FIELD INVESTIGATION ON THE EFFECTS ON OPERATING SPEED CAUSED BY TRAPEZOIDAL HUMPS

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ABSTRACT

The most effective way to reduce vehicle speed on urban low volume roads, such as residential streets, is the installation of traffic calming systems such as speed humps and tables. In those roads in which these measures are applied, a reduction in traffic volume and accidents is generally observed, with clear benefits for pedestrians, bicyclists and residents.

A study was undertaken in order to investigate the effectiveness of trapezoidal speed humps in reducing the operating speed and to highlight the main factors influencing this type of traffic calming system. An urban residential street 1.8 km (1.12 miles) long, characterized by the presence of 12 humps, was monitored during two months (between October and December 2006) and several speed profiles were collected with different measuring systems.

All data were processed in order to present a statistical discrete operating speed profile, making it possible to derive a model which links hump spacing, lane width and operating speed. Such a model can be a valuable tool for road engineers in predicting, for design purposes, the effectiveness of trapezoidal speed humps in similar situations.

INTRODUCTION

In the general framework of urban road management and design, recent studies have proven that Traffic Calming Systems (TCS) constitute an asset which can be of great value in ensuring an adequate reduction of operating speeds for the purposes of safety and noise control (*1*).

TCS's are normally classified into three categories depending on the type of effects that they induce in the vehicle-driver system: vertical, horizontal and narrowing measures. Vertical measures include humps, tables, raised crosswalks and raised intersections with several geometric shapes in terms of length, width and height. Mini traffic circles, roundabouts and chicanes are considered horizontal measures, while narrowings include those measures placed in the carriageway center (median chokers or center islands), those placed near margins (two-lane chookers, one-lane angled slow points, neckdowns) and all the two-way carriageway conversions into one-way (half-closures). Narrowing measures are similar to horizontal ones but they mainly use a psycho-perceptive sense of enclosure.

The effectiveness of TCS's relies in the fact that they modify road geometry and as a consequence operate directly on the control and guidance activities of the driver, introducing physical and/or psychological effects. In particular, TCS's work mainly on the physical discomfort of drivers and only few secondary effects act on their psychological sphere: for these reasons in literature they are indicated as "self-enforcing measures".

The use of such systems is especially efficient in low-volume residential streets where several traffic components, characterized by different speed performance and occupancy, coexist. In these areas several experimental observations have shown that posted speed limits are constantly exceeded (*2*) (*3*) and that TCS's become necessary in order to protect pedestrians and other vulnerable road users (*4*).

As a secondary effect, it has been noted that TCS's cause a variation of the navigation choices of drivers and, depending upon the specific context, can induce a significant reduction of traffic volume. However, it may happen that volume reduction can lead to a higher frequency of isolated movements of vehicles, which are less conditioned and therefore are more inclined to drive at higher speeds.

The above given statements are supported by the comprehensive work carried out by Ewing (*5*) (*6*) (*7*), who synthesized the experimental results of several before-and-after studies in terms of operating speed, volume change and collision frequencies for the above mentioned three types of TCS's. Although the available database was non-uniform and posed a number of problems for analysis, Ewing observed that punctual solutions, like speed humps, have the greatest impact on operating speed, which is reduced by more than 20%. Moreover, when considering the effects on traffic volume, Ewing noted that changes are heavily dependent on boundary conditions in terms of availability of alternatives and that in those cases in which TCS's had been replaced altering the spacing between them, significant traffic volume variations occurred.

It is important to stress the fact that TCS's can be applied individually (e.g., speed humps on individual streets) or in combination with other road design measures (e.g. geometry and location of accesses, parking organization on margins, configuration and characteristics of built and natural environment, street lighting, other streetscape elements). In such cases, TCS's can strengthen road readability, thus providing the infrastructure and the surrounding environment with information which is perceived by drivers that tend to conveniently adjust their behavior. In this complex and multi-disciplinary area of road design, the pioneering reference work documented in literature is due to Smith & Appleyard (*8*) (*9*), who investigated on the effects caused by various boundary conditions on the mean speeds measured on residential streets.

As a result of the complexity of the effects caused by TCS's, it is essential to provide road engineers with design tools which can be used in urban road management. In such a context, the Authors carried out several investigations by focusing on the field performance of trapezoidal speed humps (TSH) which are widely used for speed control purposes. In particular, in this paper they show the results of an experimental campaign which considered an urban street 1.8 km long (1.12 miles) where twelve speeds humps have been installed. The goal of the investigation was to produce a simple analytical model for the design of the location of TSH's as a function of desired vehicle speed. In such a context, the specific site was considered ideal due to the number of TSH's and to their differential spacing.

