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AN ASSESSMENT ON THE EFFECTIVENESS OF TRAFFIC CALMING MARKINGS AND ALTERNATIVE FOR SPEED REGULATING STRIPS

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ABSTRACT
The objective of this study is to evaluate the effectiveness of placing Traffic Calming Markings (TrCM) at different locations along the road to influence motorists' speed, and provide an alternative to replace existing speed regulating strips on our roads. The study tested on 11 TrCM locations and the 85th percentile speed results showed that eight out of the 11 locations showed a reduction in speed while two locations have become ineffective and one location showed no change in speed. The results also indicated that TrCM was more effective when combined with other natural features such as a crest, a gentle bend or presence of a narrowing effect. However, it was less effective when applied along neutral road gradients and down slopes.

With this in mind, further tests were carried out to compare the effectiveness of TrCM before and along a bend. Concurrently, similar arrangement was also carried out to determine the speed for Speed Regulating Strips (SRS) before and along a bend as a means to compare the effectiveness between the two traffic calming measures. Thereafter, the findings on both of these speed tests would ascertain the appropriate locations to provide TrCM to reduce motorists' speed and an option to replace SRS if necessary.

1 INTRODUCTION

1.1 Traffic calming
Traffic calming encompasses a series of traditional and new techniques designed to reduce excessive speed and hence enhance safety for all road users in our urban road environment.

Treatments can physically create an impact on the movement of traffic or can present a visual perception that certain roads are not intended for high speed movement. Traffic calming thus has the potential to influence motorists' speed, improve safety conditions and reduce noise pollution. In Singapore, there is a range of traffic calming measures which are primarily categorized into two areas; physical and non-physical traffic calming measures.

Physical traffic calming measures refer to those road features that provide either vertical or horizontal deflection to vehicles as drivers drive pass, which encourage them to reduce their speed when driving along a road. Some commonly used measures such as road humps, speed regulating strips and lane narrowing are recognized as an effective speed reduction technique. These are traditionally employed to address speeding incidents along our roads. Non-physical measures help to influence drivers to adjust their driving behavior and travelling speed to suit the road conditions and environment. These traffic calming features include textured surfacing, variable message signs and speed signs. These also serve to complement with the physical traffic calming measures and help to enforce the speed limit for the road.

1.2 Scope

In 2008, the Land Transport Authority (LTA) of Singapore released the Land Transport Master Plan (LTMP) to outline LTA's intention to introduce new traffic calming initiatives to alert motorists to lower their speeds to suit the environment, thereby enhancing safety for all road users. One of the new initiatives planned in the pipeline is TrCM which is a form of psychological traffic calming measure and aims to influence drivers' behavior by reducing the perceived lateral clearance in the travelled lane using road markings.

As a new initiative, TrCM need to be trialed and tested to ascertain its effectiveness and efficiency in speed reduction. In addition, when in comparison with other existing physical traffic calming measures, we need to assess whether TrCM fare better or worse or even comparable with them. This study will aim to determine the potential of TrCM and its feasibility as an effective speed reduction tool on the road network.

2. RATIONALE BEHIND TrCM INITIATIVE

2.1 Physical traffic calming measures

There is no doubt that physical measures (e.g. humps and speed regulating strips) are effective tools to address speeding. However, they may be unpopular with residents or motorists as these vertical deflections can generate a level of noise disturbance (residential area) and this effect is amplified when heavy or goods vehicle travel over them. In addition, when vehicles cross these physical measures at inappropriate speeds, they can cause damage to vehicles (i.e. hump) and discomfort to the occupants. They can also encourage sudden acceleration and deceleration by drivers. On high demand roads, its presence can significantly reduce capacity, leading to traffic congestion.

Hence, LTA initiated the introduction of a psychological (non-physical) measure to overcome some or all these posed problems while still retaining the capability of reducing vehicle speeds. Such form of measure can then be employed at sensitive areas such as schools, hospitals and dense residential places where speeding coupled with noise pollution from physical traffic calming measures is a concern.

