Indian J.Sci.Res. 17(2): 93-99, 2018

ISSN: 0976-2876 (Print)
ISSN: 2250-0138(Online)

A REVIEW OF TRAFFIC CALMING MEASURES

[1] Korra Ravi Kiran, [2] Dr. M.Kumar, [3] CH.Anukesh
[1,2,3] Department of Civil Engineering, University College of Engineering. Osmania University, Hyderabad

Abstract- Traffic calming measures (TCMs) are mainly used to address speeding and high cut-through traffic volumes on neighborhood streets, with the goal of increasing both real and perceived safety of pedestrians and cyclists, and also improve the quality of life within neighborhoods. High speeds and traffic volumes can create an atmosphere in which non-motorists are intimidated, or even endangered, by motorized traffic. Along with the additional amount of traffic generated within the neighborhood, cut-through drivers are often perceived as driving faster than local drivers. Traffic calming measures tend to improve pedestrian and cycling travel conditions, as reduced vehicle speeds and traffic volumes tend to make walking and cycling safer, more comfortable and convenient. Street design features that improve safety and mobility encourage walking and promote pedestrian travel. The USA Institute of Transportation Engineers (ITE) defined traffic calming in the following way: “the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behavior and improve conditions for non-motorized street users”. There are various traffic calming measures for reducing vehicle speeds which are separated in three categories 1) vertical deflection 2) horizontal deflection and 3) physical obstruction in that the most effective traffic calming measures for reducing vehicle speeds involve vertical deflections in the carriageway. Other measures may be used in supporting roles such as road narrowing, chicanes, islands, central islands etc. which comes in the category of horizontal deflections and physical obstructions, these measures are very dependent upon spacing for their effectiveness. 85th percentile speeds of less than 30kph may be achieved by implementing these methods. Studies have shown that traffic calming can reduce accident levels by up to 40%, and have a significant impact on reducing the severity of accidents. Area wide traffic calming schemes seek to calm both main roads and residential roads, however main road traffic calming is still a relatively new concept, and generally does not involve the use of vertical shifts. This paper mainly focuses on various types of traffic calming measures which are currently used on roads to reduce speeds of the vehicles and to improve pedestrian and cycling travel conditions, as reduced vehicle speeds and traffic volumes tend to make walking and cycling safer, more comfortable and convenient

Keywords— Vertical Deflections, Horizontal Deflections, Road Narrowing, Speed Hump and Speed Bump

I.Introduction

The concept of traffic calming was introduced in the Dutch town of Delft in 1970 when city officials built a 0.26-foot (8-centimeter) road hump at the end of an alley (Schlabbach, 1997). The concept of traffic calming has spread throughout Europe, Asia, the United States, and Australia. Since various interpretations of what traffic calming is have emerged, the Institute of Transportation Engineering (ITE) developed a standard definition of traffic calming in 1997. Their definition is as follows: Traffic calming is the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behavior, and improve conditions for non-motorized street users. (Lockwood, 1997) This definition was intentionally made broad to apply to all the situations in which traffic calming may be an option but narrow enough to carry a definite meaning. A number of traffic calming programs have been successfully implemented in the world. A variety of traffic calming devices have been utilized in these programs including closures, diverters, chicanes, traffic circles, roundabouts, and speed humps, speed bumps. The primary objective of this traffic calming is to produce a road network that is driven calmly, smoothly and safely by motorists, at speeds which are appropriate to the local environment taking into consideration the presence of other vulnerable road users. Traffic calming seeks to change motorists behavior ‘to civilize the car’ without necessarily altering people’s journey routes. Traffic Calming measures were first introduced within residential areas to try and calm through traffic to prevent it from endangering the lives of local people living in properties fronting roads which may have become busy ‘thoroughfare’ routes. Nowadays in these circumstances it has become practice to introduce area-wide schemes incorporating 20mph speed limit zones and physical traffic calming measures.