BACKGROUND

Trapezoidal speeds humps (TSH), also called "speed tables" or "speed platforms", are flat-topped speed humps. In case they are marked for pedestrian crossing, they are also called "raised crosswalks" or "raised crossings". TSH's do not have a predefined length, but typically are long enough to contain on their top the wheelbase of a passenger car. The flat part of a TSH is normally connected to the pavement surface with linear ramps that are more gently sloped than in the case of ordinary speed humps (SH), and therefore lead to operating speeds which are generally higher than those measured for SH's. Horizontal markings or textured materials can be used in their signalization, thus improving their visibility and leading to the enhancement of speed reduction effects.

In technical literature it is suggested that the spacing between humps should be properly defined. Although first applications considered a length greater than 150 m (492 feet) (*5*), the Bellevue (WA) experience (*10*) suggested the adoption of shorter spacing: thus, too short (about 30 m – 98.4 feet) or too long (300 m – 984 feet) spacing were continuously modified in order to reach target speeds associated to greater safety levels. The lesson learned from this case study suggested that spacing should be included in the range of 100-150 m (328 – 492 feet). Similar Danish experiences lead to the publication of standards in which hump spacing was defined as a function of the maximum allowable speed (Table 1) (*11*).

TABLE 1 Relationship between reference speed and spacing between successive speed humps according to Danish standards

Reference speed	**Hump spacing**
(km/h)	(m)
10-20	25 (max 50)
30	75
40	100
50	150

Based on the experimental data collected in field studies in Denmark, Australia and the U.K., Ewing (*5*) derived the 85th percentile speed at the midpoint between two humps ($V_{85,mp}$) as a function of spacing (S). The corresponding equation reported in the *Delaware Traffic Calming Design Manual* (*12*), is the following:

$$V_{85,mp} = V_{85,sp} + a\cdot(V_{85,b} - V_{85,sp})\cdot(1 - e^{-b\cdot S})$$

where $V_{85,sp}$ is the 85th percentile of hump crossing speed, $V_{85,b}$ is the 85th percentile of speed measured in the considered road section before introduction of humps, a and b are two experimental coefficients respectively equal to 0.56 e 0.004. Speed values are expressed in mph.

EXPERIMENTAL PROGRAM

Site characteristics

The infrastructure considered in the experimental program is a local urban street located in a residential area of the city of Turin (Italy) along the left bank of the Po River (Figure 1). The road, called "Lungo Po Antonelli", has an extension of approximately 2 km and is characterized by the presence of 12 trapezoidal speed humps (TSH) with an average spacing of 147 m (482.28 ft) (minimum 75 m – 246.06 ft, maximum 190 m – 623.36 ft). Along the considered section, the two lanes have a width comprised between 3 (9.84 ft) and 3.5 m (11.48 ft). Figure 1 shows the location of the 12 humps together with the reference starting section. Along the entire road (Figure 2), the speed limit is set at 30 km/h (18.6 miles/h). As prescribed by

Italian specifications (*13*), TSH's have a height of 7 cm (2.75 inches) and a flat top of 120 cm (47.24 inches), while the two ramps are 40 cm (15.75 inches) long. No quantitative data on ADT was available; pedestrian activity was reported to be extremely low. The street is close to the Po River, in which a linear park can be found. Moreover, a bikeway is also present near the carriageway.