2.2 Perceptual traffic calming markings

The concept of influencing drivers' behavior by employing perceptual counter-measures to speeding can be defined as "manipulations of the road scene presented to a driver that can influence his or her subsequent behavior with relatively low cost additions or modifications to the road or roadside. This change can then alter the driving environment perceived by the driver" (Godley et al.). There are a number of perceptual counter-measures to reduce motorists' speed. Some of these include transverse lines, transverse chevron markings and 'Dragon's Teeth'.

Transverse Pavement Markings comprise of two major types namely, transverse lines and transverse chevrons. Transverse lines can either be provided across the entire travel lane or at the edges of travel lane (Figure 1 refers). These markings are made up of a series of parallel bars typically spaced at a decreasing interval as it approaches a potential hazard such as a junction, change in road layout or a community. The main function is to create an illusion that the vehicle's speed is increasing, thus inducing motorists to slow down. In a study carried out by Denton (1980), transverse lines were applied to the approach to Newbridge roundabout in Midlothian, Scotland. Speed data was conducted three weeks prior to installation and three weeks after installation. Results collected shown a significant reduction on both 85th percentile (30%) and mean speeds (23%). In another study reported in DoT (2009), the results were not that significant. Transverse lines were provided on three approaches into Union city, Iowa. Results collected over a three month period showed little change in prevailing speed, a reduction between 1mph (1.6kph) to 2mph (3kph).

Transverse chevron markings are similar to transverse lines except that they consist of a series of converging chevron markings instead of parallel bars (Figure 2 refers). They are marked at decreasing interval in the direction of travel to give the perception that the driver is going faster as the lane is narrowing. A study conducted in Roland city, Iowa showed that in the 1st, 3rd, 9th and 12th month, the 85th percentile speed after installing chevron markings decreased up to 4mph (6kph), while 1mph (1.6kph) was more typical over the past 12 month period (DoT 2009).

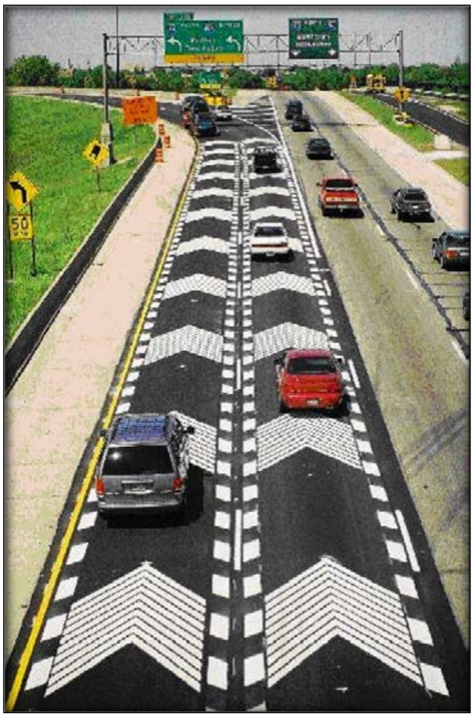
'Dragon's teeth' is made up of two parallel sets of triangular markings laid along the edge of a lane. The intention of these markings is to instill a visual perception that the approaching lane is narrow and the triangles can provide an additional "gripping" and funneling visual effect so as to encourage motorists to reduce their speed. In UK, 'Dragon's teeth' is used to reduce motorists' speed as they approach a village or residential area. These markings have been used in conjunction with gateways[1]. They are usually laid on the approaches to the gateways into villages or residential area. In a research carried out by Transport Research Laboratory , speed results taken at two villages (Craven Arms and Dorrington) where 'Dragon's teeth' are provided, the results showed that inbound speeds are reduced by between 8mph (13kph) and 10mph (16kph) (DfT, 2000).

