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Traffic Microsimulation Study to Evaluate the Effect of Type and Spacing of Traffic Calming Devices on Capacity

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Abstract

Traffic calming is widely implemented to improve road safety. However, the implementation of traffic calming devices implies less capacity of cross-town roads. The present research used traffic microsimulation to study the effect of traffic calming devices on the cross-town roads capacity based on different type and spacing of devices. Average delay was calculated. Then, capacity of the road was obtained for a fixed traffic calming device spacing as the flow rate from which delay presented exponential growth. Capacity of a cross-town road varied between 810 and 1300 vehicles per hour and lane with traffic calming devices spacing from 25 to 400 meters.

Keywords: Traffic calming, Speed table, Speed hump, Capacity, Traffic microsimulation

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1. Introduction

Traffic calming is a practice that has been implemented primarily in developed countries. In some countries, this technique has been incorporated through the urban design of public space. Usually, traffic restraint programs are part of the overall plan for transport and the environment. Traffic calming has two main objectives: the reduction in the frequency and severity of accidents; and improving the environment for a local area (Sanz, 2008). This implies, in some cases, the decrease in traffic flow and, of course, reducing the speed of vehicles traveling through the area.

Among the elements used in traffic calming highlight physical measures involving vertical deflections, such as speed tables, speed humps and speed bumps. A speed hump is a raised curved area in the roadway pavement surface

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extending transversely across the travel way. A speed bump is a shorter speed hump. Speed tables are flat-topped speed humps, through a prefabricated or built on site with a trapezoidal longitudinal profile, designed specifically to maintain a reduced speed and to allow pedestrians to cross on top.

Many manuals have been developed to provide engineers guidance on traffic calming measures (TCM) (Ewing and Brown, 2009; ITE, 2007; Ministerio de Fomento, 2008; Dirección General de Obras Públicas de la Comunidad Valenciana, 2004, CERTU, 2010). Geometry and the most appropriate location of TCM were provided, as well as recommended traffic flow range to implement TCMs. According to Spanish guidelines, no vertical TCMs are recommended on cross-town roads with annual average daily traffic (AADT) higher than 5000 vehicles/day (veh/d). The value is higher on other guidelines where AADT is limited to 10000 veh/d (CERTU, 2010; FHWA, 2009).

Several research has been carried out to analyze the effect of TCMs on traffic operation. Operating speed reductions were found about 18% (Ewing, 1999, Hallmark et al., 2002, Zech et al., 2009). Before and after studies were carried out on speed tables and speed humps. Mean speeds were reduced from 6 to 13 km/h on different locations (Hallmark et al., 2002, Hallmark et al., 2008, Zech et al., 2009). Speed reduction on speed humps was higher than the other devices (Fehr & Peers Transportation Consultants, 2010). Speed bumps were found non-effective (Pau and Angius, 2001). The lack of statistically significant differences between the speed values observed, in the same street, at the speed bump or quite far from it, suggested that probably a combined effect of poor efficiency of the device and immurement of drivers to vibrations and noise was present.

On the other hand, speed reduction was reported to depend mainly on the spacing between traffic calming devices (Ewing and Hodder, 1996, Garcia et al., 2010). Moreover, cumulative effect due to close spacing was also concluded (Zech et al., 2009, Abate et al., 2009). However, effects of TCM typology and spacing on capacity or operation performance on cross-town roads were not analyzed.

2. Objectives

The aim of the study was to determine the effects of vertical traffic calming measures implemented on a cross-town road on its capacity and operation performance.

The main objectives of the research were: to observe and analyzed drivers' behavior on five cross-town roads with traffic calming measures by using GPS trackers; to calibrate and validate a microsimulation model; to apply the model to different traffic demand and spacing between elements; and to analyze the results. Consequently, the applied methodology included three main components: field study; microsimulation model; and analysis of the results. Each one of the stages is being developed on the following sections.

