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Effectiveness of and Public Perception about the Installation of Transverse Rumble Strips with Road Studs

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Abstract. The installation of transverse rumble strips (TRS) is a common practice to reduce vehicle speed and alert drivers on the roadway. However, the combination of TRS with road studs to enhance traffic safety is still not widely used by local authorities. This paper aims to evaluate the effectiveness of and the public perception about the installation of TRS with road studs. A field observation was carried out on the TRS road section with and without road studs for speed evaluation. A questionnaire survey was also conducted to assess the public perception towards the installation of this measure. The results indicate that the mean speed at the TRS road section with road studs was lower than the speed at the TRS road section without a road stud and its effectiveness was evaluated using a statistical test. Responses from the questionnaire survey showed that respondents agree that both TRS with and without road studs can reduce speed effectively. Respondents also believed that the installation of road studs might cause damage to the vehicle. This paper concludes that TRS installed with road studs effectively reduces speed which is consistent with the results of the public perception survey.

1. Introduction

Road traffic injuries are the leading cause of death globally with approximately 1.3 million fatalities each year. In 2018, the World Health Organization (WHO) [1] estimated the global rate of road traffic deaths to be 18.2 per 100,000 people. In South-East Asia alone, the regional rates are the second highest with road traffic deaths at 20.7 deaths per 100,000 people. The huge number of yearly deaths from road traffic accidents has been recognized as one of the main challenges caused by unsustainable transport, hence, making road safety relevant and a key priority [2].

Motorization in Malaysia is growing rapidly due to which, the country has had the highest fatality risk in the world since 1996 [3]. Speeding, which is defined as driving too fast for road conditions or exceeding the posted speed limit, has been a significant contributing factor in traffic fatalities nationwide. Many scientists pointed out that the impact of speed on the number of accidents and injury severity is greater than almost any other known risk factors [4–6]. Thus, controlling vehicle speed can prevent accidents, reduce the impact when they occur, and lessen the severity of injuries sustained by the victims.

Managing speed has been a central issue in the last decade. One of the engineering practices to combat speeding and other unsafe behaviour is the use of traffic calming devices. Traffic calming uses physical design and other measures to improve safety for motorists, pedestrians and cyclists, especially in urban and residential areas. Speed humps, raised pedestrian crossings, raised junctions (plateau junctions), rumble strips, narrowing the road width, and speed zones [7] are among the traffic calming devices that force road users to go at the permissible speed on roads and streets. Nevertheless, the effectiveness of road calming devices depends on the geometric design [8].

Rumble strips are an effective countermeasure for reducing roadway departure crashes [9]. Among the types of rumble strips, transverse rumble strips (TRS) are a common choice to warn drivers of a need to slow down or stop or of other upcoming adverse situations that may not be anticipated by an inattentive driver. This is done so engaging their auditory and tactile senses in addition to their visual senses through traffic signals. However, continuous exposure to noise and vibration by transverse rumble strips often results in diminished effectiveness and erratic behaviours leading to additional safety challenges [10]. TRS were also installed as a countermeasure along roadways to alert drivers to lane departures or changes in roadway environment, such as the nearing of stop-controlled intersections [11].

TRS is commonly used in Malaysia [12] at interchange ramps, climbing and downhill road sections, and approaching intersections. However, in practice, TRS does not always ensure compliance with the speed limit. Thus, it encouraged some local authorities to combine TRS with road studs on the travel lane. The effectiveness of TRS in improving road safety can be measured using two distinct methods; direct and indirect. Direct method analyzes by taking the accident data into account while the indirect method describes potential treats [13]. To provide some basic insight, the present study evaluated the effectiveness of TRS when applied with road studs. The effectiveness of this practice is assessed through speed reductions since the impact of speed management measures on road safety can be made using intermediate criteria such as changes in vehicular running speed caused by a specific measure [14]. The study also considered public perception through a questionnaire survey. The findings of this study are expected to assist road planners and engineers in providing better solutions in reducing speed in urban and residential areas.

2. Methodology

In the following sub-sections, the methodology for experimental research and questionnaire survey are presented.