[1]Gateways are a road feature designed to highlight to drivers that they are entering an area of changed road use (e.g. a village)

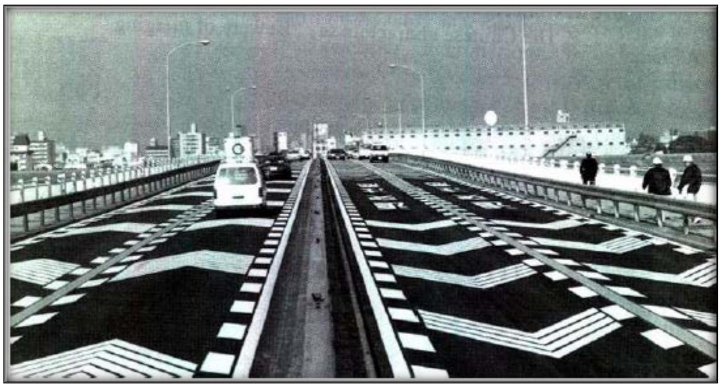
USA (rural road)

USA (rural road)

Figure 1: Examples of transverse lines on the road in USA (Source: Lee, J.H et al, 2009)



USA (Highway)



Japan (Highway)

Figure 2: Examples of transverse chevron markings in USA and Japan (Source: Drakopoulos, A., Vergou, G, 2003)

In considering the local context, LTA adopted 'Dragon's teeth' markings for its speed calming applications. Speed reduction effectiveness between each speed calming measures is comparable, but the design of the 'Dragon's teeth' markings is viewed as a good balance between visually intrusive and speed calming effective. In principle, TrCM has similar traits to

'Dragon's teeth' where two parallel sets of white triangular markings are laid along the lane. TrCM is provided with the purpose to trigger motorists' awareness of the need to reduce their speed. Figure 3 and Figure 4 shows a typical layout of 'Dragon's teeth' markings and TrCM along a lane respectively.

Figure 3: A typical layout of 'Dragon's teeth' markings (Source: DMRB Vol 6 Sect 3 Part 5 TA87/04)

Figure 4: A typical layout of TrCM

There is no specific constraint on the number of 'Dragon's teeth' markings to be provided, but generally, they will consist between 9 and 17 pairs of teeth. The size of the 'teeth' may increase in size as the hazard is approached or they may be of similar size, generally with a 750mm base and 600mm height (DMRB, 2004). The design for TrCM is slightly improvised from 'Dragon's teeth' for Singapore road network. It generally consists of 10 or 18 sets of white triangular markings covering a total length of 53m or 91m respectively. The length of

TrCM is dependent on the speed limit of the road where the former is used at 50kph and the latter at 60/70kph road. As for the design of the triangles, the base is fixed at 500mm but the height is varied. This variation is dependent on the road width with the lateral distance (centre portion of the lane) between each pair of pointing triangles maintained at 1.5m. The spacing between each set of triangles is not fixed at regular interval but is designed to decrease gradually from 8m to 2m to give motorists an increasing speed effect, hence influencing their driving behavior and in turn lower their travelling speed as they approach the hazard. Figure 5 and Figure 6 shows the design layout for ‘Dragon’s teeth’ and TrCM.

