the noise analysis literature are summarized in Table 2.

Table 2: Summary of the previous noise analysis studies

Author	Method Used	Gap
Mustafa et al., 2019	- The noise level meter was placed at an elevation of 1.2m from the ground level. - Every 15 minutes, the noise level, has been recorded. - Used a comparison with average speed.	No comparison with the speed measurement.
Kadar et al., 2013	- Noise level meter placed at 1m depth from the ground level. - For about 12 hours, the noise intensity was calculated at 15-minute intervals. - A comparison was made with traffic volume	The average noise level was not measured.
Wewalwala et al., 201	- The sound level meter has been installed on a stand 1.5 meters from the ground floor, 1.0 meters from the outer driving lane side. - Two different sets of measurements were used. - Vehicle categories: Passenger cars, passenger vans, three-wheelers, bicycles, and lorries	Only one road was selected for noise measurement. No comparison was made with speed measurement.

Source: (Literature Sources)

2.3 Literature study of speed hump models

Several speed hump models have been developed and utilized in the past for a variety of objectives. The majority of studies simulated the speed hump using VISSIM software. Table 3 summarizes some of the previous literature related to speed hump simulations.

Table 3: Summary of the previous simulation models

Author	Method Used	Gap
Chimba et al., 2019	- VISSIM microsimulation was used to simulate individual vehicle motions to measure traffic efficiency. - Reduced Speed Area (RSA) tool was used to simulate the speed hump.	The model has not been calibrated.
Kiran et al., 2020	- VISSIM microsimulation was used to simulate individual vehicle motions to measure traffic efficiency. - RSA tool was used to simulate the speed hump. - Two models (with humps & without humps) were developed for each stretch and results were tabulated	The study was conducted only for a one-speed hump.
Nair et al, 2013	-In this study, the impact of speed restriction measures on road safety and level of service has been measured. -RSA tool has been used to simulate the Speed hump	Use of the speed gun to measure the speed is not effective when compared to the video camera technique.

Source: (Literature Sources)

3 METHODOLOGY

In the modern world, with the growing population and advancements in the transportation field, the use of private vehicles for mobility has become very common. In this situation, traffic calming devices play a prominent role in the present day. Traffic calming devices such as road humps contribute to the enhancement of living conditions by reducing vehicle accidents and ensuring the surrounding environment is safe from possible collisions. However, placing a speed hump in a random location does not resolve the issue of highways entirely. It may have downsides such as increasing emergency response time, causing damage to cars, increasing noise levels, and causing discomfort for drivers (Tester *et al.*, 2004). Therefore, the main objective of the study is to perform a speed analysis and obtain a regression model to predict the profile of the speed hump for the desired speed reduction as well as the desired noise level for each of the selected four vehicle categories. Furthermore, the Level of Service in the presence and absence of a speed hump was observed using VISSIM modeling software. Lake Drive Road in Nawala has been chosen for this study. For speed observation, all the vehicles have been categorised into four vehicular categories like category A for two-wheelers, category B for three-wheelers, category C for passenger cars, and category D for MSVs. For noise observation, all the vehicles have been categorised into five vehicular categories like category A for motorcycle, category B for three-wheelers, category C for passenger cars, category D for MSVs, and category E for MGVs. For the speed data collection, several methods had been adopted by past researchers such as speed measuring through speed guns (Kiran, Kumar, et al, 2020), analyzing traffic speed patterns using a video camera (Teja et al, 2017), and utilizing a drone camera (Arthanayake et al, 2020). By considering the pros and cons of such methods, the droner camera has been chosen as the best method for data collection. Therefore, a video camera mounted on a drone was utilized for the primary data collection. The “Tracker” application was used to obtain the speed data, and the VISSIM modeling software was used to demonstrate the presence and absence of the speed hump. The noise level was determined using the "Sound Meter" application, which rated 4.8 out of 5 in Google Play Store. Here, a selected road section is required to reduce external factors that led to the decrease in vehicular speed. Therefore, by considering several factors Lake Drive Road was selected with varying speed hump profiles for the primary data collection in the Western Province, Sri Lanka.