3. Field study

The first stage of the research consisted of the selection of five cross-town roads in the province of Valencia (Spain). The cross-town roads were selected according to the recommendations of a previous road safety study, taking into account: AADT; length of the cross-town road (L); and type of existing traffic calming measures. The selected towns were: Genovés (AADT = 2600 veh/d; L = 925 m); Quatretonda (AADT = 3240 veh/d; L = 685 m); Llutxent (AADT = 2930 veh/d; L = 580 m); Albalat de la Ribera (AADT = 4230 veh/d; L = 860 m); and Chelva (AADT = 650 veh/d; L = 1250 m). A total of 16 speed tables and 5 speed humps were distributed along the cross-town roads. The characteristics of the sites were analyzed by Garcia et al. (2010).

Data collection was carried out with passive GPS trackers, which stored every second both time and position of the vehicle. Two road controls were located at least 1 km before and after the town. Passenger cars were stopped and their drivers were asked to collaborate in the study. A passive GPS tracker was placed over their car and they were encouraged to drive as usual. A similar methodology was successfully used on another research (Perez et al., 2010). It was proven not to influence drivers' speed selection and behavior. A sample of at least 100 passenger cars per direction during the morning period was obtained in each road segment. Consequently, continuous speed profiles and acceleration profiles were obtained from more than 900 vehicles (Figure 1). Then, a successive data debugging process was done. Near 10 % of the initial sample was discarded due to non free-flow conditions, detour or stopping.

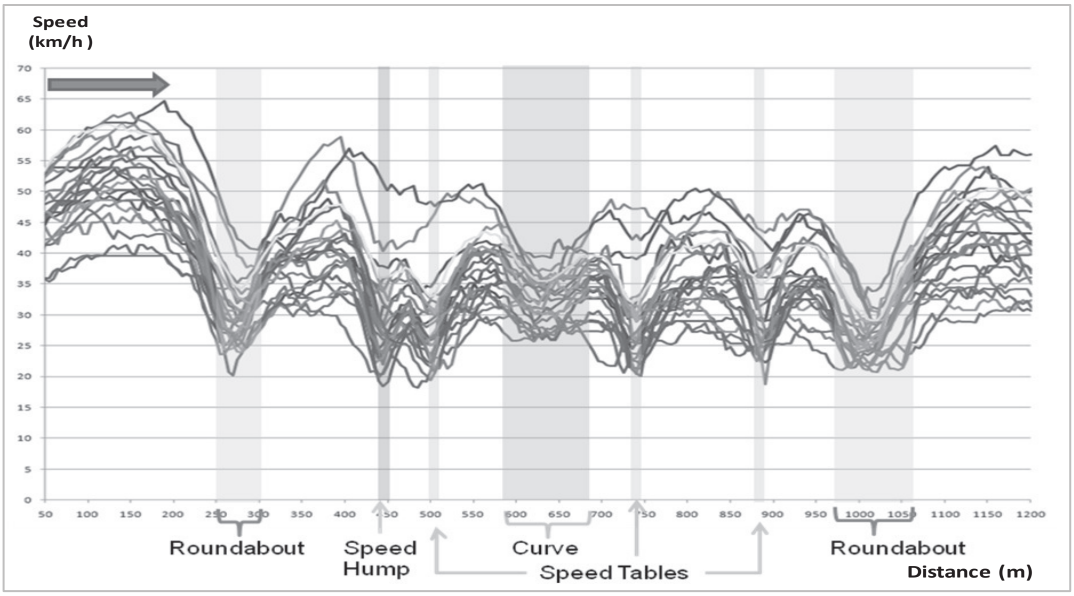

Figure 1. Individual speed profile sample at Genovés cross-town road.

Besides, vertical traffic calming measures were measured using a digital profilometer. The actual longitudinal profile of the devices was obtained at the point where vehicles tires passed over the speed tables. The digital profilometer gave one list of (x,y) coordinates with a precision of 1/8 of a millimeter. After data collection, the coordinates were filtered and rotated. Finally, slopes and height were calculated (Garcia et al., 2010).

The profiles were related to the location and characteristics of the traffic calming devices. Subsequently, actual drivers' performance was associated to traffic calming measures characteristics.

4. Microsimulation model

The traffic simulation model VISSIM 5.1 was selected to analyze capacity at cross-town roads with vertical traffic calming measures. A brief description of the traffic simulation model is presented in this section, as well as main features which are critical in modeling traffic operations.