II.Type of Traffic Calming Measures

The process of selecting a correct traffic calming measure is of great importance and is unique for each section of the road network. Planning, consultation and execution of the correct TCM must be done according to the existent circumstances and desired objectives. The main traffic calming measures used are separated in three categories:

Horizontal Deflection:

Traffic calming measures that force the driver to maneuver around the horizontal obstacle and create

[1]Corresponding Author

perception of narrower roads. There are two types of horizontal deflection: the first type prevents the driver from moving in a straight line by creating a horizontal shift in the road, which forces drivers to slow their vehicles in order to safely drive through the measure; and the second type that is designed to narrow the width of the travel lane. By doing so the usable surface of the road is reduced, causing drivers to slow their vehicles to maintain the level of comfort. Additionally, schemes that narrow the travel lane can improve pedestrian safety by reducing the width of the crossing. These measures can also have the effect of reducing traffic volumes; however, the effects will typically be lower than on speed reduction.

Vertical Deflection:

Traffic calming measures that create a change in the height of the road. Vehicles slow down to avoid the discomfort from the bumping sensation when travelling over it. Vertical deflection measures are mainly used to reduce vehicle speeds, with lower effects on traffic volumes. They can also be used to improve the safety of pedestrian crossings. These measures typically perform better if implemented in series, than when isolated. The number and spacing of vertical traffic calming measures in a series influences the deceleration and acceleration intensity of a vehicle traveling over them.

Table 1- List of commonly used Traffic Calming Measures

Horizontal Deflection	Vertical Deflection
Curb Extension	Textured Pavement
Curb Radius Reduction	Speed Hump
Chicane	Speed Cushion
Lateral Shifts	Speed Tables / Raised Crosswalk
Traffic Circle	Raised Intersection
Roundabouts	Continuous Sidewalk

The following information describes each type of traffic calming measure on its main physical characteristics, effects on traffic volumes and speeds, and appropriated location. Figures with a scheme representing the design of the TCMs when implemented are presented to all types.

III.Horizontal Deflection

Curb Extension:

Bulbouts, bumpouts, curb bulbs, chokers, curb extensions and neck downs are synonymous terms for an extension of the curb. A Curb Extension is a traffic calming measure, (as shown in the figure 1) primarily used to reduce road width and causes a physical perception of a narrower road on the driver, which reduces speed. Curb extensions can improve pedestrian safety by providing refuge and shorter crossing distance (CCL, 2014). Curb extension is appropriate for all street classifications (local roads, collectors and arterials), but works particularly well in locations with significant pedestrian activity, such as schools zones where they also have the benefit of defining the parking area (PennDoT, 2001).

Curb Radius Reduction:

Curb radius reduction is horizontal intrusion of the curb on the intersection corner, creating a smaller radius, as shown in Figure 5. This measure slows down vehicle right-turn speed due to the tighter corner caused by the smaller radius. It can also improve pedestrian safety by decreasing the crossing distance. Curb radius reduction is acceptable primarily on local roads, but also on collector roadways with inferior extent. In addition, curb radius reductions should not be used on transit routes requiring a right turn (CCL, 2014; PennDoT, 2001).

Fig. 1 Curb Extension and Curb Radius Reduction

Table 2- Expected impacts associated with Curd Radius Reduction and Curb Reduction Extension

Speed	Can reduce speed. Most curb extensions result in speed reductions of 1.6-3.2 km/h. Potential to reduce speeds by up to 8 km/h, when applied significant narrowing the travel lanes (Boulter, 2001; PennDoT, 2001). Slow vehicles making a right turn by reducing the curb radius (PennDoT, 2001).
Traffic	Curb radius reduction increased difficulties associated with the operation of long vehicles (A. B.

	Silva & Santos, 2011).
Safety	Reduce the crossing distance for pedestrians (A. B. Silva & Santos, 2011). Improve the line-of-sight of pedestrians and make pedestrians more visible to oncoming traffic (PennDoT, 2001). Can reduce accidents by 25% (in relation to a speed reduction of 8 km/h) (Boulter, 2001).
Other	Can result in loss of one on-street parking space on each side of the road and can prevent illegal parking close to intersections (PennDoT, 2001; A. B. Silva & Santos, 2011). May make it difficult to accommodate full bicycle lanes (PennDoT, 2001). Improve neighborhood appearance with landscaping and/or textured treatments (A. B. Silva & Santos, 2011).

