A Comparative Study of Speed Humps, Speed Slots and Speed Cushions

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Abstract. The primary objective of this study was to compare speed humps with two newer traffic calming devices that are gaining popularity in the US, the speed slot and speed cushion. Crossing speed and driver behavior were measured at selected traffic calming devices on roadways in the Washington DC metropolitan during the summer of 2003. The subject devices include:

- 12-ft and 22-ft asphalt speed humps;
- 14-ft prefabricated speed humps;
- 22-ft speed slots; and
- 10-ft speed cushions.

All ranged from 2.5 to 4.0 inches in height. Video surveillance technology was used to collect data, including vehicle crossing speed, lateral placement and braking frequency.

Preliminary results revealed that speed slots allowed the highest average and 85th percentile crossing speeds. Speed cushions, 12-ft speed humps and 14-ft prefabricated speed humps recorded the lowest crossing speed and relatively high frequency of braking maneuvers.

The designs of the speed hump and speed cushion encouraged drivers to travel centrally within their lane. Lateral positioning while traversing the speed slot was varied; a large percentage of drivers attempted to place the vehicle's left tires in the slot.

INTRODUCTION

Statement of the Problem

As the adoption of various traffic calming practices continues throughout the U.S., use of the speed hump as a standard traffic calming device steadily increases. However, speed humps have also become the center of a traffic engineering controversy. Emergency response agencies and community groups have been cited in the belief that speed humps increase the amount of time for an emergency vehicle to respond to calls.[1,2,3] This has resulted in hesitation and resistance regarding installation of speed humps. In reply to these concerns, two variations of the speed hump design are beginning to gain popularity in the U.S., the speed slot and speed cushion. Although the use of the speed slot and cushion is fairly common in European countries, its effectiveness as a traffic calming device in the U.S. is yet to be seen. Differences in driver behavior and vehicle characteristics between European countries and the U.S. make research in this area vital to the progress of traffic calming in the United States.

Research Goals

The goals of this effort was to perform a comparative analysis of the three traffic calming devices by examining crossing speed, driver behavior and brake pedal use. Specific questions to be addressed are:

- How do speed humps, slots, and cushions affect driver's speed at the device?
- When the devices are placed in series, is the crossing speed at a second or third device different than at the initial device?
- How do speed slots and cushions affect driver's selection of lateral crossing location behavior differently than speed humps?

BACKGROUND

Speed Humps

In 1997 the Institute of Transportation Engineers (ITE) approved the *Guidelines for the Design and Application of Speed Humps*, RP-023A, which provided recommended practice based on national and international research and experience.(4) ITE reported that speed humps should be installed on roadway facilities classified as local streets by the American Association of State Highway and Transportation Officials (AASHTO). The roadway should not be more than two travel lanes or traveled significantly by long wheel-based vehicles. Additionally, it should have a horizontal curve of 300 feet radius or more and a grade of eight percent or less. The posted or prima facie speed limit should be 30 mph or less; ITE warned that installation on roadways with a higher speed limit warranted careful consideration.

Design

The design of a speed hump can be defined by specifying the length of its base, the height of its crown and the shape of its surface profile, as shown in Figure 1. ITE recommended a height of 3-inches for speeds of 20 to 25 mph and 4-inches for speeds of 15 to 20 mph. For length, ITE recommended 12 feet.