4.1. Traffic simulation program

VISSIM 5.1 is a microscopic multimodal traffic simulation model. It can assign behavior to individual vehicles as they circulate from their origin to their destination. Furthermore, most of the macroscopic features can be also analyzed because of the microscopic rules calibration. Besides, different transportation modes and their interactions can be modellized. VISSIM 5.1 can be applied to multiple scenarios such as mobility studies, intelligent traffic systems (ITS), management systems and traffic control systems (Fellendorf and Vortisch, 2001).

The traffic simulation program is constituted by two subprograms. Traffic flow model is built on the first subprogram, where all network features are defined. The second subprogram rules behavior of vehicles, pedestrians, etc., depending on value of traffic flow parameters. The Wiedemann's vehicle behavior model is implemented on VISSIM 5.1. The model defines vehicles' response as a function of perceived relative speed between a vehicle and the previous car. Four different responses are deduced: free flow; approaching; following; and braking. Lane changing model is also implemented.

4.2. Model calibration and validation

The traffic simulation model was elaborated to reliably represent the observed behavior. Therefore, a calibration of the model was needed. Genoves cross-town road was selected to calibrate the model. The adjusted data on the model were: traffic flow; composition; grade; and speed profile. Speed profiles were defined in the model by means of 7 percentiles: 0, 5, 15, 50, 85, 95 and 100. They were calculated using the individual speed profiles obtained in the field study from a sample of more than 900 drivers.

In order to model temporary changes of vehicle speed around TCMs, one model link around them was created. Its length was 5 m and constituted reduced speed areas. The speed profiles distributions which were obtained from the field study were assigned at the center of the reduced speed area, as well as average deceleration and acceleration.

However, drivers developed also another behavior near TCMs which was not considered on reduced speed areas. Desired speed decision areas were defined from 25 meters around the TCMs, upstream and downstream. These areas were usually located at speed signs and their length was considered as the longest speed reduction before a TCM. Observed speed profiles were considered on these areas.

Once the model was defined and calibrated, a validation of its results was needed. The model validation compared the results on the model with the observed data in Genovés. The selected checking variable was speed profile distribution as the other variables were constants during simulations.

4.3. Simulated scenarios

Once the simulation model was calibrated, different scenarios were applied in order to analyze the effect of traffic calming devices on capacity. An ideal cross-town road was created with only one tangent 1400 m long. The scenarios differed on TCMs spacing and type. Spacing between TCMs varied from 25 to 400 m. The TCMs were distributed along the central 900 meters. In the first and last segments (250 meters long each one) the speed were not affected by the speed tables or humps. The number and location of TCMs was deduced from their spacing. Three different TCMs were considered: speed tables with entrance ramp slope (*ERS*) lower than 5%; speed tables with entrance ramp slope higher than 5%; and speed humps. The effect of heavy goods vehicles (*HGV*) was also simulated. Speed data were computed using percentages of *HGV* between 0 and 20%, with 5% step. For each combination of the previous variables, traffic flow was increased from 100 veh/h to 2100 veh/h, with 200 veh/h step. Table 1 summarizes the simulations carried out.

Table 1. Simulated scenarios

Traffic calming measure	% Heavy goods vehicles	Spacing (m)	Initial traffic flow (veh/h)	Last traffic flow (veh/h)	Traffic flow step (veh/h)	Simulations
No TCMs	0	-	100	2100	200	11
Speed table (*ERS*<5%)	0-20 (Step 5)	25	100	2100	200	55
		50	100	2100	200	55
		100	100	2100	200	55
		200	100	2100	200	55
		400	100	2100	200	55
Speed table (*ERS*>5%)	0	25	100	2100	200	11
		50	100	2100	200	11
		100	100	2100	200	11
		200	100	2100	200	11
		400	100	2100	200	11
Speed hump	0	25	100	2100	200	11
		50	100	2100	200	11
		100	100	2100	200	11
		200	100	2100	200	11
		400	100	2100	200	11
					TOTAL	396

After the scenarios were created, simulations were carried out. Each simulation lasted 75 minutes. A warm up period of 10 minutes was used to fill the cross-town road with traffic and stabilize the traffic flow. The latest 5 minutes were also discarded. The corresponding data were deleted from the output file.