Chicane:

A chicane is a series of alternating mid-block curb extensions or islands that narrow the roadway and require vehicles to follow a curving, S-shaped path, discouraging speeding. Chicane design consists of a series of 3 curb extensions constructed at mid-block location on alternating sides of the street. Raised landscaped islands or delineators are usually provided at both ends of a chicane in order to increase the drivers awareness of the need for a lateral shift. Along the road sections containing a chicane the street parking may be restricted. They are most appropriate on local streets, with two-lane on two-way streets or with one-lane on one-way streets (CCL, 2014; PennDoT, 2001).

Fig. 2 Chicane used for the Traffic Calming

Table 3- Expected impacts associated with Chicanes.

Speed	Speed reduction of vehicles. A 8 to 20.9 km/h reductions in the chicanes and 1.6 to 9.7 km/h in the surrounding area (A. B. Silva & Santos, 2011)
Traffic	Reduction in traffic volumes, with records where the reduction reached 20 %(A. B. Silva & Santos, 2011). Easily negotiable by emergency vehicles (CCL, 2014).
Safety	Trend to reduce the number of accidents, by approximately 35% (in relation to a speed reduction of 11 km/h), though with increased potential for accidents by screening of vehicles (A. B. Silva & Santos, 2011).
Other	Reduction of the noise level due to lower speeds and traffic volumes (A. B. Silva & Santos, 2011). Landscape rehabilitation improves street appearance (PennDoT, 2001). Require loss of on-street parking spaces (PennDoT, 2001).

Lateral Shifts:

Lateral Shifts presented in Figure are half of a chicane. To cause travel lanes to bend one way and then bend back to the original direction of travel are implemented on the street curb extensions or pavement markings. It's typically used to slow vehicles down by forcing drivers to maneuver through the bend. They can be used on collectors or even arterials, when implemented with the right degree of deflection. Lateral shifts can be considered when high traffic volumes and high speed limits prevent the use of other traffic calming measures (CCL, 2014).

Fig. 3 Typical Example of Lateral Shifts

Traffic Circle:

Traffic Circle is a raised island located in the center of an intersection. It forces vehicles to travel through the intersection in a counter-clockwise direction around the raised island. The traffic circle typically has a circular shape, measuring between 5 m and 7 m in diameter, and can include landscaping within the circle. Traffic circles prevent drivers from speeding through intersections by blocking the through movement. They are most effective when there is a vertical landscaping design in the center, since it increases its visibility to the drivers and provides aesthetics to the neighborhood. Traffic circles are more suitable for intersections of local streets without high pedestrian or left-turn traffic volumes (CCL, 2014; PennDoT, 2001).

Fig. 4 Typical Example of Traffic Circle

Roundabouts:

Roundabout is a measure similar to the traffic circle, but they are larger and typically require additional right-of-way for the vehicles circulating on it. The central island diameter of a single lane roundabout can measure between 17 and 33.5 m. As Figure 5 indicates, raised splitter islands are need at roundabouts to channel approaching traffic to the right. They are found primarily on arterial and collector streets, often substituting intersections that were controlled by traffic signals or stop signs (CCL, 2014; PennDoT, 2001).

Fig. 5 Typical Example Roundabout

Table 4- Expected impacts associated with Traffic Circle and Roundabouts.

Speed	Speed reduction of vehicles. On average, speeds are reduced from 6.4 to 9.6 km/h (PennDoT, 2001). However, depending on the street intersection case can occur a higher speed reduction (13 km/h) or an increase in speed (4 km/h) (Várhelyi, 2002).
Traffic	Increased capacity and fluidity. When compared with yield regulated intersections it results in an increase of about 40% on the capacity of the intersection and corresponding reduction in waiting times (A. B. Silva & Santos, 2011). May make it difficult for emergency vehicles, buses, and trucks to turn left (PennDoT, 2001). May be inappropriate on major emergency response routes. Emergency service vehicles are delayed by 1 to 11 seconds per traffic circle, with most delays falling between 5 and 8 seconds (PennDoT, 2001)
Safety	Can significantly reduce motor vehicle collisions, by reducing the number of potential conflict points at an intersection (PennDoT, 2001). Replacing conventional intersections resulted in a reduction of collisions by 39% and 76% in overall accidents and with injuries, respectively. The reduction of accidents with fatalities was over 90% (A. B. Silva & Santos, 2011). May make pedestrian crossing more confusing at the intersection (Leslie W. Bunte, Jr., 2000).
Other	Enhances neighborhood appearance when properly landscaped (PennDoT, 2001). May require removal of some on-street parking (PennDoT, 2001). A potential reduction in noise levels up to 4 dBA (A. B. Silva & Santos, 2011).