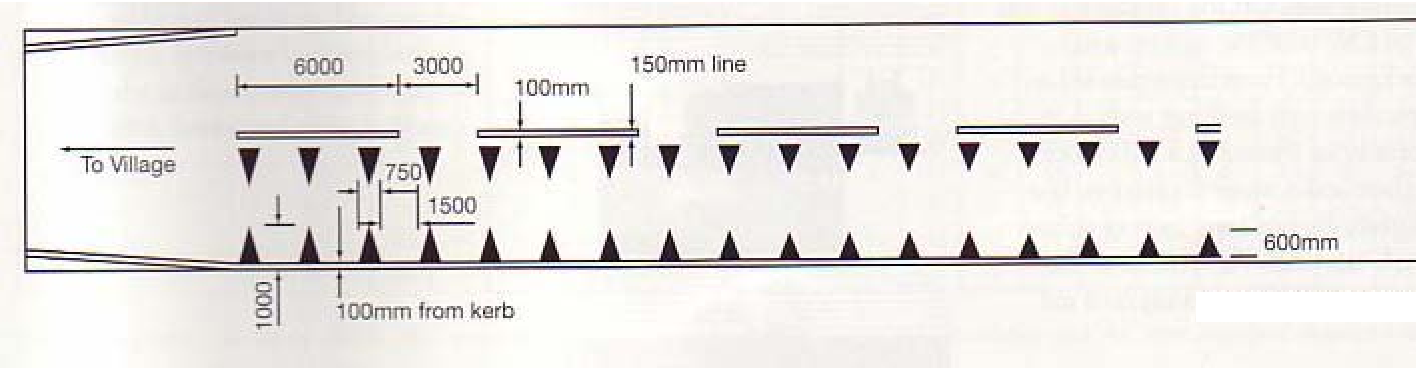


Figure 5: ‘Dragon’s teeth’ design layout (Source: DfT Traffic Advisory Leaflet 1/00)

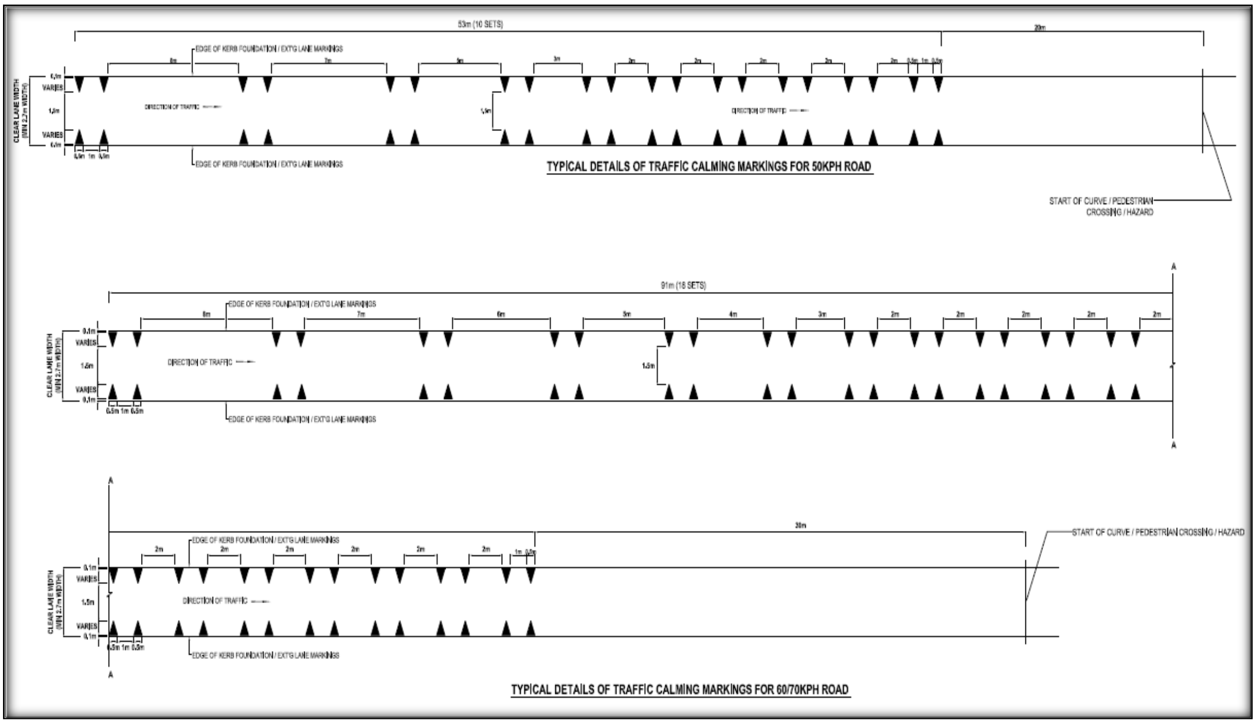


Figure 6: TrCM design layout (Source: LTA Standard Detail Road Elements, 2009)

3. IDENTIFICATION OF TrCM LOCATIONS

3.1 Selection of TrCM locations

With the design layout of TrCM in placed, it is important to shortlist potential locations where TrCM can be trailed and tested for its speed calming effectiveness. This can be assessed on a macro and micro level, such as landuse needs and drivers' behaviour. These factors will be considered for future implementation.