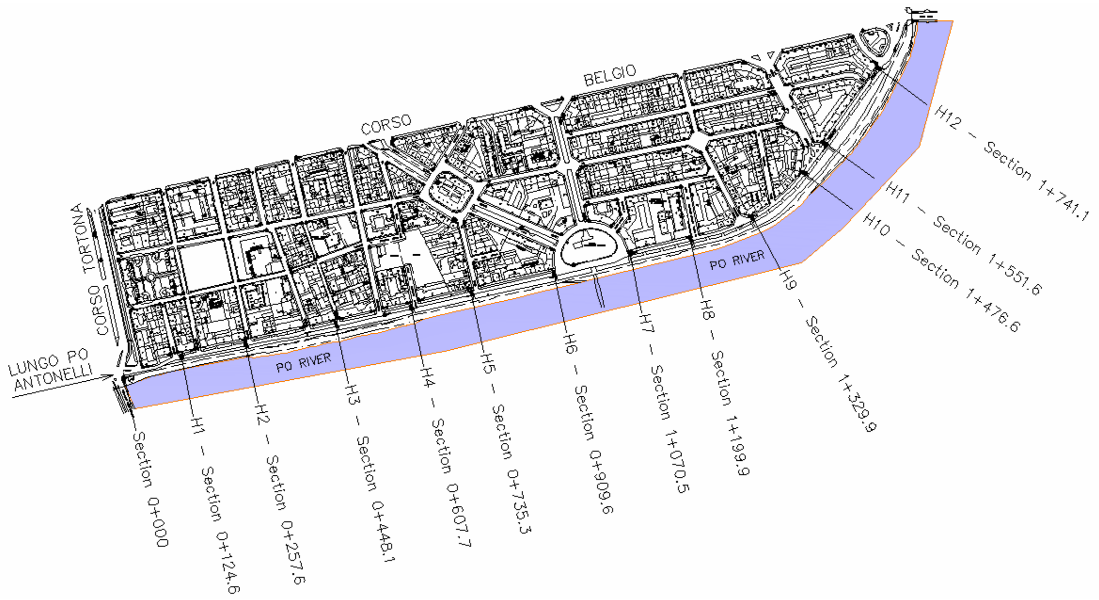


FIGURE 1 Plan view of the site and TSH locations

On-road measurements

The field investigation carried out along the considered road included the collection of speed and position data of the vehicles in transit by means of longitudinal and transversal measurements. Longitudinal data (speed and position) were collected by making use of a laser speed gun connected to an acquisition system (Figure 3-a). The system was located in positions not be visible to drivers and considered only isolated vehicles, thus neglecting information which could be affected by external conditioning effects or effects associated to the dynamics of traffic flow. In the case of transversal (position) measurements, a high-speed digital videocamera (Figure 3-b) located at the speed humps was employed and from the consequent analysis of successive frames actual speed was also estimated. Data acquisition was carried out throughout weeks but not during peak hours.

Each set of data was referred to the progressive distance along the road. As an example, the entire set of speed data (1690 recorded values) derived from the two systems is shown in Figure 4.

On-vehicle measurements

Further field investigations were carried out by employing an instrumented vehicle (Figure 3-c) with the purpose of validating speed measurements obtained from the laser gun and the digital videocamera. The vehicle is equipped with a system called "Romeo", developed by the Research Group of the Politecnico di Torino. It is constituted by an assembly of a monoaxial accelerometer, which reads accelerations along a predefined direction, a potentiometric encoder, for the measurement of linear displacements and an incremental rotative encoder, which allows the measurement of longitudinal speed. Data acquisition is carried out in real-time with a system mounted on board.