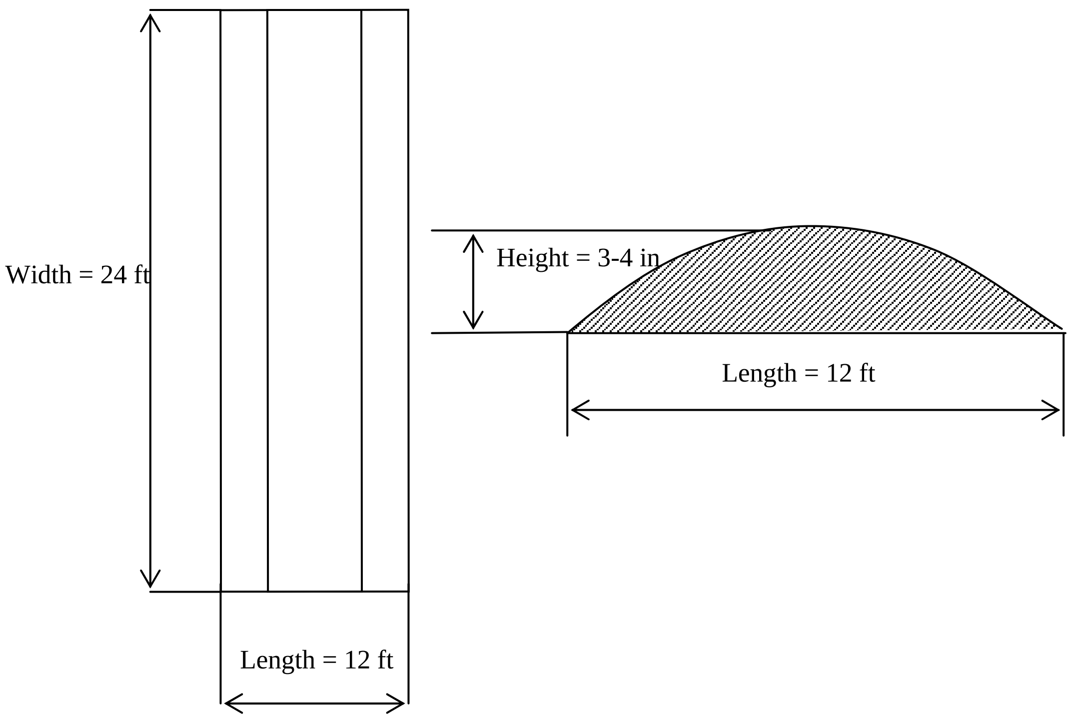

Figure 1. Schematic of a Typical Circular Speed Hump.

For use on a typical residential street, ITE reported that the most common designs are the circular or parabolic speed hump as shown in Figure 2. An alternative design, the flat-topped design, is also shown in the Figure 2.[4]

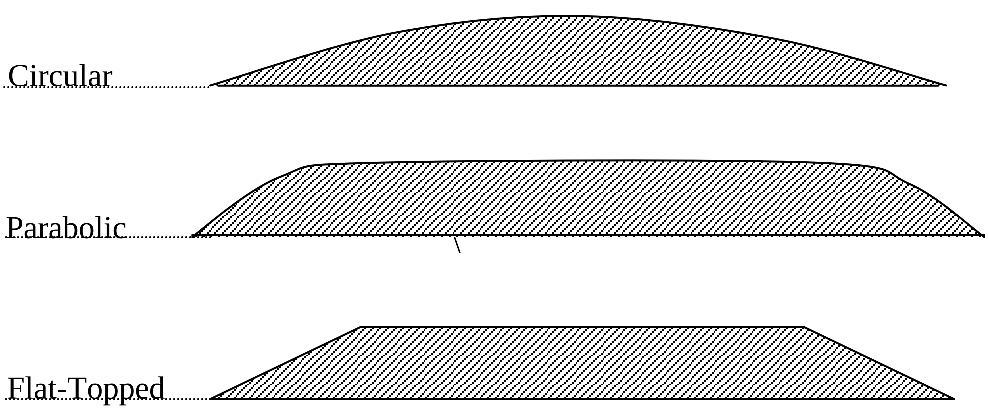

Figure 2. Typical Design Profiles of Speed Humps.

Speed Slots and Speed Cushions
Due to concerns that speed humps influence response times and passenger comfort of emergency response vehicles, modified designs of speed humps were created.[1,2,3] Like speed humps, speed slots and speed cushions are both raised areas across the road with the intent of reducing vehicle speed. However, speed slots and cushions were designed to avoid excessive discomfort or damage to emergency vehicles by making separations in the hump. Figure 3 compares the typical design of speed humps, slots, and cushions. Speed slots are similar to speed humps in that they extend across the roadway but they have "slots" or tire grooves along each side of the centerline in order to allow emergency response vehicles to avoid of the device by driving through the slots along the middle of the road. Unfortunately the emergency vehicle must straddle the centerline and travel in both lanes of the roadway, increasing the risk to both the emergency vehicle as well as other vehicles.