3.2 Criteria for provision of TrCM

The criteria will look into two areas; namely, the surrounding environment which is landuse (macro) and operating environment which relates to drivers' behaviour/speed (micro). We will first look at the macro level. This refers to an area or locations of the surrounding land use where there are concerns to noise pollution caused by physical traffic calming measures (i.e. hump or speed regulating strips). These include places such as residential, hospital, nursing home and schools where traffic noise can be unpopular and disturbing to the residents and children. At a micro level, TrCM can be provided at locations where there are feedbacks of speeding concerns on a stretch of road or location, and when the surveyed speed results indicated that the 85th percentile speed made by motorists are 10kph above the posted speed limit. This 85th percentile speed is often referred as the critical speed. Motorists who exceed the 85th percentile speed are usually considered to be driving faster than is safe under prevailing conditions. This factor is commonly used by safety practitioners to determine the speed conditions on the tested road. Therefore, we can simply summarise the above criteria for TrCM in Table 1 as shown.

Table 1: Criteria for provision of TrCM

Types of environment	**Criteria**
Surrounding (landuse)	Sensitive areas (i.e. residence, hospitals, schools)
Operating (behaviour)	85th percentile speed > 10kph above posted speed limit

4. TrCM SPEED ASSESSMENT

4.1 Speed trial locations

A total of 11 trial locations are identified across the road network. These locations are shortlisted after regular consultations with internal divisions where speeding is the main concern highlighted. A 'before' and 'after' speed study was carried out to ascertain the effectiveness of TrCM at these locations. The before speed tests were conducted between 2008/2009 and after speed tests in 2011. A minimum of 200 vehicle sample was recorded for each test. These 11 locations and their 'before' and 'after' speed results are shown in Table 2.

Table 2: Summary of TrCM speed count results

Summary of speed count results 'before' and 'after' 85th percentile speeds

No	Location	Description	85th %tile Before TrCM (kph)	85th %tile After TrCM (kph)	Change in speed (kph)	(%) change	Significance at 95% confidence level
1	Site 1 (slip rd off expressway)	Downslope (before bend)	62	64	+2	3.2	N.A
2	Site 2 (collector road)	Downslope (before bend)	69	72	+3	4.3	N.A
3	Site 3 (collector road)	Upslope (after bend)	48	43	-5	-10.4	Yes
4	Site 4 (collector road)	Neutral (no bend)	47	47	0	0	-
5	Site 5 (slip rd off expressway	Upslope (before bend)	63	58	-5	-7.9	Yes
6	Site 6 (local road)	Upslope (no bend)	47	42	-5	-10.6	Yes
7	Site 7 (local road)	Neutral (at bend)	53	49	-4	-7.5	Yes
8	Site 8 (slip rd onto expressway)	Neutral (at bend)	68	62	-6	-8.8	Yes
9	Site 9 (collector road)	Downslope (at bend)	59	56	-3	-5.3	Yes
10	Site 10 (collector road)	Downslope (before bend)	58	56	-2	-3.4	Yes
11	Site 11 (collector road)	Neutral (narrowing effect)	64	53	-11	-17.2	Yes

Based on the speed results obtained from the 11 trial locations, it is evident that 8 out of 11 TrCM locations remain effective. Statistical tests performed at 95% confidence level also suggest the effectiveness of TrCM in speed reduction at the 8 locations. Two locations (No.1 and 2) have not shown a reduction in speed after implementing of TrCM, while only one location (No. 4) shows no change in its speed. The speed results also provide a clear indication that the potential of TrCM can be enhanced when combined with other road features such as a crest, a road bend or presence of narrowing effect on the applied road. However, TrCM is less or not effective when placed along down slopes or neutral road gradient.

Overall, the results show that TrCM is an effective traffic calming measure when applied at locations with such characteristics. For a more robust assessment, TrCM is further tested for its effectiveness when approaching a danger area such as bends. Another run of speed trials are carried out to ascertain the most effective location, whether it is before or along a bend for TrCM. In addition, the speed trial will also experiment whether TrCM can be used as an alternative measure to replace SRS.