Many demand scenarios were considered in this analysis. As the aim of the research was to determine the capacity of different TCMs spacing and type, traffic flow was progressively increased. At each simulation, vehicles' average delay on the segment was obtained. A total of 396 simulations were carried out.

5. Model results

The results of the simulation experiments are analyzed and discussed in two parts: capacity impacts and operational performance.

5.1. Capacity impacts

Capacity of a road segment was defined as the maximum hourly rate for cross-town road measured in vehicles per hour. Capacity of each scenario was deduced based on average delay. Average delay was represented depending on traffic flow. Then, capacity was determined as the traffic flow from which average delay increased exponentially instead of being calculated using a predetermined threshold. Consequently, no delay threshold was used. The main results are discussed depending on the TCM: speed tables; and speed humps. Moreover, operational conditions at capacity were deduced. A discussion about the effect of *HGV* is also included.

5.1.1. Speed tables

The analysis of capacity impact has been conducted depending on entrance ramp slope (*ERS*) of the speed table.

The entrance ramp slope was found as the key factor on speed selection: the higher entrance ramp slope, the lower speed over the speed table (Garcia et al., 2010). However, no statistical correlations were found between speed tables' height and the speed over the speed table or the speed reduction. Therefore, the analysis of speed tables was separated depending on the *ERS*: lower than 5% and higher than 5%. In this first analysis, no heavy vehicles were taking into account.

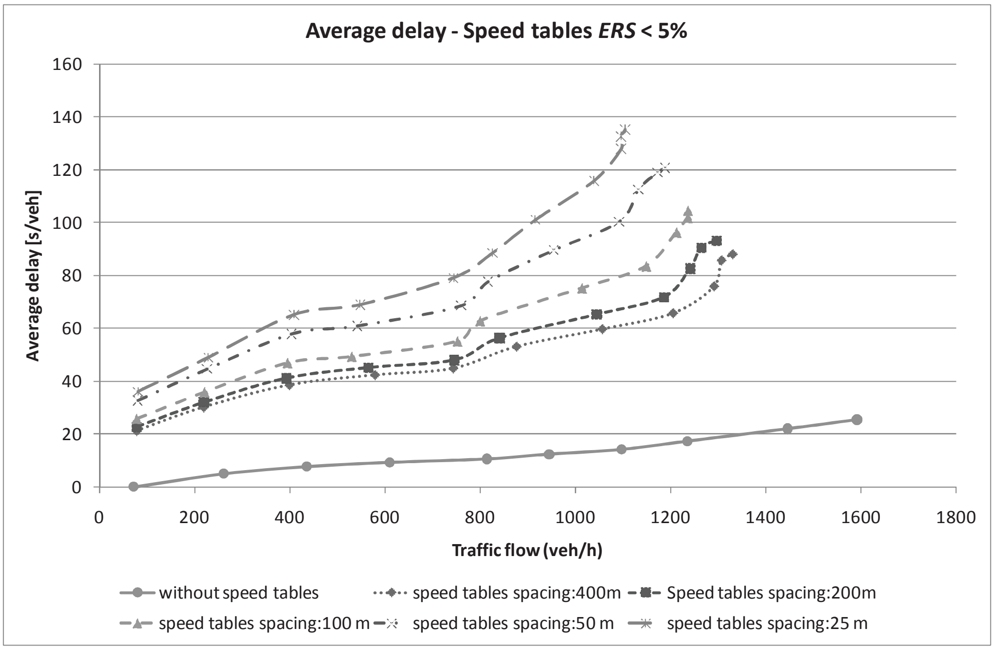

Figure 2. Average delay for speed tables with entrance ramp slope lower than 5%.

As Figure 2 and Figure 3 show, average delay with speed tables depended on both spacing and traffic flow. Consequently, capacity depended on TCMs spacing. Average delays at capacity varied from 75 to 105 seconds, on speed tables with *ERS* lower than 5% while the values ranged from 95 to 142 seconds on the second type. The average delay increased from 50% to 100% depending on the type of ramp. *ERS* was confirmed to be a key factor on average delay; and, therefore, on capacity.