Speed cushions are smaller than lane width and are rectangular or square in shape.[5] These characteristics allow for an emergency response vehicle to straddle the cushion while remaining in its respective lane. Figure 3 shows the typical dimensions and layout of speed humps, slot and cushions.

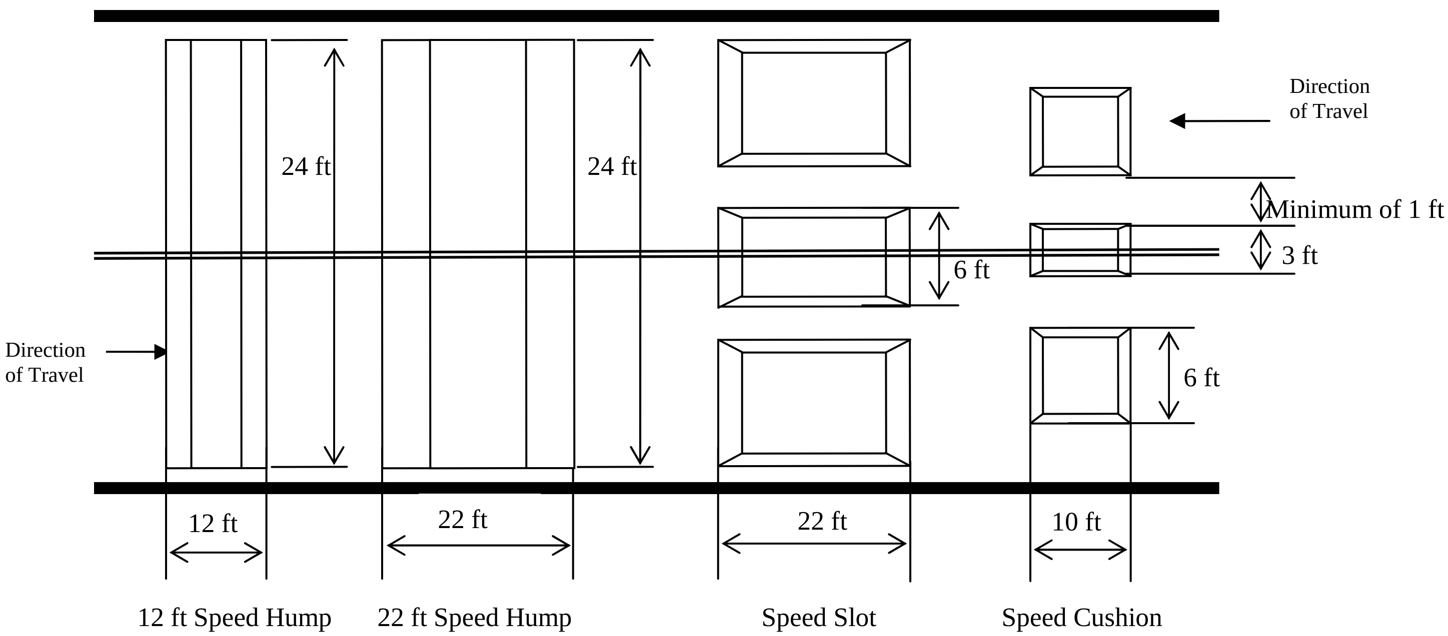

Figure 3. Schematic of Speed Hump, Speed Slot and Speed Cushion.

The basic designs of both the speed slot and speed cushion are very much like the speed hump. However, additional modifications have been made for the speed cushion to accommodate for the wider vehicle width of cars in the US. Table 1 shows recommendations made by the City of Austin Texas and the United Kingdom Department of Transport. Figure 4 shows a diagram of the typical speed cushion.

Table 1. Recommended Speed Cushion Design Characteristics.

