Evaluation of the Effectiveness of Traffic calming measures

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ABSTRACT

The main objective of this research is to evaluate the effectiveness of various traffic calming measures on achieving their predetermined objectives. The first stage focused on the influence of measures like Speed table, Rumble strips, Road studs and Lane narrowing implemented in isolation under the same conditions, on the speed of unimpeded vehicles has been investigated by evaluating differences in speed profiles of individual vehicles. Their effect on safety was assessed by comparing the accident data before and after installation of these measures. The second stage measured the operating speeds of vehicles passing through successive measures using a GPS based mobile application, Speedometer in 2 seconds interval to have an insight on the relationship between spacing and speed. The raw speed data were analysed and formed significant relationships which formed the basis of a multiple linear regression model for the speed profile of unimpeded vehicles in a given traffic calmed link.

Keywords: Unimpeded vehicles, Speed profiles, GPS Speedometer, Traffic calmed link

1 INTRODUCTION

Speed is one of the main risk factors for road traffic safety, influencing accident probability and severity. One of the main tasks of institutions responsible for road safety is to ensure that the drivers comply with the speed limits. Traffic calming encompasses various means of physical speed management, implemented individually or in combination that are applied where the speeds are excessive and/or inappropriate, with a goal of reducing the speed to an acceptable level. After a certain time period from the installation of safety measures it is important to assess their impact on road safety. It is necessary to determine if road safety measures installed in particular locations give a positive impact.

The knowledge of relative impact of various traffic calming measures would be a valuable contribution to effectively tackle the problems faced by traffic planners and to achieve effective schemes which meet predetermined objectives. In addition to this engineering approach, it may also contribute to an economic assessment such as social cost-benefit analysis to determine whether the investments will be worth the gains in safety.

1.1 OBJECTIVES

1. To investigate of the impact of the most typical existing traffic calming measures and to arrive at the most effective measure by:
   i. the comparison of the before and after crash data
   ii. analyzing the speed profiles in the vicinity of each Traffic Calming Measure (TCM) to obtain the influential zone of each, standard deviation and reductions of speed.
2. To use the parameter delay time obtained from speed profiles for provision of a decision-making tool for ambulances, fire trucks, police cars etc. to choose alternative routes

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3. Identifying the optimal spacing between adjacent TCMs in a series of two or three measures from the speed profiles and speed spacing model.
4. Developing an empirical model for the speed profile of traffic calmed links for unimpeded vehicles.

1.2 LITERATURE REVIEW

Li et al. (2013) has summarized many studies and the results showed that the implementation of speed cameras significantly reduced the vehicle speed and the number of accidents near camera sites. Pauw et al. (2014) evaluated the traffic safety effects of fixed speed cameras on highways in Flanders-Belgium and concluded that speed cameras are an effective measure to improve traffic safety at locations with a high number of speed violations. The evaluation showed that severe accidents, with severe injuries and fatalities, decreased with 29% from before to after. Laura Jateikienė (2016) studied speed humps located at a distance larger than 600 m from each other (the sections do not overlap) as separate objects since in case of such distance a stable driving speed is not maintained and the required effect of the measure is not achieved. And vice versa, when the distance between the speed humps is smaller than 600 m (the sections overlap) the measures were studied together as one object.

Based on the studies, implementing speed humps on roads reduces the number of injury accidents about 41% (Elvik, 2009). Chen et al. (2013) assessed the effect of various safety countermeasures implemented in New York City. The changes in average accidents per year per location from the before period to the after period on the sections where speed humps were placed showed that the number of fatal and injury accidents decreased by about 33%. To ensure approach speeds are compatible with anticipated operating speeds of devices, Austroads (2008) suggests 20 km/h as the upper limit to the speed differential, meaning that an isolated device should have an operating speed not more than 20 km/h below the existing free speed at that point.

The selection and placement of devices that can potentially reduce free speeds to meet target speeds are vital in devising speed management treatments. The empirical speed-based design process developed by Brindle (2005) is a practical approach for designing such a scheme. It employs the concept of maximum speed differential (i.e., difference between free speed and device operating speed), which indicates the speed reduction at the location where a device is to be installed

2 METHODOLOGY

The study was conducted in two stages, where the in the first stage the influence of measures like speed table, rumble strips, road studs and lane narrowing implemented in isolation under same conditions, on the speed of unimpeded vehicles has been investigated. Second stage considered multiple calming measures in a sequence existing in a road length not more than 1.2 km. The study measured the operating speeds of vehicles passing through successive measures. The proposed methodology for the research work is given in figure 1.