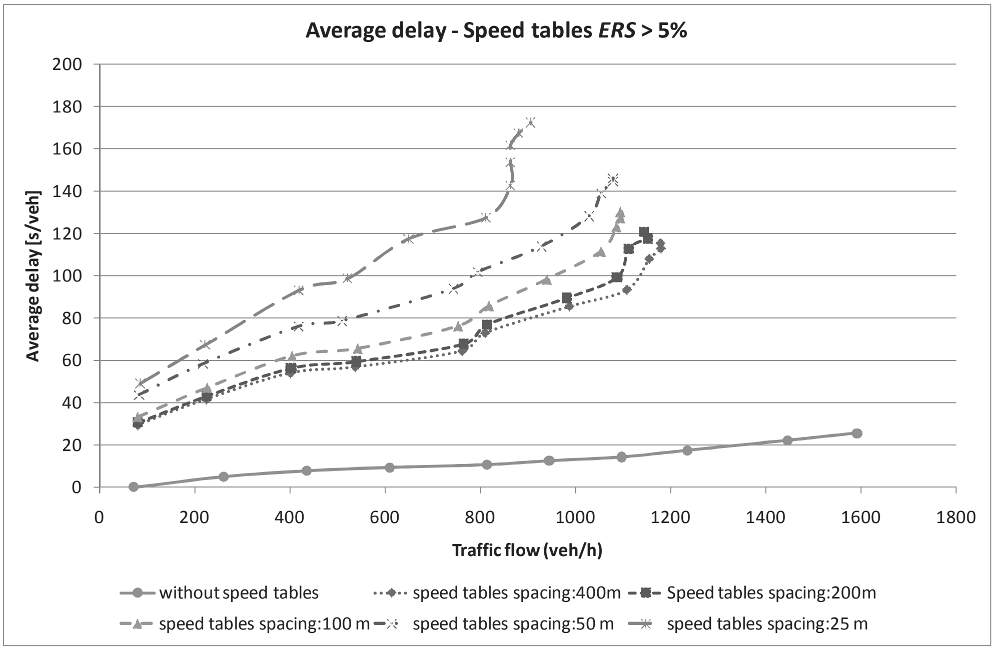

Figure 3. Average delay for speed tables with entrance ramp slope higher than 5%.

The figures show that, without TCMs, traffic operation was similar to a basic cross-town, as no speed reductions were taking place due to TCMs. Basically, the demand was fully satisfied until the highest traffic flow introduced on the model. As TCMs were introduced on the model, the capacity of the cross-town decreased, as shown in Table 2, and the difference was higher on speed tables with higher *ERS.* Higher capacity values could be proposed. However, conservative values were preferred. Both proposed and maximum capacity values were established.

On speed tables with lower *ERS*, the implementation of devices separated 400 m on the cross-town road implied a reduction of 25% on capacity. Furthermore, capacity decreased from theoretical 35% with devices separated 25 m, while spacing of 100 m reduced capacity in 28%. The capacity decreased to 1040 veh/h when speed tables spacing was minimum (25 m). Speed tables with higher *ERS* presented even greater differences. 400 m spacing implied a decrease of 31% on capacity. The lowest capacity presented a 50% reduction on capacity. The second observation was that, there was two critical spacing beyond which an operational breakdown occurred. The first critical spacing was common to all speed tables, and it was located at 400 m. The second critical spacing depended on the entrance ramp slope: 100 m; and 50 m, for entrance ramp slope lower than 5% and higher than 5%, respectively.

Operational conditions at the former capacity values were analyzed by determining their related levels of service (LOS). The Highway Capacity Manual (2000) methodology for urban streets was used. According to both functional and design category, cross-town roads were classified as class II urban street. Average travel speed at capacity was calculated for each capacity value. Then, level of service was deduced (Table 2). LOS at capacity varied between D and F. So, the proposed values represented operating conditions near congestion. Consequently, the definition of capacity as the traffic flow input from which delay increased exponentially was accurate. It can be observed that the closer the spacing, the worse operating conditions. Moreover, unstable flow was achieved with spacing lower than 100 m. On the other hand, speed tables with higher *ERS* presented all LOS lower than E.