IV.Vertical Deflection

Speed Humps:

Speed humps are a gradual rise and fall in the pavement surface, usually with a circular profile, to a maximum height of three inches over a distance of 12 feet in the direction of travel. Typically they are installed in a series of two or more separated by about 200 feet. This type of speed hump is installed only on local residential streets. The primary purpose of speed humps is to produce sufficient discomfort to a driver to reduce travel speed to 15 mph, which is posted as the advisory speed. The spacing of speed humps is such as to result in an average

85th percentile speed of 25 – 30 mph between humps, depending on the spacing. This design causes drivers to reduce speed, yet allows them to maintain control of their vehicles. Drivers of longer wheelbase vehicles, such as trucks and buses, will normally have to reduce speeds to less than 15 mph to avoid discomfort. For this reason, this type of speed hump is not usually installed on transit, truck, or emergency response routes.

Fig. 6 Typical Example of Speed Hump

Table 5- Expected impacts associated with Speed Humps.

Speed	Slow vehicles down to 24 - 32 km/h at each hump and 40 - 48 km/h in between properly spaced humps. It also can reduce speeds by about 8 km/h in the vicinity of humps (PennDoT, 2001).
Traffic	Volumes are reduced, on average by about 18% (PennDoT, 2001). Not recommended for major emergency service routes. 7 m speed humps caused 0 to 9 seconds of delay and 4 m speed humps caused 1 to 9 seconds of delay (PennDoT, 2001). Negative impact on the wear of buses and other long vehicles (CCL, 2014)
Safety	Can reduce vehicle conflicts; and lead to an accident reduction up to 50% (if there is a speed reduction of 16 km/h) (Boulter, 2001). Should not be a problem for cyclists or motorcyclists, except at high speeds (PennDoT, 2001).

Speed Cushion:

As seen in Figure 7, speed cushions are narrower speed humps that are typically installed in the center of each travel lane. Speed cushions are typically 2 m in width and range in length from 2 to 3 m. Passenger vehicles cross the speed cushions in the same way as speed humps, while emergency vehicles are able to drive through the measure without having to step over it, due to their wider wheel track. Thus, emergency services response times are not affected as much, if at all.

Fig 7 Typical Example of Speed Cushion

Table 6- Expected impacts associated with Speed Cushion.

Speed	Reduction travel speed. Can slow vehicles down by 12 - 14 km/h (Ahn & Rakha, 2009; Boulter, 2001).
Traffic	Reduction in vehicle traffic volumes (A. B. Silva & Santos, 2011). Allows passage for emergency vehicles, buses or other large vehicles, and bicycles (CCL, 2014).
Safety	Reducing the number of road accidents. Can contribute to an accident reduction of 40% - 45 % (if there is a to speed reduction of 13 km/h - 14 km/h) (Boulter, 2001).
Other	May increase noise pollution, due to vehicle deceleration and acceleration (CCL, 2014)

Speed Tables / Raised Crosswalk:

Speed tables and raised crosswalks are a gradual rise and fall in the pavement—typically to a maximum height of three inches over a distance of 22 feet in the direction of travel. The central 10-foot section of the table is flat. They may be used singly for a raised crosswalk, or in a series of two or more for the purpose of speed reduction. When used as a raised crosswalk, the table should extend all the way to the curb, possibly requiring new storm drainage construction, thus increasing cost considerably. Speed tables and humps usually taper down to street grade at the gutter, thus leaving the gutter open for normal drainage. The long length of speed tables allows long wheelbase vehicles to cross with substantially less jolting than with the 12-foot humps, permitting higher speeds. Their longer profile results in higher speeds across and between the devices compared to speed humps. Thus these devices may be used on collector streets where speeds are usually higher, and which may also be emergency vehicle and bus routes. Usually, speed tables and raised crosswalks are placed midblock, but a raised crosswalk may be permitted at an intersection under certain circumstances.