3.1 Selection of the location.

The major purpose of site selection was to reduce external factors that led to the reduction of the vehicular speed. The Lake Drive Road, Nawala route was selected for this study since this road has an average traffic density during off-peak hours, ensuring that a vehicle's motion is not disrupted by other cars. Here four different hump profiles were selected as shown in Figures 1-4 for speed measurements and three different hump profiles were selected for noise level measurement. The characteristics of those different hump profiles are shown in Table 4.

Figure 1: Seed Hump 1

Figure 2: Speed Hump 2

Figure 3: Speed Hump 3

Figure 4: Speed Hump 4

Table 4: Speed Hump Characteristics

No	Height(mm)	Width (m)
Hump-1	70 mm	8.75 m
Hump-2	85 mm	9.21 m
Hump-3	100 mm	7.31 m
Hump-4	90 mm	8.46 m

3.2 Collection of speed measurement data

A drone camera was used to measure the speed of the vehicles since it can be used to determine the speed of a vehicle at any point utilising Tracker software, whereas a speed gun is only capable of determining the speed of a vehicle at one location. Here data were collected on Saturday from 11.00 am to 12.30 pm. Firstly, 5m markings were labelled on the road with a range of 30m as shown in Figure 5.

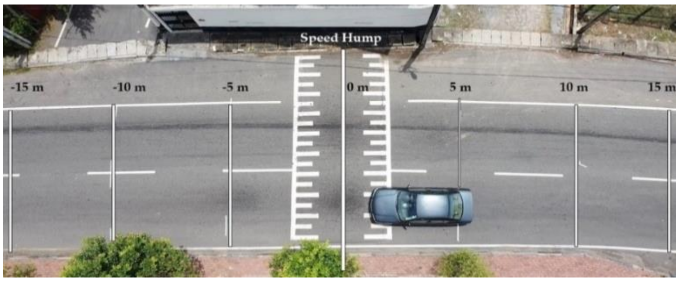

Figure 5: Labelled 5m markings before and after the speed hump

After, using a drone camera, video footage was recorded for four different hump profiles. Then, using the Tracker software, the speed for each of the four vehicle categories (bikes, three-wheelers, cars, and Medium Size Vehicles (MSV)) was extracted.

3.3 Collection of Noise measurement

For the Noise measurement, the "Sound Meter" application which has 4.8 ratings out of 5 was used. Here a smartphone was placed 1m above the ground level and 7m apart from the hump to capture the noise level as shown in Figure 6.

Figure 6: Smartphone placed on a tripod to obtain the noise level

3.4 Develop a simulation model

Two models were developed using the microsimulation program VISSIM which were created to demonstrate the real-time behaviour of vehicles in the presence of humps as well as to understand the behaviour of vehicles in the absence of speed humps. The Speed hump with a height of 90mm was selected for the VISSIM simulation. Vehicle behaviour in this region was calibrated in terms of delays and queue length. Those values were taken from a study done by Gunarathne et al. (2021) in the same area. Figure 7 depicts the outcome of the simulation.

3.5 Data analysis

Two multiple linear regression models were developed to predict the speed reduction and the noise level as a function of the height of the speed hump. The dependent variable was speed reduction (%) for the first model, whereas the independent variables were hump height, hump width, and vehicle type. Noise level (dB(A)) was used as a dependent variable in the second model, whereas hump height, hump width, and vehicle type were used as independent variables. SPSS software was used for data analysis. For the speed data analysis, 320 vehicles were considered, whereas 225 vehicles were considered for the noise data analysis. Both the noise and speed reduction models were validated primarily by verifying the assumptions. The equation for multiple linear regression is similar to that of basic linear regression, except for the additional terms.