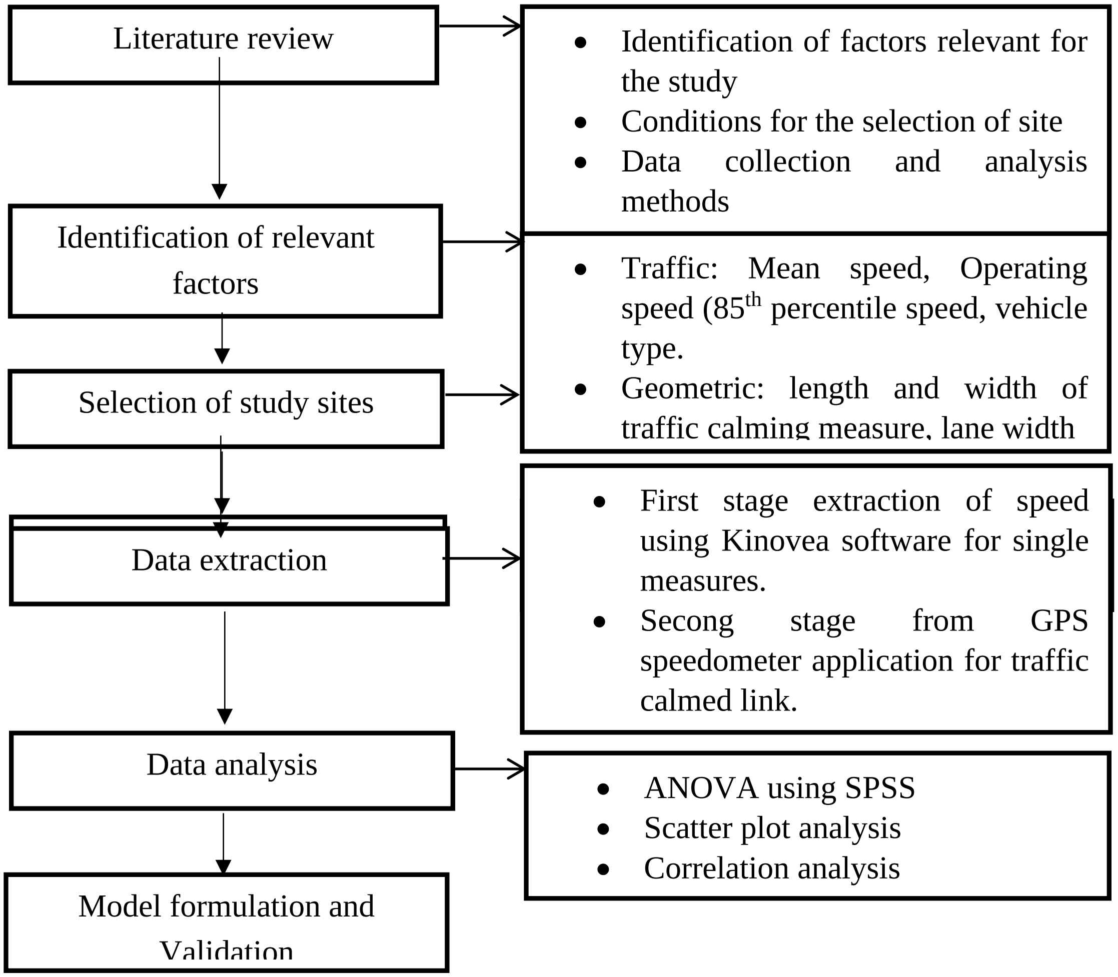

Fig.1. Methodology of the study

3 ANALYSIS OF MEASURES IN ISOLATION

This is the first stage considering traffic calming measures existing in isolation. Measures analysed were Speed table, Rumble strips, Road studs and Lateral shift. As this study is an investigation of drivers' behavior when they are negotiating calming measures, it is reasonable to study behavior when a driver has absolute control over the decision about his/her driving style without being pressured by other vehicles. A vehicle travelling under these conditions has been termed an unimpeded vehicle, which means that the driver is not being affected by the motion of the vehicle immediately preceding him/her in the traffic stream, or by other agents (pedestrians, cyclists and opposing vehicles).