2.1. Experimental Research on the Effect of TRS with Road Studs

Experimental research was aimed at determining the extent of vehicle speed reduction resulting from TRS with road studs. The research was conducted at three sites; one site has a TRS section installed with road studs and the other two sites have a road section with TRS only as control sites. The sites' photos are shown in figure 1. All sites are two-lane dual carriageway roads and located in residential areas where the speed limit is 60 km/h. The effect of TRS with and without road studs was determined based on instantaneous speed and the vehicle type. Study sites with a 210 m long section were divided into five points as shown in figure 2; Point A as the upstream end and Point E as the downstream end. Points D and E have TRS, Points B and C are the transition while Point A is free from the influence of TRS. The placement of Point A requires the consideration of stopping sight distance. Research on instantaneous speed was carried out at all points using radar gun and the speed data were recorded together with the type of vehicles. The measurements were taken on a workday during the off-peak daylight period.

(a) TRS with road studs (b) TRS without road studs

Figure 1. Photos of the study site.

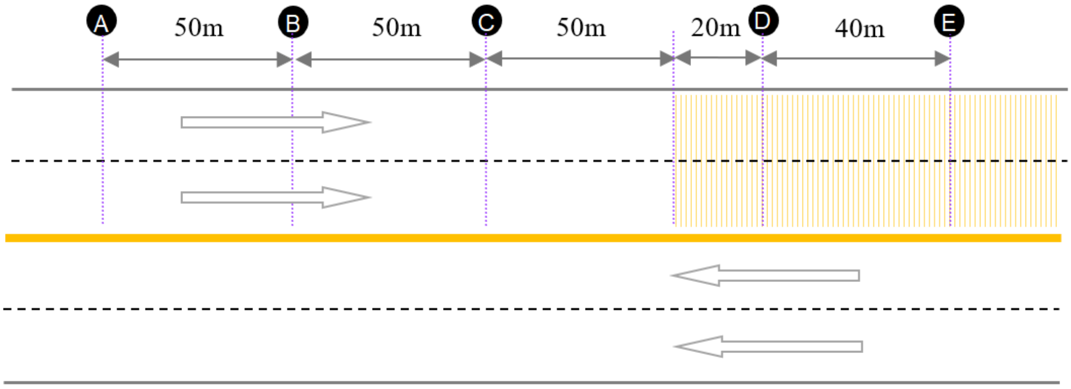

Figure 2. Layout of typical setup at the study site.

To produce reliable experimental results, the quantity of data collected must be assured. The minimum sample size of the test data that satisfies the research requirements can be determined by the following equation [15]:

$$\mathrm{N} = \frac{Z^2 p(1-p)}{E^2} \tag{1}$$

where, N is the minimum number of samples required; Z is the confidence coefficient, E is the maximum allowable error in data measurement and p is the ratio of the number of measured samples to the total traffic flow during the measurement period. Note that Z is used to characterize the reliability. Thus, $Z = 1.65$ is utilized for 90% confidence level and $Z = 1.96$ is for 95% confidence level. Using the maximum allowable error of 5%, and the confidence level of 95%, the minimum sample size is 384. The observed data in this research at each site is much larger than the minimum sample size, so the sample size of this research satisfies the requirements.

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2.2. Questionnaire Survey of Public Perception

A survey of public perception was based on a simple questionnaire developed for this study. The questionnaire was divided into three sections. Section A covered demographics, Section B was related to travel information and Section C was about the effectiveness and the impact on the vehicle. The items in Sections A and B were multiple-choice questions while items in Section C were scored based on a five-point Likert-type response scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree). The questionnaire was distributed randomly to respondents through an online survey. The link to the questionnaire was shared through a WhatsApp. 397 responses which met the minimum requirement of the study were obtained over three months with a majority completing the survey within the first month. Respondents were also informed that the submission of completed questionnaires implied their consent to participate in the study. The responses on the questionnaire were kept anonymous for confidentiality and privacy of information. Data preparation and analysis were carried out using IBM SPSS (Statistical Package for the Social Sciences) Statistics version 22.

3. Results and Discussion

The following sub-sections present the results of the experimental study and the survey.