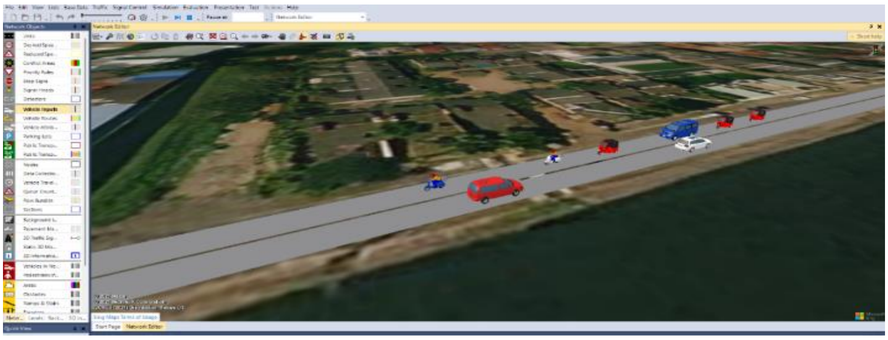

Figure 7: 3D view of the simulation

4 RESULTS AND DATA ANALYSIS

4.1 Findings of speed measurements

Figure 8, shows the average vehicle speed for each vehicle category between -15m and 15m from the speed hump.

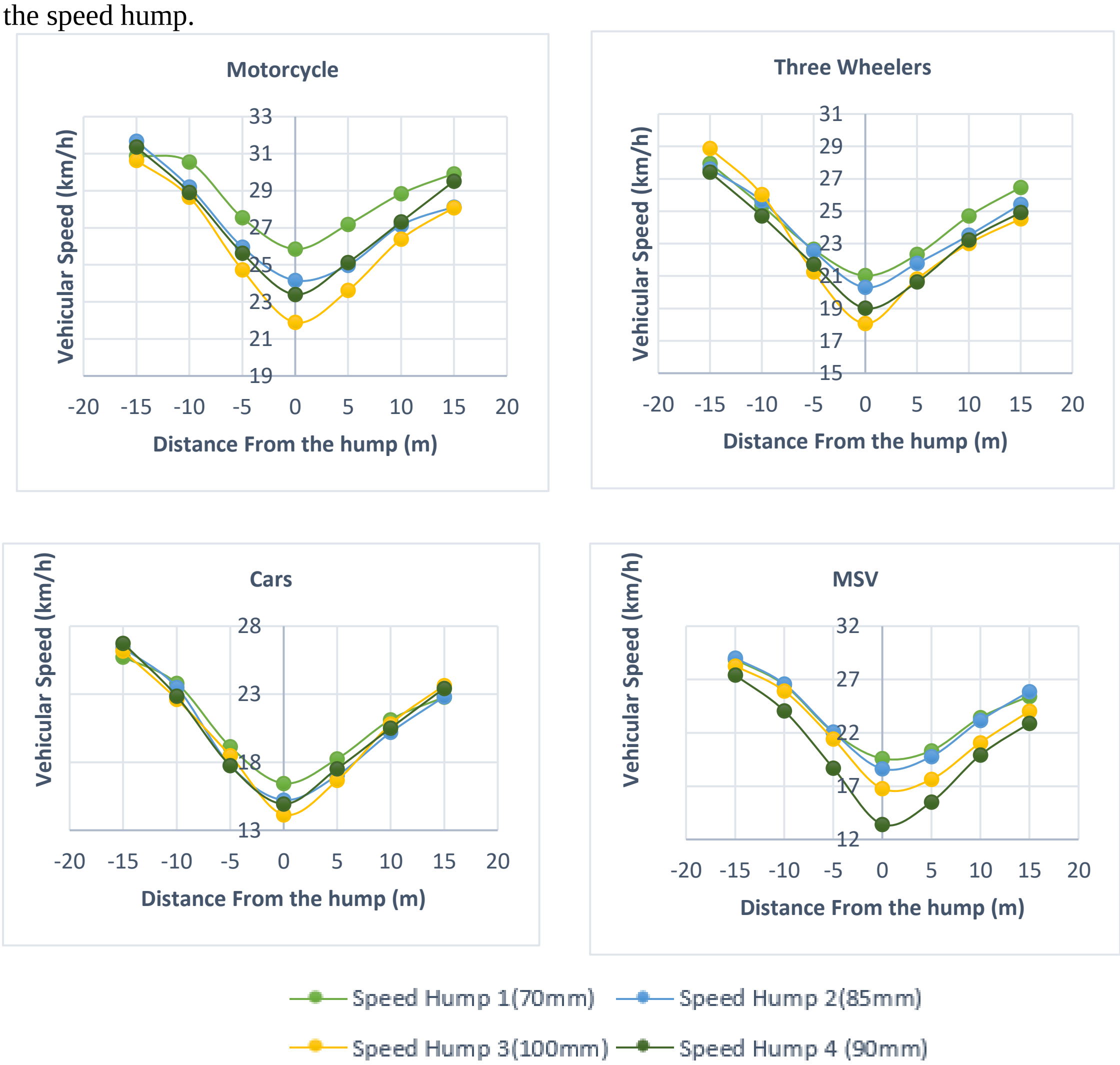

Figure 8: Speed Variation due to different hump profile for the four vehicle categories