Design Characteristics	**Austin, TX**[6]	**United Kingdom**[7]
Base Length	10-ft or 12-ft	2 to 2.5 m (6.56 to 8.20 ft)
Base Width	6.5 ft or 3 ft	1.6 to 1.9 m (5.24 to 6.23 ft)
Maximum Height	3 ±¼ in	80mm (4.15 in)
On/Off ramp Gradient	1:8 at 18 in	1:8
Side Ramp Gradient	1:6 at 24 in	1:4
Transverse Gap	12 in wide	750 and 1000 mm (2.46 ft to 3.28 ft)

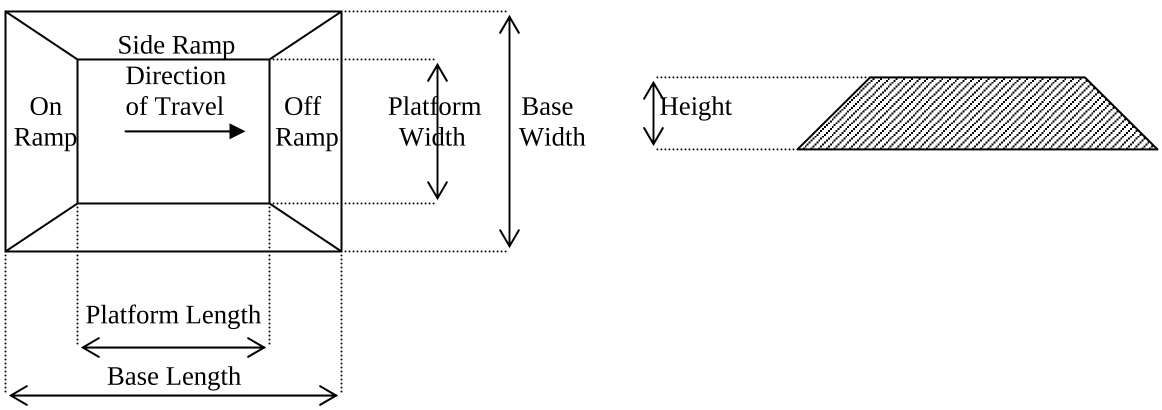

Figure 4. Aerial and Cross-Sectional View of a Speed Cushion.

Speed Cushion Studies

A 1998 study by Layfield and Parry that examined speed cushion schemes in the United Kingdom concluded that although speed cushions are not as effective as speed humps in reducing speeds, they are important because they decrease driver discomfort especially in large buses. Speed cushions were reported to have two to seven mph higher 85th percentile crossing speeds than speed humps and one to two mph higher 85th percentile speeds between devices. [8]

The study by Layfield and Parry found that passenger discomfort was low at speed cushions for large buses if the cushions were straddled centrally, but otherwise had similar effects as speed humps if not straddled centrally. [9]

Driver Behavior at Speed Cushions

In observing driving behavior, Layfield and Parry found that 55 percent of all cars and 90 percent of all buses in the study attempted to centrally straddle the speed cushions. In the three abreast configuration, 40 percent of all drivers drove with one tire between the nearside and middle cushions. [8] A study by Pau on how speed bumps may induce improper driver behavior in Italy, characterized improper movement as total or partial avoidance in a park or bus lane. This study found that a significant percentage of drivers attempted to totally avoid speed humps by traveling in the park or opposite lane.[5]

Emergency Vehicle Response Time at Speed Cushions
In a 2000 study by Bunte investigated the effects of the speed cushion on the response times in Austin Texas. Results showed that speed cushions had very little impact, if any, on increasing response times of emergency response vehicles. Average delay times were less than a second, except for the vehicle that was transporting a critically ill/injured patient which had an average delay of 4.84 seconds on total travel time. Overall, the study found that speed cushions are less detrimental to negatively impacting emergency response times than speed humps.[10]

DATA COLLECTION METHODOLOGY AND ANALYSIS

Site Selection

The study investigated speed humps, slots and cushions in the Washington, D.C. metropolitan area. Beyond device length, which was a function of the device type, the following criteria were used to select the ten sites used in the study:

- Height: 2.5 – 4.0 inches;
- Separation: 150 – 700 ft;
- Street Width: 25 – 35 ft;
- Number of Lanes: 2 lanes, one in each direction;
- Street Classification: Residential, local; and
- Parking: Unrestricted on one or both sides.

For each site, observations and photographs were taken at each location to record road geometry, classification, posted and advisory speeds, traffic volume and speed hump, slot, or cushion characteristics. Table 2 presents the ten sites and type of associated traffic calming device. Additional information about each site is found in Appendix A. During the site selection process, local transportation officials were contacted.

Table 2 Sites Selected for Study.