In the light of these definitions, the following criteria were established to select data for editing, so that in these situations data were removed:

- Vehicles starting or stopping within the street section
- Vehicles' behavior affected by pedestrians, cyclists or animals
- Conflicts between opposing vehicles

The following Table 1 lists a sample of the locations considered in the study.

Table 1. Locations considered in the study with types of measures and details

Sl.no	Study sites	Type of measure	Characteristics
1	Near Chevarambalam	Road studs	Road studs of 10 rows making a total width of 3.4m. Each stud with a dimension of 8 x 10.5 x 1.7 cm
2	In front of Baby memorial Hospital	Speed table	18 cm height , 10.8 m total width with a slope of 1:20, top width 2.2 m and slanting lengths 4.1&4.5 meters respectively on both sides.
3	Near Thondayad	Lateral deflector	Physical barrier reducing the road width of by 2 m.
4	Kuttippuram-Thrissur road	Rumble strips	Rumble strips with a total width of 7.4m. Each raising of 15cm width and 7.8 cm depth

Locations were selected on the basis of uniformity in geometry and feature to minimize the effect on speed measurements. The study areas selected were in Calicut &Thrissur Districts. The criteria for the selection were:

- Midblock of at least 70m length
- There shouldn't be any influence from the nearest bus stops
- There shouldn't be any influence from the nearest intersection
- Presence of high-rise building to place the camera

The vehicles considered should be in a free flow without any impedance of pedestrians /other vehicles

3.1 Crash data analysis

Crash data analysis enables the assessment of impact of traffic calming measures on road safety.

For the analysis of the impact of different types of traffic calming measures installed on the roads. the data on different types of accidents like fatal, grievous, injury and property damage on the road sections equipped with these traffic calming measures before and after the installation of measures on every site were collected and compared. The following figures, fig.2(a), (b), (c). (d) respectively show the percentage reduction in number of accidents after the installation of each of these measures.

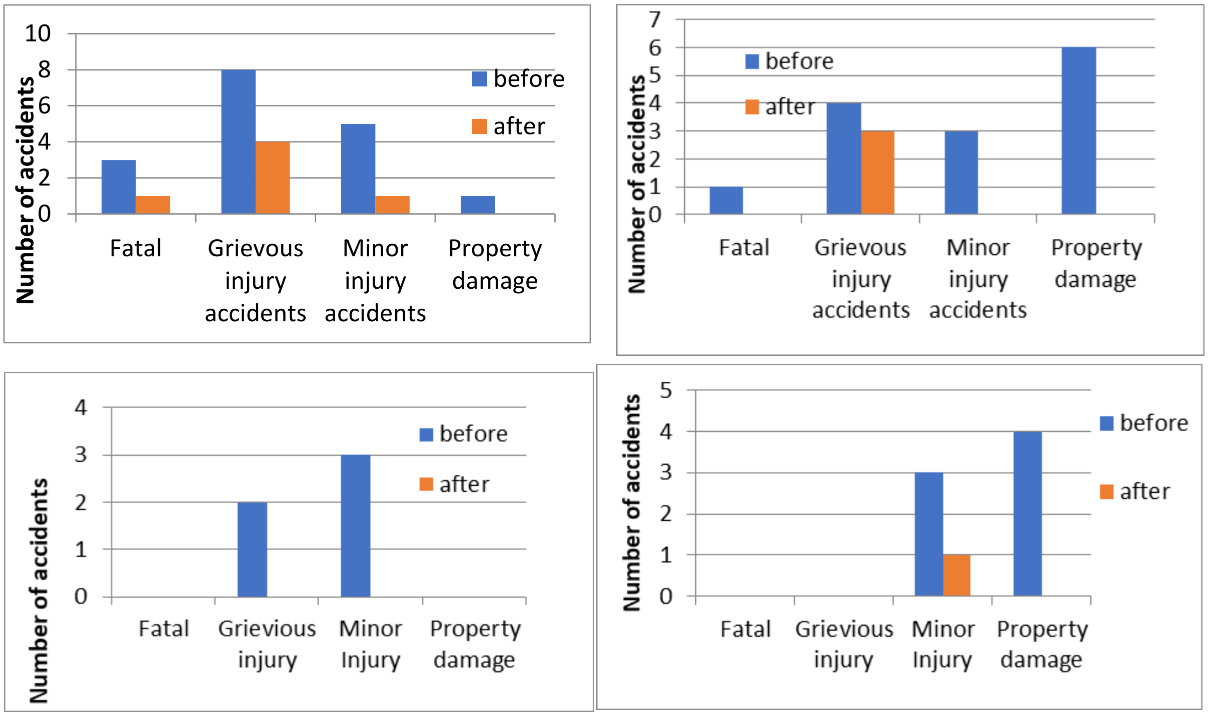

Fig 2. (a), (b), (c), (d). Number of accidents before and after the installation of Road studs. Speed table, Lateral shift, Rumble strips respectively.