Here the yellow line on the graph represents the vehicle's speed variation on the highest hump height, which is 100mm, and the green line represents the vehicle's speed variation on the lowest hump height, which is 70mm. As shown in Figure 8, for all the four vehicle types, the height of the hump rises, while the speed of each vehicle decreases. Here, for motorbikes, the speed reduction percentages for hump heights of 70mm, 85mm, 90mm, and 100mm are 13.6 %, 14.08 %, 20.73 %, and 22.04 %, respectively. Therefore, it is clear that as the height of the hump rises, the speed reduction is increased. Also, the average speed reduction for motorcycles, three-wheelers, cars, and MSVs are 17.62 %, 22.67 %, 34.38 %, and 30.64 %, respectively. Therefore, it can be observed that cars have a higher speed reduction which is 34.38% while motorcycles have the lowest speed reduction which is 17.62 % owing to the speed hump. Then, the average speed reduction due to all four humps was identified as 26.33 %. Further, cars have the highest speed regain percentage which is 34.38%, whereas motorcycles have the lowest speed regain percentage, which is 17.62%. Finally, based on observed data, none of the vehicles exceeded the allowed speed limit of 40 km/hr due to the presence of the speed hump. As a result of the hump's placement, it will become more secure for both residents and drivers.

4.2 Findings of the noise measurements

Figure 9 represents the average noise level variations derived by observing three different hump profiles.