Site ID	Device Type	Road Classification	Segment Length	Street Width and Parking	Posted Speed
1	Hump-12-ft	Residential, school	1079 ft	24 ft wide, parking on both sides	25 mph*
2	Hump-12-ft	Residential	1388 ft	24 ft wide, parking on both sides	25 mph*
3	Hump-12-ft	Residential, school	1427 ft	32 ft wide, parking on both sides	25 mph
4	Hump-22-ft	Residential, Collector for local interstate, school	816 ft	27 ft wide, permit parking on both sides	25 mph

5	Hump-22-ft	Residential, Local, school	1866 ft	25 ft wide, parking on both sides	25 mph**
6	14-ft Prefabricated Hump	Residential, school, major hotel	1372 ft	30 ft wide; 2 lanes parking on one side	25 mph
7	Slot	Residential	2857 ft	34 ft wide, 2 lanes, parking on both sides	25 mph
8	Slot	Residential, collector for Route 50, school	2837 ft	36 ft wide, 2 lanes, parking both sides	25 mph
9	Cushion	Residential	2743 ft	26 ft wide, 2 lanes, parking on both sides	25 mph
10	Cushion	Residential; cut-through for two local arterials	2456 ft	27 ft wide, 2 lanes, parking on one side	25 mph

* 15 mph advisory speed placard at device
** 20 mph advisory speed placard at device

Vehicle Classification

Vehicles were classified as to belonging to one of seven different groups. These classifications were primarily based on vehicle suspension, handling and ground clearance. The seven classifications are as follows:

- Passenger car;
- Luxury / High performance car;
- Pick-Up Truck;
- SUV / Minivan;
- Trucks;
- Buses; and
- Other (service vans, etc).

Data Collection Methodology

Video camera surveillance was used to collect speed data and to document driver behavior. A digital video camcorder discretely set-up at the site recorded driver response to the devices. The placement of the video camcorder permitted the observation of the traffic calming device and at least a 50 ft approach to the device. Data for vehicles traveling in both directions were collected simultaneously. Data were collected for two-hour periods during weekdays between 10 am and 2 pm during good weather conditions.

Data Reduction

Videos from the video camera surveillance were viewed; speed and lateral position data were extracted and put in an Excel spreadsheet. Devices that were in a series were designated as first, middle, or last at a particular site and the same type of device was used throughout the series. A series consisted of either two or three devices.

Video-frame analysis was used to collect the crossing speed data. Based on the knowledge that the video camcorder recorded 30 frames per second, the number of frames needed for the vehicle's front tire to traverse the length of the device was used to calculate the vehicle's average crossing speed. Only vehicles traveling under free-flow conditions were used for the analysis; following vehicles were of no interest due to the influence of a lead vehicle. Data were extracted for vehicles traveling in each direction. Approximately 100 data points were used for each site when possible.

Crossing vehicles were classified as passenger car, sports utility vehicle or pickup truck/minivan. Also, braking and any erratic behavior such as evidence of loss of control was documented.

Data relating the driver's choice of lateral placement when crossing the device was subjectively recorded from the video. Lateral placement was classified as the following:

- Driving in the center of the lane;
- Crossing over the centerline;
- Driving with the left tires in the groove (only for slots and cushions); or
- Driving towards the right side of the lane.

RESULTS

Speed Analysis
Descriptive statistical analysis was performed, in which the average and 85th percentile speeds and standard deviation were calculated. Various results will be highlighted in the following tables. Table 3 shows the average and 85th percentile speeds of devices that were either stand-alone or were the first in a series. As can be seen, the 12-ft speed humps, 14-ft speed prefabricated speed humps and the speed cushions all generated average speeds that were approximately 10 mph and 85th percentile speed that were less than 15 mph. The 22-ft speed humps and the speed cushions had higher average speeds. The 85th percentile speed at the speed slots was over 25 mph.

Table 3. Average and 85th Percentile Speed (in mph), by Device Type.

Device Type	**Average Speed**	**85th Percentile Speed**
Speed Hump-12-ft	9.6	12.3
Speed Hump-22-ft	15.2	18.8
Prefabricated Speed Hump-14-ft	10.6	14.3
Speed Slot	20.5	26.5
Speed Cushion	10.1	12.8

Table 4 shows the average and 85th percentile speeds for devices that were installed in series. For installations that consisted of only two devices, the middle device column contains "n/a." Site 4 consisted of only one speed hump. Recall that all roads were posted at 25 mph.