After the installation of road studs on an approach road to the junction, the number of fatal accidents decreased by and injury accidents decreased by 66.7%, the number of grievious injury accidents– by 50%, the number of injuries – by 80% and property damage cases by 100%.

Having made the analysis of the types of accidents, it was determined that Speed table achieved the highest percentage reduction of fatal accidents by 100, although the number of previous cases was 1, after its installation no fatal accidents were recorded. Also it showed a 25% reduction in the number of grievious injury accidents. Before the installation of Lateral deflector by traffic police, 2 grievious injury accidents and 3 minor injury accidents occurred, after their installation no accidents have been recorded., which means a 100% reduction in the number of accidents. Analysis of accident data on the road sections of State Highway equipped with Rumble Strips showed the significant decrease of minor injury and Property damage accidents by 66.7% and 100% after installation of this measure. All four of these measures placed on Road sections showed a positive effect in Reducing the number of accidents and hence they ensure increased safety

3.2 Analysis of speed distribution

Speed along the road length equipped with the traffic calming measure for a trap length 30 meter to either side of the measure was collected for individual vehicles during off peak hours, for each type of measure. The highest 85th percentile speed along the considered road stretch was assumed as the normal street speed.

One-way ANOVA test was done for finding the sections with speeds significantly lower than the street speed. Those sections showing a significant difference in speed from normal or street speed was defined as the Influential zone of the measure. The analysis and comparison of variations occurring in speed profiles, extent of speed reductions from the normal speed and the ranges of influence of each measure helped in arriving at the best measure among them. Table 2. gives the percentage maximum speed reduction achieved by measures.

Table 2. Maximum percentage speed reduction

Vehicle type	Maximum percentage speed reduction achieved			
	SPEED TABLE	ROAD STUDS	LANE NARROWING	RUMBLE STRIPS
Bus/Truck	64.35	60.99	67.53	56.25
Car	61.8	52.00	40.00	71.43
Two wheeler	62.51	48.93	54.55	73.74
LCV	63.14	57.74	47.92	82.06
Three wheeler	54.41	45.06	57.79	79.32

Table 3. shows the Length of influential zone of each measure in meters for each vehicle type separately.

Table 3. Zone of influence in meters

VEHICLE TYPE	SPEED TABLE	ROAD STUDS	LANE NARROWING	RUMBLE STRIPS
Bus/Truck	15	20	30	45
Car	45	15	35	50
Two wheeler	20	10	20	50
LCV	30	10	25	50
Three wheeler	20	5	25	45

Figure 3(a) and (b) show the sample of plotted speed profile of Two wheelers negotiating Rumble strips and the percentage speed reduction from the normal speed in the influential zone, respectively. Similar profiles were plotted for all other vehicle types negotiating each type of measures.