Table 2. Capacity of cross-town roads with speed tables

ERS (%)	Spacing (m)	Proposed				Maximum			
		Capacity (veh/h)	%/ No TCMs	Average Travel Speed (km/h)	Level of Service	Capacity (veh/h)	%/ No TCMs	Average Travel Speed (km/h)	Level of Service
-	No TCMs	1700	100	50	B	1700	100	50	B
< 5%	400	1200	71	30	D	1290	76	28	D
	200	1180	69	29	D	1240	73	27	D
	100	1150	68	27	D	1210	71	25	E
	50	1090	64	25	E	1130	66	24	E
	25	1040	61	23	E	1090	64	21	F
> 5%	400	1100	65	26	E	1155	68	24	E
	200	1085	64	25	E	1100	65	23	E
	100	1080	64	22	E	1100	65	22	E
	50	1050	62	21	F	1080	64	20	F
	25	810	48	22	F	860	51	20	F

5.1.2. Speed humps

As speed tables, the average delay was obtained without traffic of heavy vehicles. Figure 4 shows the average delay for speed humps depending on: spacing; and traffic flow. The results were compared with those related to the traffic flow without speed humps.

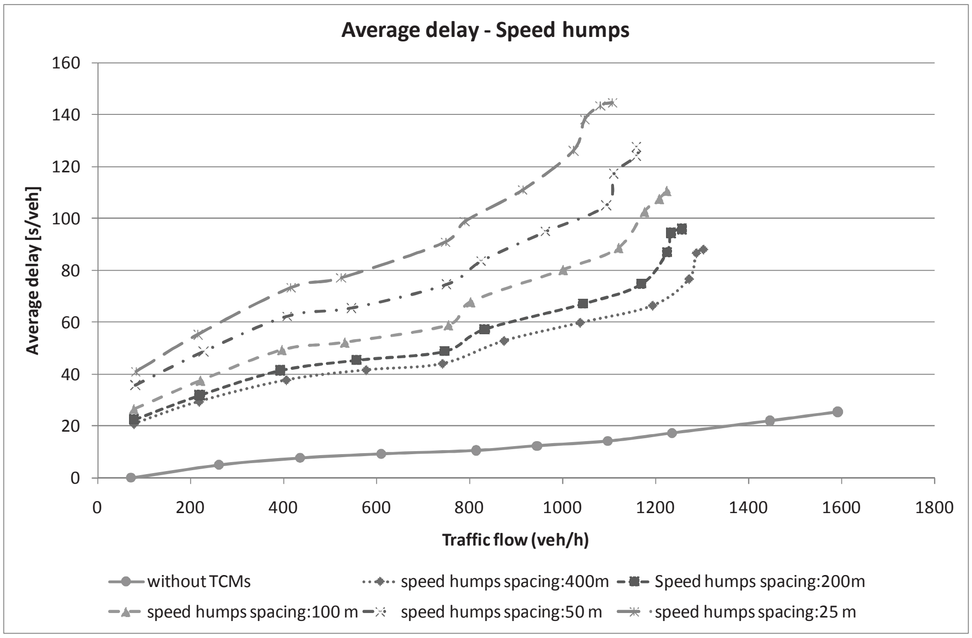

Figure 4. Average delay for speed humps.

When device spacing was greater than 200 m, the average delay for speed tables and speed humps were very similar. As spacing was reduced, speed humps caused slightly higher speed reduction than speed tables, and, consequently, lower capacity. Capacity of a cross-town road with speed humps is summarized on Table 3. It can be observed that the capacity differed from the theoretical a 36% with the shortest spacing and a 26% with the longest spacing. The sensitivity of capacity on spacing was lower than with speed tables. As the sensitivity was lower, only a critical spacing was detected: 400 m. Therefore, the implementation of only two traffic calming devices affected capacity with a reduction of 26 %. Shorter spacing did not raise delays on traffic flow near capacity substantially. Operational performance at capacity was also deduced. D and E levels of service were found. Therefore, capacity definition was supported too. As occurred on speed tables, spacing had an effect on LOS. Even the longest spacing reduced the level of service from B to D at capacity. Therefore, as stated before, implementation of TCMs implied an operational breakdown from the first device.