4.2 Speed trial for road bend and SRS

The purpose of the speed trial is to first ascertain the effectiveness of TrCM in speed calming in relation to its placement on the road before and along a bend, and lastly, to compare those speed results with SRS as a replacement measure.

Two locations are selected for the speed trial, one for TrCM and the other for SRS. Both locations have similar road layout and characteristics for easy and accurate comparison. These locations will be classified as Location 1 for TrCM, and Location 2 for SRS. The two trial locations are shown in Figure 7.

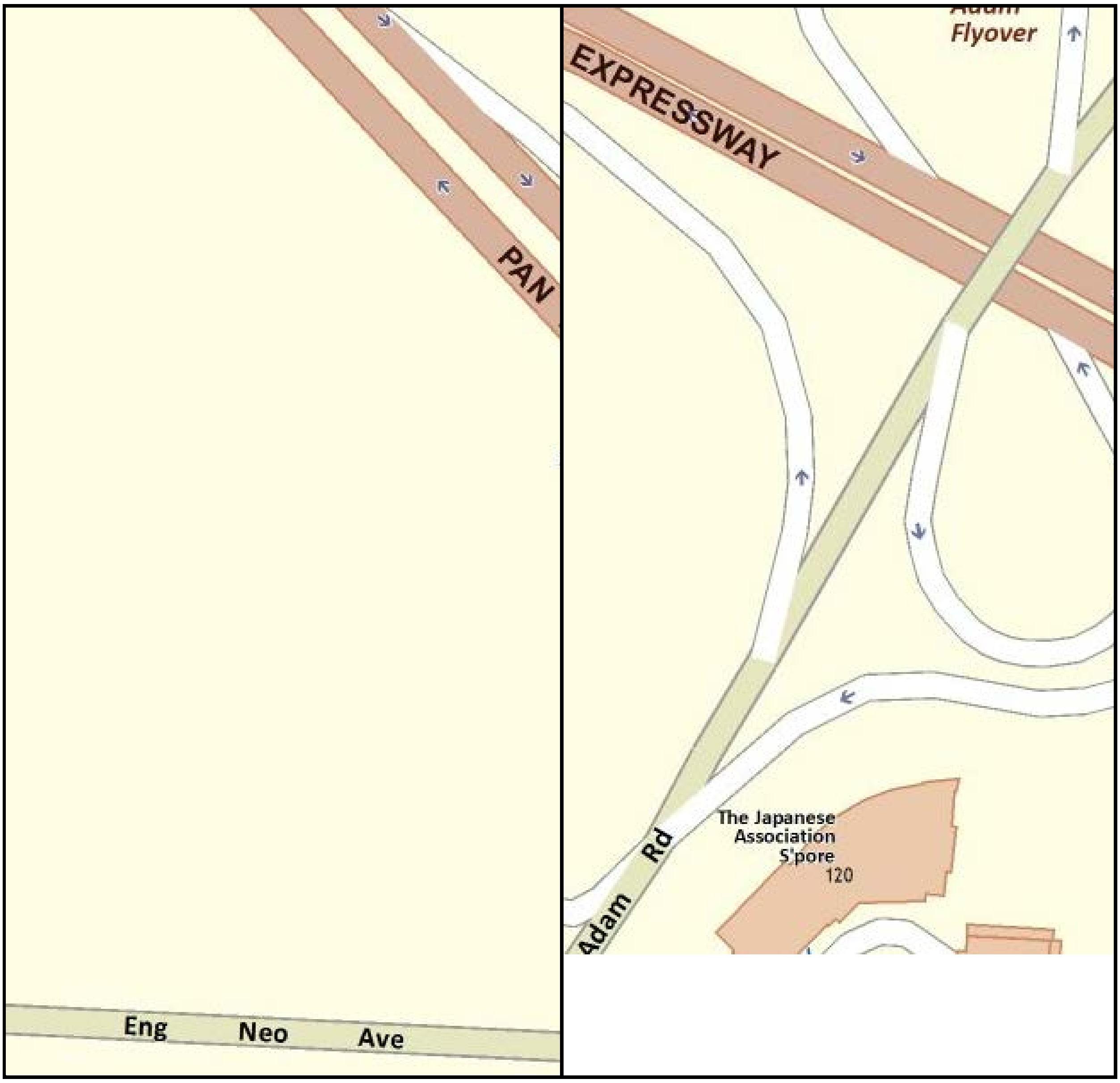


Figure 7: Speed trial locations – Location 1 (left), Location 2 (right) (Source: www.onemap.sg)