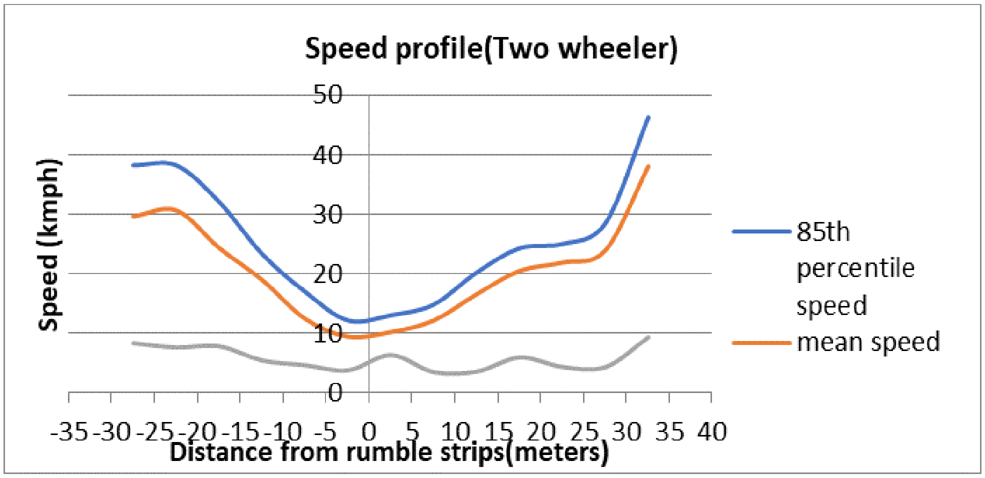

Fig.3(a) Speed profile of Two-wheeler in site with rumble strips

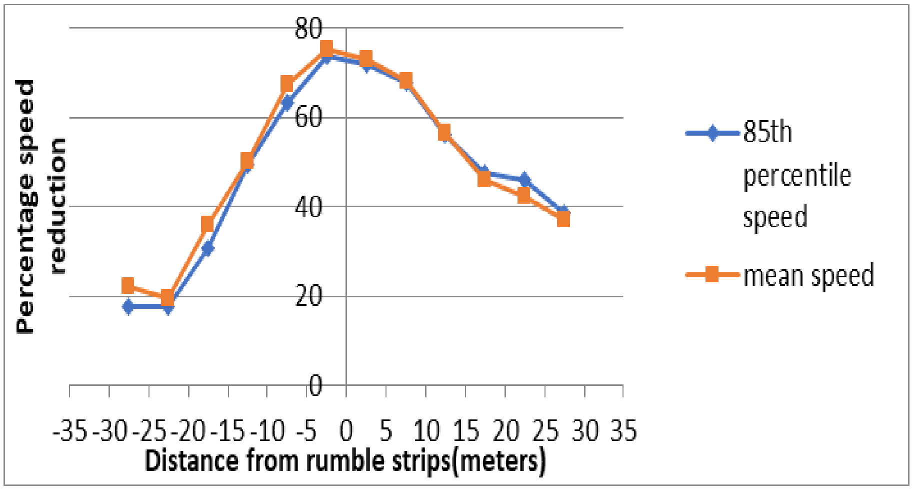

Fig.3(b) Percentage speed reduction in the influence zone.

3.3 Inferences

- Rumble strips gave the smoothest profile. Reduced speeds up to 15-20 kmph.
- Speed table reduced speeds up to 30 kmph for light vehicles, upto 20-25 kmph for heavy vehicles; showed a distinctively varying crossing speeds due to its "more forgiving nature".
- Road studs reduced speed only up to 30-45 kmph or all vehicles other than buses/trucks. For buses - upto 20-25 kmph by them. Cars were least affected.
- Lateral deflectors are also less effective in reducing speeds, as they reduced speed up to 30-35 kmph for heavy vehicles and only up to 35-45 kmph for all other types.

4 ANALYSIS OF TRAFFIC CALMED LINKS WITH MULTIPLE MEASURES

This is the second stage of the work, that deals with traffic calmed links consisting of two or three Traffic calming measures in different combinations.

Table 4. Measures in each site in the direction of travel and the spacing between them

Sl.no	**SITES**		**Spacing (m)**		**Spacing (m)**	
1	Tirur-Calicut Road	Rumble strips	395	Rumble strips		
2	Kadangode Road	Hump	72.66	Hump		
3	Tirur-Calicut Road,Perumanna	Rumble strips	56.09	Rumble strips	60.54	Rumble strips
4	Velur- Pathramangalam Road	Hump	93	Hump		
5	Pandikasala	Rumble strips	90	Rumble strips	115	Rumble strips
6	Thrissur- Kuttippuram Road	Rumble strips	676.15	Lane narrowing	553.17	Rumble strips
7	Cherinchal Road	Rumble strips	314.5	Lane narrowing		

A detailed analysis of the influence of different combinations of traffic calming measures on the speed of unimpeded vehicles has been undertaken by evaluating the differences in speed profiles obtained from various combinations of traffic calming measures involving speed humps, rumble strips and lane narrowing implemented in a sequence. The road stretches considered in the study contained two or more traffic calming measures not longer than 1.2 kilometres.