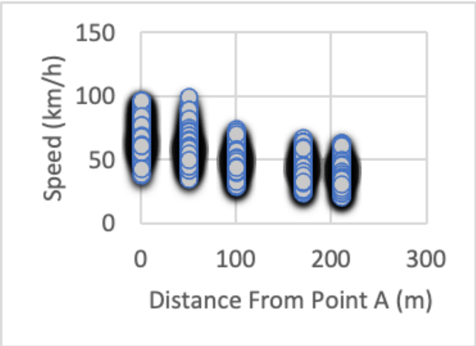
3.1. Effect on Installation of TRS with Road Studs

3.1.1 Speed analysis. Table 1 shows some statistics describing vehicle speed. The mean speed, maximum speed, and 85th percentile speed at Point E were slower than at Points A to D. Thus, the usage of TRS either with or without road studs could capture the driver's attention and alert them of upcoming roadway changes. Consequently, it could reduce the occurrence of traffic accidents. When the vehicle passes through Point A to Point E, the general trend of all speed types, including standard deviation, decreases when approaching the TRS except the maximum speed at Point B. The maximum speed at Point B is however not much different from Point A.

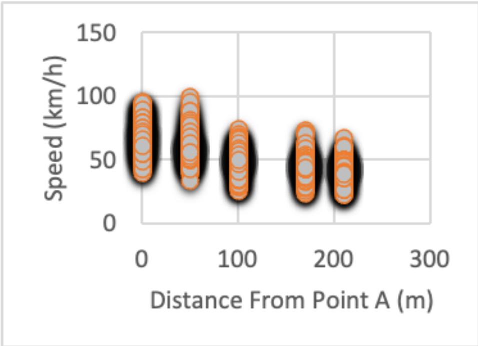
Table 1. Speed statistics.

Site	Parameter	Speed (km/h)				
		Point A	Point B	Point C	Point D	Point E
		TRS Without Road Studs				
1	Mean	71.30	60.79	51.65	47.16	43.19
	85th Percentile	86.25	69.00	58.00	53.00	49.00
	Min	38.00	34.00	29.00	24.00	21.00
	Max	97.00	100.00	74.00	67.00	63.00
	Std. Dev	12.59	10.10	7.68	7.24	7.24
2	Mean	69.74	60.68	51.35	46.70	44.08
	85th Percentile	84.55	68.00	59.00	53.00	50.00
	Min	40.00	34.00	26.00	24.00	23.00
	Max	96.00	100.00	74.00	73.00	67.00
	Std. Dev	12.52	9.75	8.38	7.40	7.09
		TRS With Road Studs				
3	Mean	71.35	60.01	50.13	43.66	40.02
	85th Percentile	85.00	68.00	58.25	49.00	47.40
	Min	35.00	34.00	27.00	22.00	20.00
	Max	98.00	88.00	79.00	73.00	60.00
	Std. Dev	12.42	9.64	9.24	7.46	7.10

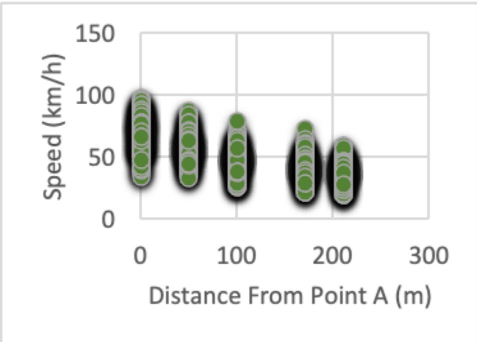
Figure 3 shows a scatterplot of vehicle speeds at five points. Point A is located at 0 m while Point E is located 210 m from Point A. In between these two points are Points B, C and D. The scattered points at Point A were generally higher in which the maximum speed was around 100 km/h. The speed of vehicles at Point B seemed similar at sites 1 and 2 with the range of speed between 34 and 100 km/h, but slightly lower at Site 3 with the speed spread from 34 to 88 km/h. The presence of road studs together with TRS 100 m ahead of the drivers really motivated those going at high speed to slow down. At Point C, the distribution of speed was lower than Points A and B. However, due to the speed of one vehicle, the maximum speed at Site 3 was found to be higher than other sites. The range of speed at Point D at Site 1 was lower than Sites 2 and 3, but at the last point, it was evident that the range of speed at Point E was lower than Sites 1 and 2. It can be understood that when a vehicle is passing through a road section with TRS and road studs, the strips and road studs will produce extra noise and vibration to encourage drivers to reduce speed and increase their alertness.