From the table it can be seen that speeds tended to remain relatively constant at each of the devices in the series. Two sites demonstrated a variation in their average and 85th percentile speeds. At site ID 5 (22-ft humps) speeds decreased and then increase along the series of humps, which were spaced approximately 500 feet apart. At site ID 9 (speed cushion) there was an increase along the series of cushions, which were separated by 550 feet apart.

It was observed that most drivers depressed their brakes when crossing any of the devices, independent of the position of the device in the series.

Table 4 Average and 85th Percentile Speeds for the Various Devices, (in mph).

Site ID	Type of Device	First Device		Middle Device		Last Device	
		Average	85 Percentile	Average	85 Percentile	Average	85th Percentile
1	12-ft-hump	10.8	12.3	n/a	n/a	9.9	12.3
2	12-ft-hump	10.1	12.2	n/a	n/a	10.2	12.3
3	12-ft-hump	9.4	11.9	n/a	n/a	9.4	12.2
4	22-ft hump	14.3	17.3	n/a	n/a	n/a	n/a
5	22-ft hump	16.3	19.6	14.6	17.4	19.2	23.7
6	Prefab 14-ft hump	10.6	14.3	n/a	n/a	10.5	13.0
7	Slot	19.5	24.7	18.3	23.7	18.6	23.7
8	Slot	21.2	26.5	17.7	21.4	19.4	22.5
9	Cushion	10.1	13.6	n/a	n/a	13.6	20.0
10	Cushion	10.1	12.0	9.7	11.4	10.5	13.3

Analysis of Traveling Speed by Vehicle Type

Crossing speeds were analyzed for each of the devices based on vehicle type. Speed were classified as fitting into one of the following groups:

- 0.0-9.9 mph;
- 10.0 – 14.9 mph;
- 15.0 – 19.9 mph;
- 20.0 – 24.9 mph;
- 25.0 – 29.9 mph;

- 30.0 – 34.9 mph; and
- 35.0 mph and over.

No one vehicle group performed differently than any other vehicle group for a given type of device. For the 12-ft humps, the most common traveling speed for each vehicle type was in the 0.0-9.9 mph speed category. For the 22-ft humps, the most travel speed for each type of vehicle was in the 15.0-19.9 mph speed category. For the 14-ft temp humps, approximately half of the vehicles were classified in the 0.0-9.9 mph speed category and half in the 10.0-14.9 mph speed category. For speed cushions, the majority of speeds were in the 0.0-9.9 mph speed category.

Table 5 presents the percentage of vehicles traveling in each speed category at the speed slots. For the most part, travel speeds were in the 15.0-19.9 mph speed category. The only result of interest was the percentage of vehicles (shown in italics) that were identified in the speed categories 30.0-34.9 and 35.0 mph and over.

Table 5. Percentage of Vehicles Traveling in each Speed Category, by Vehicle Type for Speed Slots.

Vehicle Type	**Number of Observations**	**Traveling speed (mph)** 0.0 - 9.9	**10.0 – 14.9**	**15.0 – 19.9**	**20.0 – 24.9**	**25.0 – 29.9**	**30.0 – 34.9**	**35.0 +**
Passenger Cars	238	2.1	18.5	48.7	22.3	3.8	*2.1*	*2.5*
Luxury and High Performance	72	2.8	15.3	55.6	11.1	12.5	0.0	*2.8*
Pick-up trucks	34	2.9	23.5	35.3	17.6	11.8	*5.9*	*2.9*
SUVs and Minivans	155	3.9	18.1	41.3	22.6	5.8	*4.5*	*3.9*
Trucks	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Buses	10	20.0	30.0	10.0	10.0	20.0	*10.0*	0.0
Other, (e.g., service vans)	25	0.0	32.0	44.0	16.0	4.0	0.0	*4.0*

Lateral Placement Analysis
A similar analysis was performed looking at driver selection of the vehicle's lateral placement when crossing the device. Vehicles were classified as either driving in the center of the lane, crossing the centerline, driving towards the left (or right) of the lane.