The topographic features are consistent with the classification of level or rolling terrain. The roads were mostly flat with longitudinal gradients ranging 0.16-5.1%. Segments containing signalized intersections or roundabouts were excluded from this analysis, to ensure that all the vehicles traversing the calibration segments have right-of-way. Table 4. shows the successive measures in the direction of travel. Spacing between each pair of measures are also given for every site.

5 Methodology

Measures were Speed humps, Rumble strips and Lane narrowing. A GPS Speedometer Mobile application is used in this study to acquire longitudinal speed profiles of individual vehicles passing through successive measures. This application recorded the vehicle speeds at every 2 seconds interval along the study stretches. Along with the speed values, it also gave the duration of travel along each link. At every site, a total of 60-74 trips were made with car and three wheelers as had the major share in the traffic composition of those areas. Average speed profiles in every site were plotted.

5.1 Analysis

This overview of speed profiles has helped outlining the differences and similarities among the surveyed links and has provided some information on drivers' behaviour. Considering that the sites have different characteristics in terms of the traffic calming scheme therefore making comparisons difficult, the most remarkable similarity among sites about the change in speeds.

Table 5. Mean speeds at the measures and maximum speed between measures with its position.

Sites	**Mean speeds at the measures(kmph)**	**Maximum speeds between measures(kmph)**	**Position of maximum speeds in percentage of spacing in the direction of travel**
I	22.12 (Rumble strips) 26.98 (Rumble strips)	 52.44	 52%
II	23.41 (Hump) 21.82 (Hump)	 30.42	 78%
III	21.95 (Rumble strips) 20.98 (Rumble strips) 22.88 (Rumble strips)	31.27 33.62	65% 68%
IV	23.43 (Hump) 23.00 (Hump)	 31.08	 62%
V	17.48 (Rumble strips) 19.25 (Rumble strips) 18.49 (Rumble strips)	33.62 34.19	47% 48%
VI	16.5 (Rumble strips) 26.74 (Lane Narrowing) 15.46 (Rumble strips)	62.58 59.73	60% 47%
VII	24.55 (Hump) 23.16 (Lane Narrowing)	47.62	33%

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The examination of individual speed profiles indicates that the higher the entry speed the smaller the speed reduction and therefore, the smoother the speed profiles. The entry speed is usually the maximum speed along the link and explains a proportion of the variance in driver behaviour. Speed profile plots have enabled the visual examination of the slopes, indicating the acceleration rates between a pair of data points. The slopes also suggest different acceleration rates for different types of measure, reinforcing the statement of differences in impacts according to the type of measure. It can be noted that the vertical deflection measures like humps and Rumble strips produced steeper slopes, that is, higher deceleration rates. The speed values from the speed profiles can be summarized as follows, in table 5.

5.2 Inference

- Drivers exhibiting different behavior in input speeds, respond in different ways to the measures. But the likely point to achieve the minimum speed in the whole segment is at the measure itself for all drivers.
- Comparisons of speed profiles at different sites suggest that the combination of traffic calming measures influences drivers' behavior and more aggressive and constraining measures reduce speeds to more desired levels.
- Speed is below 40kmph when the spacing is less than 90 meters for speed humps.
- Measures of same type with same characteristics showed almost same mean speed at the measure.
- The position where the maximum speed is attained between a pair of measures is different for same types of measures. It appears that the type of measure is not important in influencing maximum speed, but the spacing between measures is.

5.3 Consistency of impacts

Table 6. ANOVA results for consistency of mean crossing speeds of same type of measures.

Measures	***F***	***P-value***	***F crit***	**Result**
2Rumble strips of Site I	1.602276	0.217731	4.259677	No significant difference between the sample mean speeds at same types of measures
2 Humps of Site II	4.141808	0.2145	4.1156	
3Rumble strips of Site III	0.289656	0.749906	3.2043	
2 Humps of Site IV	1.3394	0.2562	4.1708	
3Rumble strips of Site V	0.45408	0.638341	0.4540894 3.2380	
Lane narrowing in Site VI and VII	3.308694	0.0766	4.0847	
Speed humps of all sites	1.319496	0.2715	2.5026	

The raw speed data were analysed and formed significant linear relationships. It was found that the downstream speed of a measure is a function of the speed at the measure and the speed at the measure is a function of the input speed or upstream speed. Consistency of impact of measures was also checked by testing if the means of speed at one measure is equal to the mean speed at any other one using ANOVA single factor test. The test was done at a significance level of 0.05. The results of this test are given in table 6.