A 'before' and 'after' speed survey is carried out at each trial location. A 'before' scenario is based on the current condition of the road. In this case, TrCM is located before the bend (Location 1) and SRS is along the bend (Location 2). The 'after' scenario will relocate TrCM along the bend (Location 1) and SRS before the bend (Location 2). These scenarios for TrCM and SRS are illustrated in Figure 8 and Figure 9 respectively.

TrCM trial location at Location 1	
Before TrCM before road bend	**After** TrCM along road bend

Figure 8: Before and along bend scenerio for TrCM trial location

SRS trial location at Location 2	
Before SRS along road bend	**After** SRS before road bend

Figure 9: Before and along bend scenario for SRS trial location

4.3 Speed trial assessment

During the speed trial, speed counts were obtained for about 200 motorists at each location for each scenario. The trial was conducted during off-peak periods to ensure that the traffic condition at the two trial locations is free flowing. This will help to capture more realistic speed counts that are more reflective of actual traffic condition. As highlighted in paragraph 3.2, the 85th percentile speed result will be used for analysis and comparison. After the raw speed data are collated, the speed results for TrCM and SRS are tabulated as shown in Table 3 and Table 4.

Table 3: Speed results for TrCM 'before' and 'after' study

A 'before' and 'after' speed trial using 85th percentile speed comparison				
TrCM location	Survey start point (kph)	Survey end point (kph)	Speed difference (kph)	Percentage difference (%)
No TrCM	62	48	-14	22.6
Before road bend	69	59	-10	14.5
Along road bend	72	47	-25	34.7

Table 4: Speed results for SRS 'before' and 'after' study

A 'before' and 'after' speed trial using 85th percentile speed comparison				
SRS	Survey start	Survey end	Speed	Percentage

location	point (kph)	point (kph)	difference (kph)	difference (%)
No SRS	60	51	-9	15.0
Before road bend	64	52	-12	18.8
Along road bend	62	50	-12	19.4

The results in Table 3 show that TrCM is more effective when placed along a road bend with a speed reduction of 25kph compared to 10kph when placed before the bend. However, for SRS in Table 4, the results show minimal change in speed difference when placed along or before a bend. It is noted that the speed reduction percentages are rather consistent for SRS regardless of its placement along the road. This is most likely due to motorists reacting to the audio and vibrating effect rather than the visual perception.

In comparison between TrCM and SRS, the 85th percentile speed shows that TrCM (34.7%) is more effective than SRS (19.4%) when placed along the bend, while the speed result before the bend is comparable. This shows that both TrCM and SRS are equally efficient in speed calming before the bend. Hence based on the above findings, it can be concluded that TrCM has a better potential in speed reduction when placed at danger area, in this instance a bend, and is also a more effective speed calming measure that SRS. Nevertheless, both measures are on par in reducing motorists' speed when placed before the bend.

5. CONCLUSION

It has been demonstrated that using psychological traffic calming measure can be as effective as or even better than the traditional type of speed calming techniques. This paper has shown that the potential of TrCM can be maximized based on the locations they are placed. Results have shown that TrCM is most effective when combined with natural terrain such as a crest, bend and road narrowing. Additionally, TrCM has the potential to satisfy both types of environments (surrounding and operating) as it does not contribute to noise disturbance and yet effective to address speeding issues. Nevertheless, physical measures are not to be discounted as they continue to serve as effective means of traffic calming. It is a matter of applying psychological measure to a situation in a holistic manner. Hence, TrCM and SRS can be provided concurrently at locations where straights and bend exist. It can be an alternative to replace SRS when there is a need to manage the noise level in the area and still influence motorists' behavior.

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