As expected, since speed humps do not offer the driver the opportunity of traversing with a tire (or pair of tires) not contacting the hump, lateral placement of the vehicle tended to be in the center of the travel lane. Lateral placement at speed slots was also consistent; however, at speed slots most drivers tended to drive with their left tires along the grooves of the slot.

Table 6 shows that when traversing a speed cushion, most drivers either chose to have their vehicle centrally located over the cushion or traverse the cushion with their left tire in the groove. The lateral placement selected by pick-up truck drivers is of possible concern. Even with the small sample size of 27 it was noted that almost twice as many pick-up trucks crossed the centerline, in an attempt to cross the smaller cushion located under the centerline. The average speed of vehicles crossing the centerline was 10 mph, which indicates that these drivers were not traveling at an unsafe speed, but this is an erratic maneuver that may surprise oncoming drivers. No other erratic behavior (e.g., sudden braking, swerving, etc.) was observed at the speed cushions.

Table 6. Lateral Placement of Vehicles by Vehicle Type for Speed Cushions.

		Lateral Placement			
Vehicle Type	**Number of Observations**	**Center**	**Over Centerline**	**Left Tire in Groove**	**Towards Right, Right Tires in Slot**
Passenger Cars	246	39.0	12.2	39.0	9.8
Luxury and High Performance	64	32.8	10.9	53.1	3.1
Pick-up trucks	27	44.4	22.2	25.9	7.4
SUVs and Minivans	103	40.8	8.7	42.7	7.8
Trucks	0	0.0	0.0	0.0	0.0
Buses	0	0.0	0.0	0.0	0.0
Other, (e.g., service vans)	9	33.3	22.2	33.3	11.1

CONCLUSION

After collecting data for almost 2000 vehicles, it was found that speed slots followed by 22-ft speed humps allowed the highest average and 85th percentile crossing speeds. Twelve-ft speed humps, speed cushions and prefabricated 14-ft speed humps recorded the lowest crossing speeds.

The design of the speed hump encouraged drivers to travel centrally within their lane. Lateral positioning while traversing the speed slot and cushion varied. At speed slots a large percentage of drivers shifted to the left, in an attempt to place the vehicle's left tires in the slot. At speed cushions, drivers tended to drive either centrally down the lane or shifted towards the left of the lane to place the left tires in the groove.

Speed slots, with many drivers shifting towards the left side of their lane, exhibited the highest average and 85th percentile speeds in this study, and speed cushions, with a large percentage of pick-up truck drivers crossing the centerline in order to traverse the cushion, would appear to present a safety concern to the unsuspecting, oncoming driver.

Unfortunately, crash data was not collected as part of this exercise. Future research to investigate these hypotheses may be justified.

It is recommended that further research investigate lateral acceleration generated by the various devices for selected vehicle types as well as device spacing.

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APPENDIX A: SELECTED SITE SPEED DEVICE PROFILE

Site ID	Profile/ Configuration	Height	Length	Width	Gap	Separation	Construction	Markings
1	Parabolic	2.5 in	12-ft	n/a	n/a	Range of 130-383 ft	Asphalt	Zebra
2	Parabolic	3.0 in	12-ft	n/a	n/a	437 & 419 ft	Asphalt	Zebra
3	Parabolic	3.0 in	12-ft	n/a	n/a	600 ft	Asphalt	Chevron
4	Parabolic	3.0 in	22-ft	n/a	n/a	460 ft	Asphalt	Chevron
5	Parabolic	3.5 in	22-ft	n/a	n/a	Range of 430-530 ft	Asphalt	Zebra
6	Flat-top	4.0 in	14-ft	n/a	n/a	150 & 161 ft	rubber	arrow on road prior to hump
7	symmetrical about centerline	3.0 in	22-ft	5 ft & 12-ft	18 in	490-535	Asphalt	Diagonal Lines
8	symmetrical about centerline	3.0 in	22-ft	5 ft & 14-ft	17.5 in	470-575 ft	Asphalt	Diagonal Lines
9	three cushion abreast; symmetrical about centerline	3.0 in	10-ft	7 ft	24 in	505 & 634 ft	Asphalt	Arrow
10	three cushion abreast; middle cushion off set from centerline	3.5 in	10-ft	7 ft	18 in	285 & 470 ft	Asphalt	Arrow

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