5.4 Optimum spacing between measures

The placement of calming devices should be such that there is insufficient length for drivers to reach high speeds. As rumble strips have been proved as the most effective measure in reducing speed, the desired spacing between these is found in this section. For this, the five pairs of Rumble strips from the Sites I, III and V were selected. A linear relationship was found between the spacing and the maximum speed between measures. Figure.4 represents this relation.

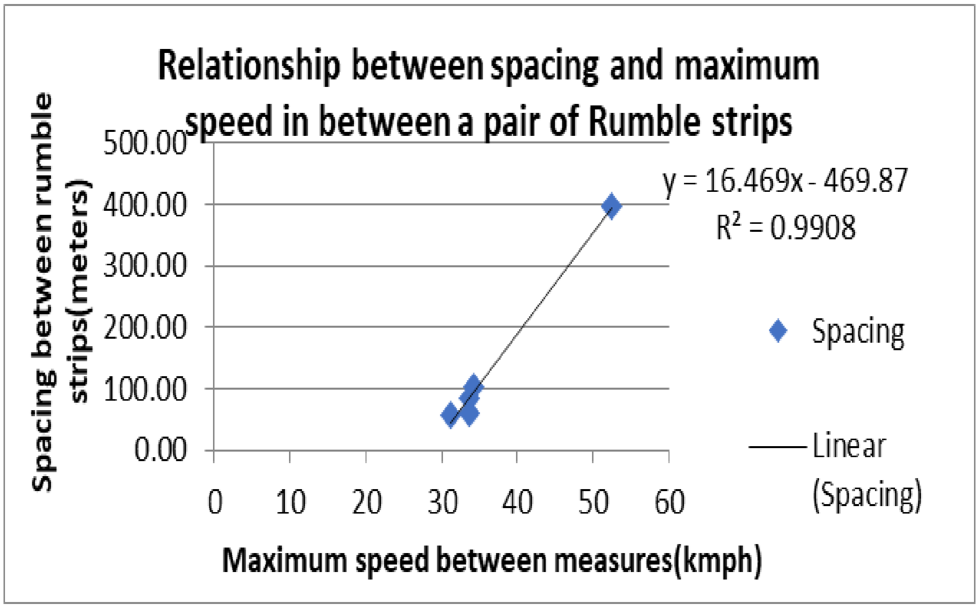

Fig.4. Linear Relationship between Spacing between rumble strips and maximum speed in between a pair of rumble strips.

Therefore, the optimum spacing between adjacent sets of Rumble strips can be modelled as:

Spacing = 16.469 Vmax - 469.87

where Vmax is the maximum speed in between the measures (or the desired speed limit of the road)

The model summary is given in table 7.

Table.7. Model summary of the linear regression model for spacing.

R	**R Square**	**Adjusted R Square**	**Std error of the estimate**	**t- statistics**
0.9954	0.9908	0.9877	15.9539	Vmax:17.944

5.5 Delay parameter

Delay is an important parameter to consider when it comes to the response times of emergency vehicles. In this section the travel times for navigating each of the study segments, recorded in the GPS Speedometer Application are compared.

To enable inter-route comparisons with different lengths, travel times have been expressed in terms of slowness (seconds/km) which is often called 'rate of motion'. The inverse average crossing speed (space mean speed) of each site also enables inter-route comparisons.

Table.8 presents the average values of travel times, slowness and crossing speeds calculated for the seven links, therefore providing a parameter to compare delays.

Table.8. Average travel time and slowness for every road segment in the study.

Sites	**Average travel time (seconds)**	**Length (meters)**	**Mean slowness (sec/km)**	**Average space mean speed (km/h)**
I (RS,RS)	64.4	572.59	112.47	32.01
II (H,H)	28	217.48	128.75	27.96
III (RS,RS,RS)	42	355	118.31	30.43
IV (H,H)	25.94	196.59	132.04	25.89
V(RS,RS,RS)	51.8	338.9	152.84	23.55
VI(RS,LN,RS)	114.8	1414.68	81.15	44.36
VII(H,LN)	52.6	465.65	112.94	31.86

Among the sites, Pandikasala Road exhibits the highest slowness where there are 3 Rumble strips in a sequence and therefore the slowest average crossing speed. Nevertheless, it has to be borne in mind that the routes with Speed humps showed high slowness also because of the characteristics of a local road.