Fig. 8 Typical Example of Asphalt Speed Tables / Raised Crosswalk

Table 7- Expected impacts associated with Speed Tables and Raised Crosswalks

Speed	Slow vehicles down to 38 - 48 km/h at the intervention, and approximately 56 km/h in between them (PennDoT, 2001). Can reduce speeds by around 12 - 16 km/h (Ahn & Rakha, 2009; Boulter, 2001).
Traffic	Discourage through-traffic. Reduce volume by 12% (PennDoT, 2001). May be considered for emergency routes, but only after close coordination with emergency service providers. Slows emergency vehicles by 4 to 6 seconds, on average (PennDoT, 2001).
Safety	Raised crosswalks improve visibility for and of pedestrians. Reducing the number of accidents by 45% (A. B. Silva & Santos, 2011).
Other	May generate noise from vehicle deceleration and acceleration (PennDoT, 2001). Variations in noise levels with an increase of 6 dBA to 8 dBA (A. B. Silva, Santos, & Seco, 2011). Addition of brick or textured materials can improve aesthetics (CCL, 2014).

V.Effectiveness of Traffic Calming Mesaures

Speed Reduction:

Vertical shifts in the carriageway have a greater impact on vehicle speeds than any other measure. Provided that the humps or ramps are spaced sufficiently close together, an 85 percentile speed of less than 30kph is achievable. Spacing should not be greater than 60m, and in general the height of the shift should be 100mm. Ramps with a shallow gradient need to be placed closer together than steeper gradients to achieve the same effect. For example 1 in 10 gradient ramps at 40m intervals have the same speed reducing effect as 1 in 7 gradient ramps at 60m intervals. Other measures such as lateral shifts, carriageway constrictions, roundabouts, small corner radii and changes in priority have an impact on vehicle speeds, but the 85 percentile speed generally remains above 30kph, although average speeds may be below the 30kph threshold.

Table 8 gives an indication of the relative speed reductions achievable from a number of traffic calming measures. The "before" situation refers to a road with a 48kph speed limit.

Table 8- Expected speed reduction effect of various Traffic Calming Measures

	Upper Limit of Maximum Speed(kmph)		Upper limit of 85 percentile speed (kmph)		Range of average speed (kmph)	
	Before	After	Before	After	Before	After
Vertical shifts in the carriageway	100	40	75	30	45-65	18-25
Lateral shifts in the carriageway	100	65	75	45	45-65	22-35
Road narrowing to a single lane	100	65	75	45	45-65	22-35
Roundabout	100	65	75	45	45-65	22-35
Road narrowing to a reduced width	100	95	75	70	45-65	40-55
Central islands	100	95	75	70	45-65	40-55

VI. Conclusion

- The most effective traffic calming measures for reducing vehicle speeds involve vertical shifts in the carriageway such as road humps, speed tables and cushions. These measures are very dependent upon spacing for their effectiveness. At a spacing of 40-60m, 85 percentile speeds of less than 30kph may be achieved.
- Other measures may be used in supporting roles such as road narrowing, chicanes, islands etc. however, these measures are less effective in reducing speeds when used in isolation.

- Studies have shown that traffic calming can reduce accident levels by up to 40%, and have a significant impact on reducing the severity of accidents
- Noise reduction through traffic calming is mainly related to reductions in traffic volumes; however the type of measures employed may create problems with noise levels. These are exacerbated if there is a high proportion of HGV's.
- Area wide traffic calming schemes seek to calm both main roads and residential roads, however main road traffic calming is still a relatively new concept, and information on this is limited. Generally schemes on main roads do not make use of vertical shifts, and therefore significant reductions in vehicle speeds are harder to achieve.

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