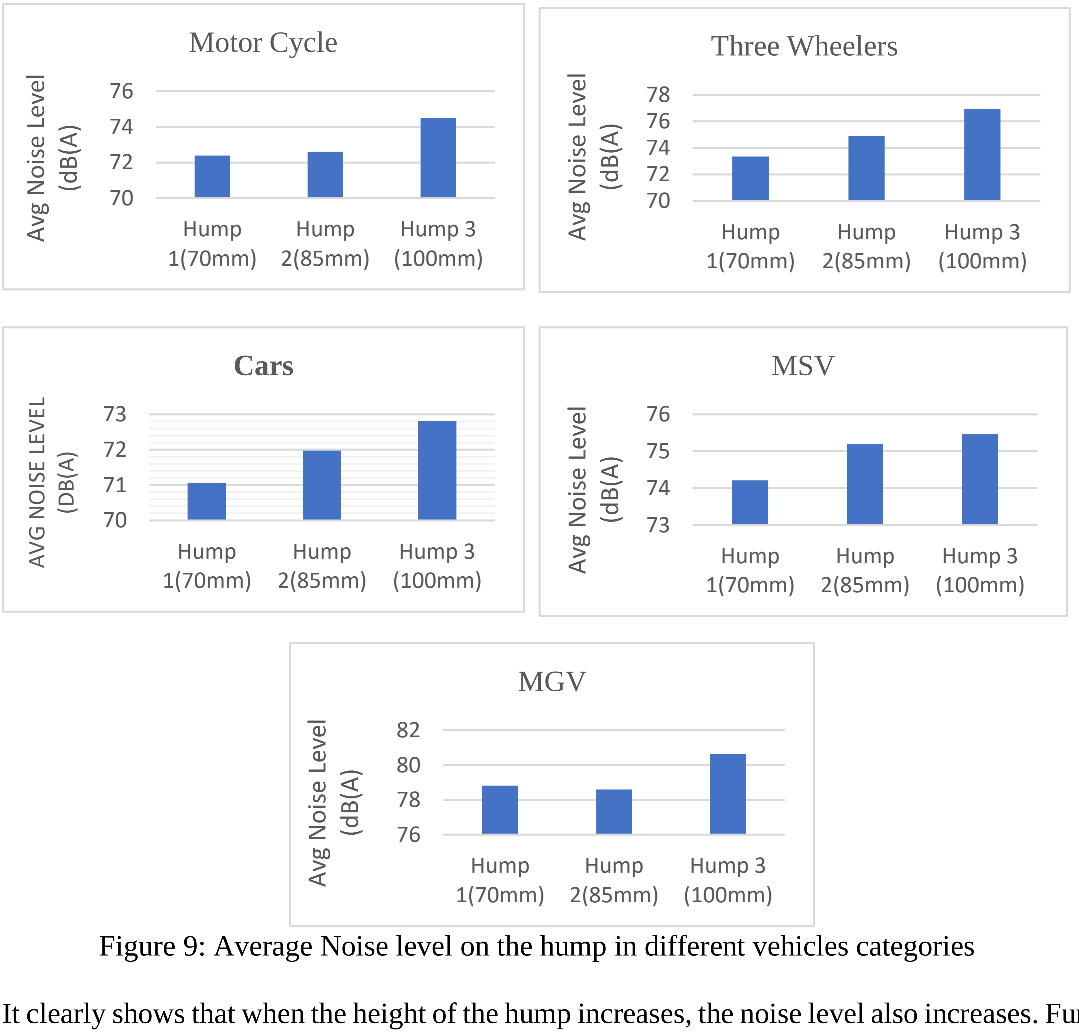

Figure 9: Average Noise level on the hump in different vehicles categories

It clearly shows that when the height of the hump increases, the noise level also increases. Further, it was observed that Medium Good Vehicles (MGV) have the highest average noise level, which is 78.82 dB(A) for the hump-1, 78.59 dB(A) for the hump-2, and 80.63 dB(A) for the hump-3. At the same time, the passenger cars have the lowest average noise level, which is 71.06 dB(A) for the hump-1, 71.98 dB(A) for the hump-2, and 72.81 dB(A) for the hump-3. The maximum allowable noise level established by the Central Environmental Authority is shown in Table 5 (Srimani, 1996). Here, it was identified that the measured average noise level for these five vehicle categories exceeded the Central Environmental Authority's permissible noise level.

Table 5: Maximum permissible noise level (Srimani, 1996)

LAeq, T (Average of the total sound energy (Leq) measured over a specified period of time (T)		
Areas	**Day Time**	**Night-time**
Rural Residential Area	55	45
Urban Residential area	60	50
Mixed Residential Area	63	45

4.3 Findings of the VISSIM simulation

In this instance, two models were developed for the presence and absence of the speed hump in order to identify the driving behaviour influenced by the speed hump. The model was calibrated using the queue length of the selected area. The existence of the speed hump indicates that LOS C is for Westbound and LOS B is for Eastbound, which has a lower degree of freedom as shown in Table 6.

Table 6: Existence of speed hump

Link No	QLen	QLenMax	Vehicles	LOS
Westbound	5.36 m	66.13 m	477	LOS C
Eastbound	2.70 m	72.20 m	465	LOS B
Average	403 m	72.20 m	942	LOS C

The absence of a speed hump, Both Westbound and Eastbound have LOS A, which is an excellent road operating condition as shown in Table 7.

Table 7: Absence of speed hump

Link No	QLen	QLenMax	Vehicles	LOS
Westbound	0.0 m	0.0 m	479	LOS A
Eastbound	0.0 m	0.0 m	467	LOS A
Average	0.0 m	0.0 m	946	LOS A

According to the acquired data, the presence of a speed hump has a detrimental effect when compared to its absence because it increases traffic congestion and decreases the degree of freedom on the road. In conclusion, the existence of the speed hump has increased the safety of the drivers and residents. However, the effect of noise and driver delay time have increased. Thus, prior to constructing the speed hump, it is recommended to determine the desired speed of the road and the noise limit. In this instance, the noise emission model and the speed reduction model will aid future designers in designing the road humps.

4.4 Data Analysis

Here, two distinct multiple linear regression models were developed for speed reduction as well as the noise level. Table 8 shows the variables that were collected. In this section, the development of those two models is discussed. SPSS software was utilized to conduct the analysis since it was recommended in previous literature.