(a)Site 1



(b) Site 2



(c) Site 3

Figure 3. Scatterplot of speed (black shadow shows the repetition of data).

3.1.2 Statistical Analysis. As vehicle speed decreased from Point A to Point E, the speed changes were evaluated using a statistical test to determine whether TRS with road stud significantly affected the mean speed. T-test was applied in this study for comparing the mean speed of two sample populations. The hypothesis for checking two different speeds is as follows:

H_0: The mean speed for one set of data is the same as the second set of data
H_a: The mean speed for one set of data is different from the second set of data

The p-value for the t-test is the probability that the null hypothesis (H_0) is true. It is interpreted as when the p-value is less than 5%, the H_0 is rejected and the alternative hypothesis (H_a) would be accepted at 95% confidence level. On the contrary, when the p-value is greater than 5%, the H_a is rejected and the H_0 would be accepted at a 95% confidence level [16].

Table 2 presents the mean speed and t-test results for road sections with only TRS as well as TRS with road studs. The results in table 2(a) suggested that the difference in mean speeds between Site 1 and Site 3 were not statistically significant at Point A and Point B, respectively. It might be that on approaching the TRS section, the vehicles were still not affected by TRS either with or without road studs. However, the mean speed comparison results at Point C, Point D and Point E were statistically significant with a reduction of 1.52 km/h, 3.50 km/h, 3.17 km/h, respectively. T-test results for mean speed between Site 2 and Site 3 in table 2(b) also showed the same results as in table 2(a) except at Point C where the difference in mean speed was not significant. This finding suggests that speed decreases with the existence of road studs on a TRS section.

Table 2. t-test for mean speed.

(a) Comparison between Site 1 and Site 3.

Point	A	B	C	D	E
Hypothesis	H0: $\mu1 = \mu3$; Ha: $\mu1 \neq \mu3$				
Mean speed at Site 1 (km/h)	71.30	60.79	51.65	47.16	43.19
Mean speed at Site 3 (km/h)	71.35	60.01	50.13	43.66	40.02
Change (km/h)	+0.05	-0.78	-1.52	-3.50	-3.17
p-value	0.959	0.326	0.028 [a]	0.000 [a]	0.000 [a]

[a] significant different, p < .05 (Reject H0)

(b) Comparison between Site 2 and Site 3.

Point	A	B	C	D	E
Hypothesis	H_0: $\mu_2 = \mu_3$; H_a: $\mu_2 \neq \mu_3$				
Mean speed at Site 2 (km/h)	69.74	60.68	51.35	46.70	44.08
Mean speed at Site 3 (km/h)	71.35	60.01	50.13	43.66	40.02
Change (km/h)	+1.61	-0.67	-1.22	-3.04	-4.06
p-value	0.111	0.391	0.089	0.000 [a]	0.000 [a]

[a] significant different, p < .05 (Reject H_0)

The analysis of speed difference was also conducted at each point based on the vehicle category. In this study, vehicles were classified into six categories as presented in figure 4. According to the figure, it can be found that a larger proportion of vehicles consists of cars with around 55%, followed by motorcycles with the proportion near to 20%. Van is the third higher proportion, and the rest of the vehicle categories share almost similar proportion. All sites present the same trends for six vehicle categories. Table 3 and table 4 show the summary of the results of the t-test on mean speeds based on vehicle categories between Site 1 and Site 3 and mean speed between Site 2 and Site 3, respectively. Result obtained from the analyzes indicate that the changes in mean speed for all categories of vehicles at Point A and Point B was found not statistically significant. Point A and Point B, which were located more than 100m from TRS, indicated that the mean speed of vehicles was not influenced by the existence of TRS with or without road stud.

The results in both tables also revealed that only cars at Point C were affected by the application of TRS with road stud. On the other hand, other categories of vehicles at the same point have a p-value more than 0.05 which indicated that there was no significant difference in the mean speed. Point D and Point E in both table 3 and table 4 proved that the difference in mean speeds for car, van, motorcycle, and small lorry were statistically significant except at Point D for the small lorry in table 3.