Table 3. Capacity of cross-town roads with speed humps

Spacing (m)	Proposed				Maximum			
	Capacity (veh/h)	%/ No TCMs	Average Travel Speed (km/h)	Level of Service	Capacity (veh/h)	%/ No TCMs	Average Travel Speed (km/h)	Level of Service
No TCMs	1700	100	50	B	1700	100	50	B
400	1190	70	30	D	1270	75	28	D
200	1170	69	28	D	1220	72	26	E
100	1110	65	26	E	1160	68	24	E
50	1050	62	24	E	1080	64	23	E
25	1025	60	22	E	1050	62	21	F

5.1.3. Effect of heavy goods vehicles

The previous analysis was carried out only with passenger cars. However, the percentage of heavy goods vehicles ranged from 0 to 15% in most cross-town roads; which usually occurs in peak-hours. Speed distributions in the model were defined for all vehicles. The specific data for heavy vehicles (including trucks and buses in this category) to be implemented in the model were: length; width; weight; power; acceleration (desired and maximum); and deceleration (desired and maximum). Average characteristics of heavy goods vehicles in Spain were used in the model.

Table 4. Capacity reductions with heavy goods vehicles

Spacing (m)	Percentage of *HGV*	
	10 %	20 %
No TCMs	100	100
400	98	95
200	98	95
100	97	95
50	97	92
25	96	90

The traffic calming device selected to study the effect of *HGV* was speed table with entrance ramp slope lower than 5%. Five percentages of *HGV* were used: 0; 5; 10; 15; and 20%. Average delays were obtained and capacity was deduced. In order to clarify the findings, capacity reductions were compared to capacity obtained with only passenger cars on Table 4.

The capacity reductions depended on spacing: the shorter spacing, the higher capacity reduction. The values varied from 98 to 90%. A wider dispersion on the results was found with 20% of heavy vehicles.

5.2. Operational performance

Operational performance was also studied based on average delay per car. It can be deduced spacing was a key parameter on average delay. Taking a constant traffic flow, three tendencies were observed: without TCMs; 400, 200 and 100 m spacing; and 50 and 25 m spacing. The differences between and within these groups were increasing as traffic flow rose. Consequently, two critical spacing were defined: 400 m; and 50 m. Operational performance with spacing from 100 to 400 m was similar; so, the first traffic calming device had a similar impact on traffic operation that 100 m spaced TCMs. The first device deteriorated traffic operation on one spot that affected to the whole cross-town road, while 100 m spaced TCMs moderated speed on the segment without a substantially high average delay increase. Spacing lower than 100 m resulted on cumulative effect of TCMs. So, two TCMs worked as only one measure and did not allow drivers to develop their desirable speed between them.

On the other hand, four performance trends were clearly defined on the relationship between average delay and traffic flow. The four zones defined different types of traffic behavior and their definition depended on the type of TCM. At lower demand levels, from 0 to 400 veh/h, delay increased rapidly as traffic flow raised. This fact was explained as interactions between vehicles were starting and disturbance was generated. The second behavior was operating at below-capacity conditions. The average performance lines were almost constants and delay presented little sensitivity to traffic flow. Interactions between vehicles were reduced as performance was in the free-flow zone of the speed-flow curve. The threshold of this second zone depended on the type of TCM. For both speed humps and speed tables with entrance ramp slope lower than 5%, the second zone extended until traffic flow between 750 and 800 veh/h. The value was not dependant on spacing. However, spacing influenced on the threshold on the other speed tables. Spacing of 25 m were on the second zone until traffic flow was 600 veh/h, while other spacing admitted traffic flow until 700-800 veh/h. The third zone was defined until capacity. Traffic operation moves from free-flow zone to forced-flow zone of the speed-flow curve. The last traffic behavior was developed once capacity was exceeded. Average delay increased exponentially as traffic operation moves towards the lower part of the speed-flow curve.