Table 8: Collected variables

Factors	Type of variable
Type of vehicle	Independent
Height of the speed hump	Independent
Width of the speed hump	Independent
Speed Reduction %	Dependent
Noise Level dB(A)	Dependent

4.4.1 Noise data analysis

The parameter estimates summarize the effect of each predictor. Here for covariates (B), Positive coefficients show positive correlations between predictors and outcome for covariates. Here, the p-value was 0.287 (> 0.05) for the width of the hump, it denotes that it is not Statistically significant and indicates strong evidence for the null hypothesis. Therefore, the model was refitted by removing the width of the speed hump. The fitted model result is listed in Table 9.

Table 9: Parameter estimation of Noise Analysis

Parameter	B	std Error	Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	67.228	1.1318	65.010	69.446	3528.534	1	.000
MGVs	6.191	.4908	5.229	7.153	159.099	1	.000
MSVs	1.800	.4908	.838	2.762	13.449	1	.000
Cars	-1.207	.4908	-2.169	-.245	6.044	1	.014
Three wheelers	1.899	.4908	.937	2.861	14.963	1	.000
Bikes	0[a]	.	.	.	.	.	.
Hump height(mm)	.070	.0127	.045	.095	30.276	1	.000
(Scale)	5.421[b]	.5111	4.506	6.521			

Then, the following equations were obtained from the model. Here, NL denotes the noise level in decibels (A), while H denotes the speed hump height in millimeters.

$$\mathbf{NL_{MGVs}} = 6.191\ (1) + 0.07\ (H) + 67.288 \quad (1)$$
$$\mathbf{NL_{MSVs}} = 1.80\ (1) + 0.07\ (H) + 67.288 \quad (2)$$
$$\mathbf{NL_{Cars}} = -1.207\ (1) + 0.07\ (H) + 67.288 \quad (3)$$
$$\mathbf{NL_{TW}} = 1.899\ (1) + 0.07\ (H) + 67.288 \quad (4)$$
$$\mathbf{NL_{Bikes}} = 0.07\ (H) + 67.288 \quad (5)$$

4.4.2 Speed data analysis

Here the p-value is 0.775 (> 0.05) for the width of the hump indicates that it is not statistically significant and denotes strong evidence for the null hypothesis. Therefore, a refitted model was developed by removing the width of the speed hump. The fitted results are listed in Table 10.

Table 10: Parameter estimation of Speed Analysis

Parameter	B	Std Error	Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	-9.680	5.6935	-20.839	1.479	2.891	1	.089
MSVs	16.300	1.9725	12.433	20.166	68.281	1	.000
Cars	17.465	1.9539	13.635	21.294	79.889	1	.000
Three wheelers	6.070	1.9600	2.229	9.912	9.592	1	.002
Bikes	0[a]	.	.	.	.	.	.
Height of the Hump	.388	.0640	.263	.514	36.747	1	.000
(Scale)	153.665[b]	12.1673	131.576	179.462			

Then, using the created model, the following equations were obtained. Here, SR denotes the speed reduction %, while H is the height of the speed hump in millimeters.

$$\mathbf{SR_{MSVs}} = 16.3\ (1) + 0.388\ (H) - 9.680 \quad (6)$$
$$\mathbf{SR_{Cars}} = 17.465 + 0.388\ (H) - 9.680 \quad (7)$$

$$\mathbf{SR_{TW}} = 6.070\ (1) + 0.388\ (H) - 9.680 \quad (8)$$

$$\mathbf{SR_{Bikes}} = 0.388\ (H) - 9.680 \quad (9)$$

4.5 Checking Model Assumptions

In this section, the assumptions of the developed multiple regression model are tested. Then the model was validated using sample data by comparing the obtained sample values to the model predicted values. The following assumptions were tested.