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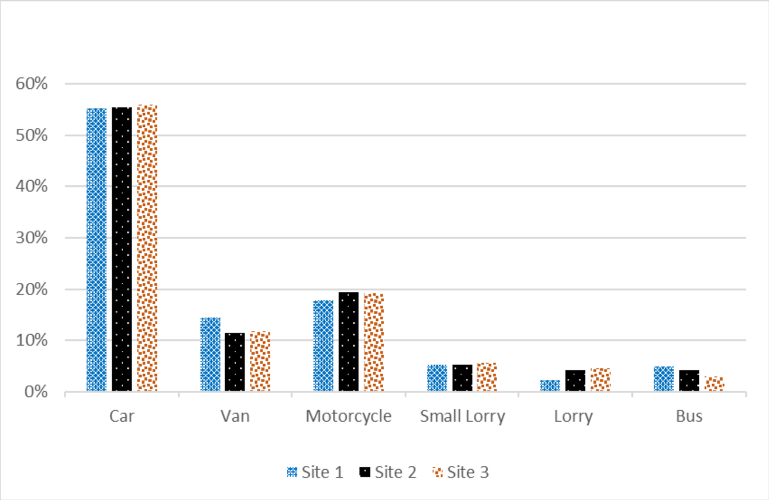


Figure 4. Vehicle composition.

Table 3. t-test on mean speed based on vehicles categories between Site 1 and Site 3.

Point	Vehicles Class	Car	Van	Motorcycle	Small Lorry	Lorry	Bus
	Hypothesis	H_0: $\mu_1 = \mu_3$; H_a: $\mu_1 \neq \mu_3$					
A	Change (km/h)	-1.50	5.25	-3.11	6.61	-0.87	4.24
	p-value	0.205	0.055	0.161	0.426	0.739	0.07
	Reject H_0?	No	No	No	No	No	No
B	Change (km/h)	0.56	-1.60	-4.99	0.84	-1.57	2.22
	p-value	0.599	0.21	0.168	0.599	0.581	0.465
	Reject H_0?	No	No	No	No	No	No
C	Change (km/h)	-2.70	0.63	-2.15	4.57	-0.40	0.45
	p-value	0.001	0.529	0.237	0.472	0.848	0.855
	Reject H_0?	Yes	No	No	No	No	No
D	Change (km/h)	-3.98	-3.00	-4.80	-2.08	-0.20	-1.58
	p-value	0.000	0.000	0.001	0.594	0.916	0.302
	Reject H_0?	Yes	Yes	Yes	No	No	No
E	Change (km/h)	-3.82	-2.09	-3.61	-3.44	2.57	0.13
	p-value	0.000	0.002	0.002	0.040	0.244	0.917
	Reject H_0?	Yes	Yes	Yes	Yes	No	No

Table 4. t-test on mean speed based on vehicles categories between Site 2 and Site 3.

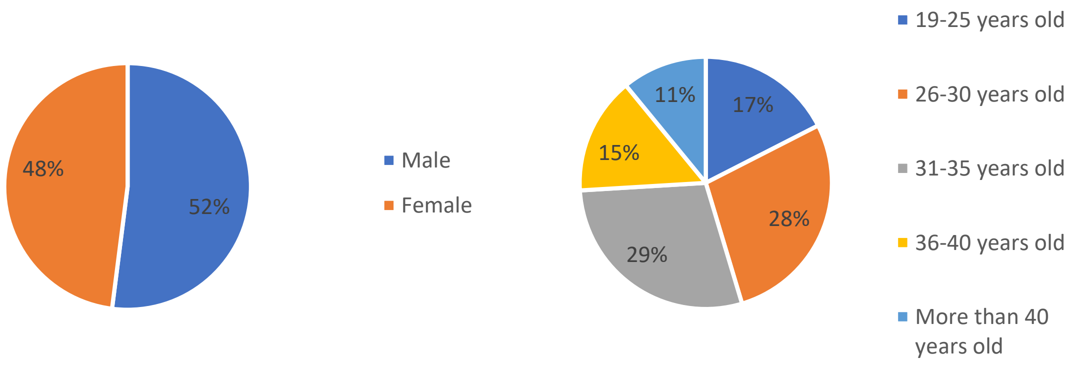
Point	Vehicles Class	Car	Van	Motorcycle	Small Lorry	Lorry	Bus
	Hypothesis	H_0: $\mu_2 = \mu_3$; H_a: $\mu_2 \neq \mu_3$					
A	Change (km/h)	2.10	5.36	-2.62	-0.38	-4.24	3.28
	p-value	0.094	0.064	0.308	0.882	0.119	0.237
	Reject H_0?	No	No	No	No	No	No
B	Change (km/h)	0.08	2.00	5.90	-0.13	-5.99	-0.06
	p-value	0.930	0.152	0.058	0.955	0.055	0.986
	Reject H_0?	No	No	No	No	No	No
C	Change (km/h)	-2.94	0.38	0.99	1.47	-0.83	1.67
	p-value	0.001	0.729	0.602	0.376	0.720	0.514
	Reject H_0?	Yes	No	No	No	No	No
D	Change (km/h)	-5.09	-3.88	-2.71	-2.76	3.02	-2.12
	p-value	0.000	0.000	0.015	0.023	0.150	0.130