As stated before, the free flow zone definition depended on the type of TCM. This zone is usually the working scenario of traffic performance; which is associated to level of service C or D. The maximum hourly traffic flow to operate in free-flow conditions on cross-town roads with traffic calming devices was assumed as 750 veh/h. Levels of service related to the former traffic flow were calculated depending on TCM and spacing. For both speed tables with *ERS* lower than 5% and speed humps, LOS C was obtained with 100, 200 and 400 m spacing; while LOS was reduced to D with 25 and 50 m spacing. Speed tables with *ERS* higher than 5% presented LOS D for all spacing. Therefore, traffic flow equal to 750 veh/h was associated to level of service C or D. According to typical Spanish daily distribution of traffic along cross-town roads, the maximum peak hour traffic volume represents between 12 and 17% of total daily traffic. Consequently, daily traffic flow per direction and lane to never operate close to capacity condition varies from 4500 to 6000 veh/day. Considering both traffic directions of cross-town roads, the recommended maximum daily traffic flow to implement TCMs is between 9000 and 12000 veh/day. The value is much higher than the 5000 veh/day recommended on Spanish Standards (Ministerio de Fomento, 1999). However, the proposed threshold accords to other Standards (CERTU, 2010, FHWA, 2009).

6. Conclusions

Traffic calming is a road safety countermeasure which aim is the reduction of the accidents and their severity by lowering speed and, in some cases, traffic flow. However, the implementation of traffic calming devices implies less capacity of cross-town roads and has operational effects; which have not been studied on the literature.

The present research used traffic microsimulation to study the effect of traffic calming devices on cross-town roads capacity and operation performance based on different type and spacing of devices. In order to obtain realistic data, a field study was carried out. Continuous speed profiles were obtained from more than 900 actual drivers on five cross-town roads with traffic calming measures (TCMs). Drivers' behavior was calibrated and validated on a microsimulation model using VISSIM 5.1. Then, the model was applied to different scenarios that could not be developed on the real-world. The case study included both speed tables and speed humps.

The influence of TCMs spacing on the capacity along a cross-town road was evaluated. The average delay was calculated for different traffic calming devices spacing and traffic flow rate. Then, the capacity of the road was obtained for a traffic calming device spacing as the flow rate from which the delay presented exponential growth. Levels of service (LOS) at capacity varied between D and F. The capacity of a cross-town road varied between 810 and 1300 vehicles per hour per lane with traffic calming devices spacing from 25 to 400 meters. Furthermore, in case of 100 meters spacing the obtained capacity was around 1150 vehicles per hour per lane; which means a reduction of 32% of the theoretical capacity of 1600 veh/h. Two critical spacing were found: 400 m and 50 m. TCMs effect on capacity were similar with 100 to 400 m spacing. Consequently, the first TCM implemented on a cross-town road had the highest influence on the segment. On the other hand, spacing lower than 50 m caused cumulative effect since drivers could not develop their desirable speeds. Therefore, the capacity was highly reduced.

The influence of speed tables and speed humps on capacity was also compared. The study concluded that capacity was not influenced by these types of traffic calming device if the entrance ramp slope of the speed table was lower than 5%. Speed tables with higher entrance ramp slope could reduce 50% capacity if they are located every 25 m. On the other hand, influence of heavy goods vehicle on capacity was studied. It was found that heavy goods vehicles can reduce from 2 to 10% capacity of a cross-town road depending on TCMs spacing and percentage of heavy vehicles.

As for operational performance at cross-town roads with TCMs, four different types of behavior were detected. One of the important conclusions of the analysis was that, at moderate traffic levels, there was a critical level of traffic flow from which average delay started to increase more rapidly. This level depended on both type of TCM and spacing, but it was near 750-800 veh/h; which represented level of service C, with spacing higher than 100 m, and LOS D with spacing lower than 100 m. According to the Spanish typical distribution of traffic across the day, maximum hourly traffic flow estimates were extrapolated to daily traffic flow. Therefore, TCMs are recommended on cross-town and urban roads with annual average daily traffic (AADT) between 9000 and 12000 veh/day; so, traffic operation performance will never be close to capacity conditions.

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