1. The dependent variable is normally distributed, and it is a continuous variable
2. Contain two or more independent variables
3. Independence of observations
4. The variance of the residuals is constant
5. A linear relationship between the dependent and the independent variable
6. This test does not have any multicollinearity
7. Check the significant outliers and highly influential points
8. The residuals are approximately normally distributed

As a result, the dependent variable is normally distributed, then the first assumption is satisfied. Also, there are three independent variables included in the test; therefore, it satisfies the second assumption of the multiple linear regression. Additionally, the residuals are independent in this model, and the Durban Watson values obtained were 2.172 and 2.086 for noise analysis and speed analysis, respectively, which are closer to 2. Therefore, the third assumption was satisfied. Here, the relationship between the independent and dependent variables is linear; additionally, the plot of standardized residuals vs. standardized predicted value shows no apparent signs of funneling, and the VIF score is well below 4, indicating that there are no issues with multicollinearity in the model, implying that the fourth, fifth, and sixth assumptions were met. Finally, no significant outliers were identified, and the residuals are approximately normally distributed. Thus, all MLR assumptions were satisfied for the obtained two models.

5 DISCUSSION

After collecting the data, two MLR models were created to predict the speed reduction and noise level, as a function of the hump height, and all assumptions were checked. Subsequently, the obtained regression models were validated.

Here, it was observed that, when the height of the hump increases, there is a decrement of vehicular speed but an increasement in the noise level. Also, it was observed that average speed reduction for the motorcycle, three-wheelers, cars, and MSVs are 17.62 %,22.67 %, 34.38 %, and 30.64 %. Therefore, passenger cars have a more significant speed reduction when compared to other vehicles. Further, it was identified that the noise level at the speed hump exceeded the permissible noise level according to the Central Environmental Authority guidelines, Sri Lanka, and also it was observed that MGVs have the highest average noise level, whereas passenger cars have the lowest average noise level for each selected hump profile. Finally, the VISSIM simulation shows that the existence of the speed hump reduces the average level of the service of the road from LOS A to LOS C. Therefore, it was identified that the presence of a speed hump has a detrimental effect compared to its absence.

6 LIMITATION AND RECOMMENDATIONS

The experimental findings indicate that the hump's height substantially impacts both speed reduction and noise levels around the hump. This research examined about 30m range while speed data collecting. To obtain the maximum reduction in speed, it is recommended to utilize a larger area. Additionally, vehicle speeds may vary significantly depending on road conditions as well as the time of day. Also, the speed of the vehicle could also vary depending on the signboard prior to the speed hump and the presence of speed hump markings. For this study, there were no signboards identified before the speed hump, and only markings were present on the speed hump. In general, the differences in hump profiles have a substantial effect on vehicle speed. Here the average noise level was found to be greater than the permitted level. It caused a serious issue for those who live near the road. However, the noise level measurement method using a smartphone is not very accurate. Further corrections for background noise and vehicle engine noise need to be done in future studies. Therefore, a proper investigation is recommended prior to installing speed humps. Since limited research on the impact of hump characteristics on driver behavior has been conducted in Sri Lanka, the created model may serve as a guide for future improvements of the speed hump.

7 CONCLUSIONS

This research was conducted in the residential area of Lake Drive, Nawala. A drone camera was used to gather speed data, and vehicular speed was measured between -15m and 15m from the speed hump's center. The spotted speed was extracted using a tracker software, and the noise level was measured using a smartphone application. Then, two MLR models were created to predict the vehicle's desired speed reduction and noise level in terms of hump height. These connections offer field engineers with a valuable tool for designing hump shapes for speed control as well as noise control. The paper's primary results revealed that the vehicle speeds decreased as vehicles reached each road hump. Also, the average speed observed was less than the permissible speed limit on this road. Additionally, the observation showed that passenger cars had a higher percentage of speed decrease than other vehicles. Here it was identified for all categories, a 10mm increase in the height of the speed hump reduces the speed by 3.88 % as well as for all categories, a 10mm increase in the height of the speed hump increases the noise level by 0.7 dB(A). Moreover, MGVs generate the highest noise level on average, while passenger vehicles generate the least noise level on average for each of the chosen hump profiles. Additionally, it was observed that the noise level surpassed the acceptable limit set by the Sri Lanka Central Environmental Authority. Consequently, it will cause long term harm and disruptions to the people who live near the residential road in the long run. Finally, it was observed that the average LOS dropped to LOS C from LOS A due to the presence of the speed hump. Also, it was observed, a minor difference in hump height, increases the driver's delay time and the noise level near the speed hump significantly. Therefore, it is suggested to follow a guideline prior to constructing a speed hump. Finally, it can be concluded that the objectives of the research were accomplished.

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