	Reject H_0?	Yes	Yes	Yes	Yes	No	No
	Change (km/h)	-5.09	-3.88	-2.71	-2.76	3.02	-2.12
E	p-value	0.000	0.000	0.015	0.023	0.150	0.130
	Reject H_0?	Yes	Yes	Yes	Yes	No	No

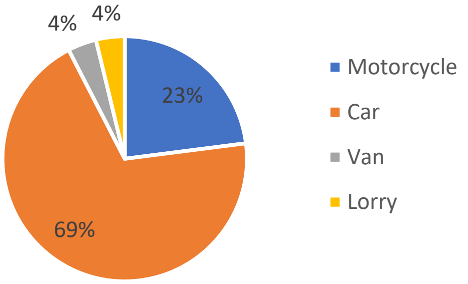
3.2. Public Perception

Figure 5 shows the attributes of the respondents. Of the 397 respondents, 206 (52.14%) were male and 191 (47.86 %) were female. The respondents aged 19–25 comprised 17% of the total proportion while those between 26–30 years comprised 28%, those between 31–35 years comprised 29%, and those between 36–40 years and more than 40 years comprised 15% and 11%, respectively. The percentage of respondents aged 26 to 35 was found to be larger than the other age groups. In this survey, the car was the most frequent vehicle used and it made up 69% of the total proportion, followed by motorcycle at 23%. The percentage of van and lorry were evenly distributed at 4% each. In terms of driving experience, 156 (39%) respondents out of 397 respondents had a driving experience between 6–10 years. 100 (25%) respondents out of 397 respondents have a driving experience between 11–15 years. Four percent of the respondents have a driving experience of more than 20 years, thus showing that this survey also considered drivers with a wide experience on the road.

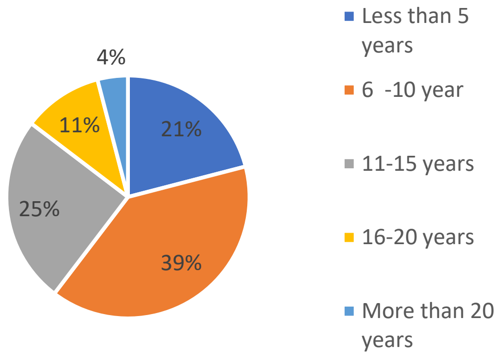
The respondents were asked on how frequently they were traveling on road sections of TRS with and without road studs per day. Results shown in figure 6 indicated that only 17 (4%) of the respondents traveled on the road without TRS while the rest have experience traveling on TRS every day. Most of the respondents (38%) met four to six TRS per day. 72 (18%) of respondents met TRS more than nine times per day. For TRS with road studs, it was found that 200 (51%) of the respondents met TRS between one to three times per day. This result revealed that TRS with road studs had been used in rural areas to alert drivers that they are approaching a lower speed zone or a stop-controlled intersection. On the other hand, only 96 (24%) of the respondents encountered TRS with road studs for about four to six times daily. The number of respondents who do not meet TRS with road stud per day was higher than the number of respondents who met TRS without road studs.