6 Multiple linear regression model for speed profile

The prediction of maximum speeds between measures is one of the main interests when planning a scheme. Therefore a multiple linear regression model for speed at a given point in a traffic calmed link was modelled using SPSS.The variables like entry speed (V1), distance to Speed hump(dt(H)), distance from Speed hump(df(H)), distance to Rumble strips(dt(R)), distance from Rumble strips (df(R)), width of the measure(w) and dummy variables H,L,R and g (which indicate the presence of a measure and descending gradient greater than 2.6%) showed a very good linear relationship with Speed at a point when the Correlation analysis was done. Variables were selected such that the problem of multi-collinearity is avoided.

The speed profile model for unimpeded vehicles in a traffic calmed link having any combinations of Rumble Strips, Speed humps or Lane narrowing is given as:

Speed = -5.41+ 0.79 V1+ 0.15 dt(H) + 0.14 df(H) + 0.2 dt(R) + 0.15 df(R) – 2.85 H+ 4.88 L + 0.55 R - 8.91 g -2.49 w

Table.9. Model summary for the model formulated.

R	R square	Adjusted R square	Standard error of the estimate	t-statistics
0.808	0.653	0.650	4.75	V1 : 28.83 dt(H) : 2.07 df(H) : 5.67 dt(R) : 22.87 df(R) : 28.44 H : -1.97 L : 2.03 R : 0.39 g : -10.50 w : -10.02

From the model-curve fit at each site, the speed profile model was shown to be a good representation for the general trends of the data from the calibration sites with the exception of the prediction of the effects of the Lane narrowing on speeds. As the variables, distance to the Lane narrowing and distance from the lane narrowing were not included in the model, it failed to predict the speeds in the vicinity of Lane narrowing.

7 CONCLUSIONS

(a)The most effective traffic calming measures for reducing vehicle speeds involve vertical shifts in the carriageway such as speed tables and rumble strips. Other measures may be used in supporting roles such as Horizontal shifts and Road studs.

(b)Rumble strips produce the lowest operating speed for all types of vehicles. These devices are also most influential in reducing street speed, as proven by the sizeable speed change and small dispersion of speeds. This reduces speeds up to 15-20 kmph. The rumble strips have the longest influential zone for all classes of vehicles.

(c)Speed table do not perform as well as rumble strips. This reduces speed moderately. They can reduce speed up to 30 kmph for light vehicles and up to 20-25 kmph for heavy vehicles. Though street speeds are kept below the limit, operating speeds are approximately 15 kmph higher than those at rumble strips for cars, two wheelers, three wheelers and LCVs, but for buses only about 5 kmph. The gentler design of the observed speed tables enables drivers to operate their vehicles at higher speeds.

(d)Road studs showed a shorter zone of influence for every vehicle type except bus/truck compared to that of speed table, rumble strips and lane narrowing. This reduces speed only up to 30-45 kmph or all vehicles other than buses/trucks. For buses the speed is reduced up to 20-25 kmph by them. Cars were least affected by Road Studs

(e) Lateral deflectors are also less effective in reducing speeds, as they reduced speed up to 30-35 kmph for heavy vehicles and only up to 35-45 kmph for all other types of vehicles. This suggested that drivers were only slightly affected by the constriction of the roadway and chose to maintain their speeds along the streets.

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(f) The analysis of average speed at the measures through the descriptive statistics has suggested different impacts according to the type of measure. The results showed that the same type of measures gave same impact in terms of speed, though they had slight variations in their geometry as ($F<F_{crit}$ and $p>0.05$). Consistency between the maximum speeds between same types of measures were also checked which gave positive results. There are also significant linear relationships between speeds at downstream of a measure, upstream of a measure and speed at the measure.

(g)The speed profile model which can effectively achieve the objective of predicting speeds of unimpeded vehicles for a given combination of traffic calming measures can be formed using the input speed, distance to and from measures, width of measure, and longitudinal gradient of the road and the dummy variables which indicates the presence of a certain type of measure.

(h) Analysis of travel times showed that the traffic calmed links where more than 2 sets of Rumble strips cause the highest delay for vehicles.

(i)The model developed for the optimal spacing between various measures using the spot speeds and spacing measurements can be used by the local agencies and they can develop their own models for the optimal spacing in the future based on the compilation of the speed data base.

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