(a) Gender (b) Age



(c) Frequent vehicle used



(d) Driving experience

Figure 5. Respondents' attributes.

The respondents were also asked about their average vehicle speed on the main residential road. As presented in figure 7, most respondents (35 %) had an average speed between 46 and 60 km/h. These speeds were almost similar to the spot speed observed at the site when the drivers were approaching TRS with or without road studs. About 131 (33%) drove with an average speed between 30 and 45 km/h. Surprisingly, there were a few respondents who drove more than 90 km/h on the main residential road. This speeding behaviour might lead to road accidents in the residential area.

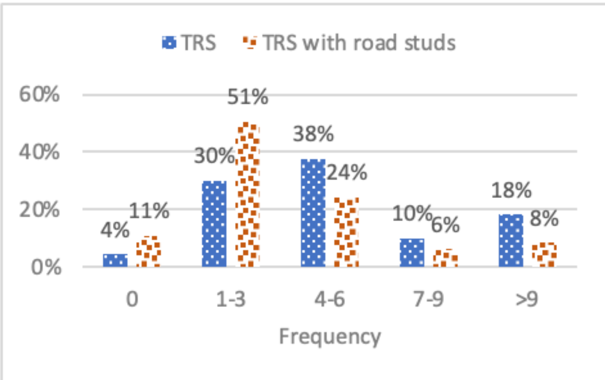


Figure 6. Respondents' travelling frequency.

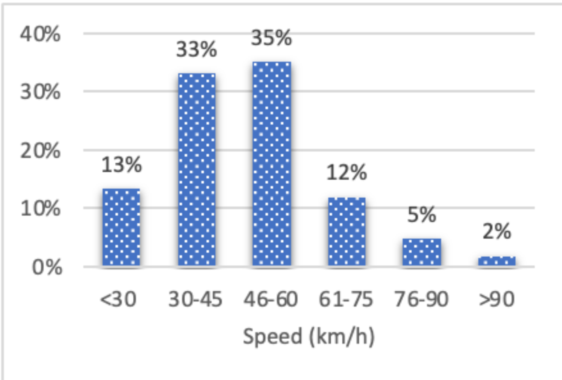


Figure 7. Respondents' operating speed.

Public perception towards TRS with and without road studs were assessed using a Likert scale and the results are as shown in table 5. As can be seen from the table, most of the respondents agreed that TRS with and without road studs could effectively reduce vehicle speed. It shows that these devices which were placed across the travel lanes of the roadway and were perpendicular to the flow of vehicles were able to alert respondents about the upcoming hazard. Respondents had neutral responses when asked about vehicle damage due to TRS. However, the results showed that a majority of the respondents believe that TRS with road studs can cause damage to the vehicle. The application of road studs might cause monetary losses in the form of bent wheels, damaged tires and suspension componentry, broken wheel joints and even more so, the loss of lives that may result from the aforementioned.

Table 5. Public perception towards TRS with and without road stud.

No.	Questions	Mean	Level of agreement
1.	Transverse rumble strip reduce speed effectively.	3.616	Agree
2.	Transverse rumble strip installed together with road stud reduce speed effectively	3.929	Agree
3.	Transverse rumble strip cause damage to vehicles	2.671	Neutral
4.	Transverse rumble strip installed together with road stud cause damage to vehicles	3.621	Agree

4. Conclusion

This study was conducted by focusing on the effectiveness of and public perception about the installation of TRS with road studs. Three locations were selected as study sites to determine the effectiveness of TRS with road studs on speed reduction. A simple questionnaire was also developed to know public perception towards TRS with and without road studs. The key findings obtained in this study are:

- The speed analysis conducted indicates that the operating speed was reduced at all sites when vehicles traveled from Point A to Point E. However, the speed reduction was lower with the presence of road studs. In addition, the speed reduction was more obvious on TRS with road studs.
- In terms of statistical analysis, the difference in mean speed was statistically significant at Point D and Point E. Cars, vans, motorcycles, and small lorries were significantly different in speed at these two points.
- Assessment of public perspective indicates that respondents agreed that TRS with and without road studs could reduce speed effectively. Respondents have neutral responses when asked about vehicle damage due to TRS. However, a majority of the respondents believe TRS with road studs can cause damage to vehicle.

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