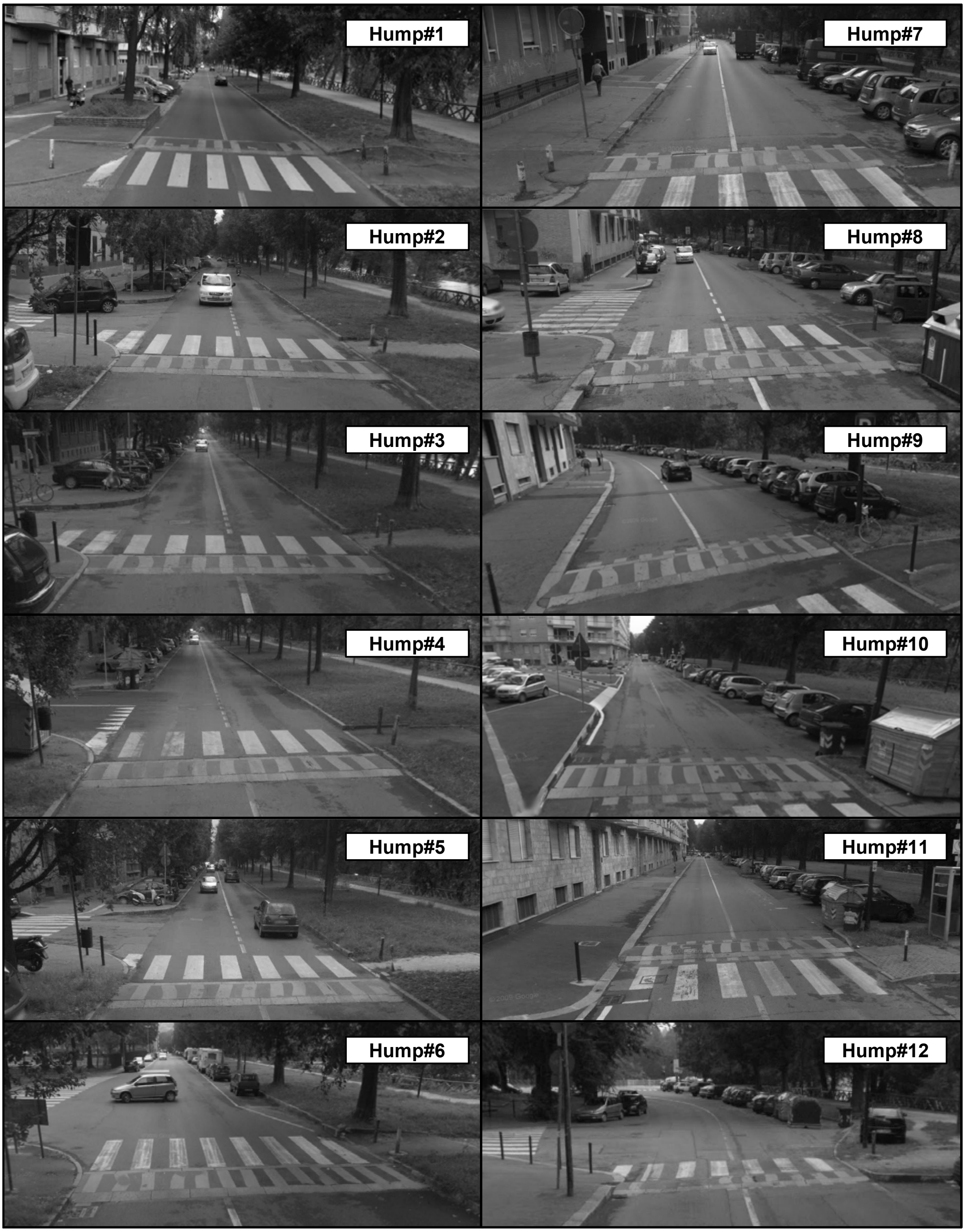


FIGURE 2 Perspective views of the 12 trapezoidal speed humps considered in the investigation

Data treatment

Speed data were divided in sub-sections: across the TSH's, in the sub-sections leading to and away from the TSH's (at 30 m – 98.4 ft – on each side), and in the central part (around the center between two consecutive humps). For each sub-section speed data were analyzed to derive the average value and the 85th percentile value, which corresponds to operative speed.

The data collected over the humps, referred to conditions in which speed is strongly affected by external conditioning, were calculated by analyzing the digital images and were thereafter subjected to appropriate treatment (chi-squared tests) in order to verify the existence of a normal distribution. Since the analysis yielded a positive response in all cases, the corresponding data were taken into account in the following phases of data evaluation.

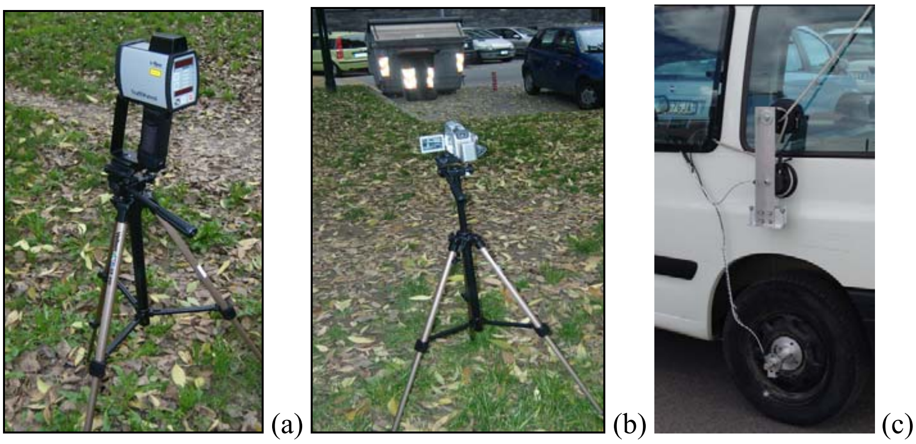

(a) (b) (c)

FIGURE 3 Laser gun (a), digital videocamera (b) and Romeo system (c) employed in the investigation

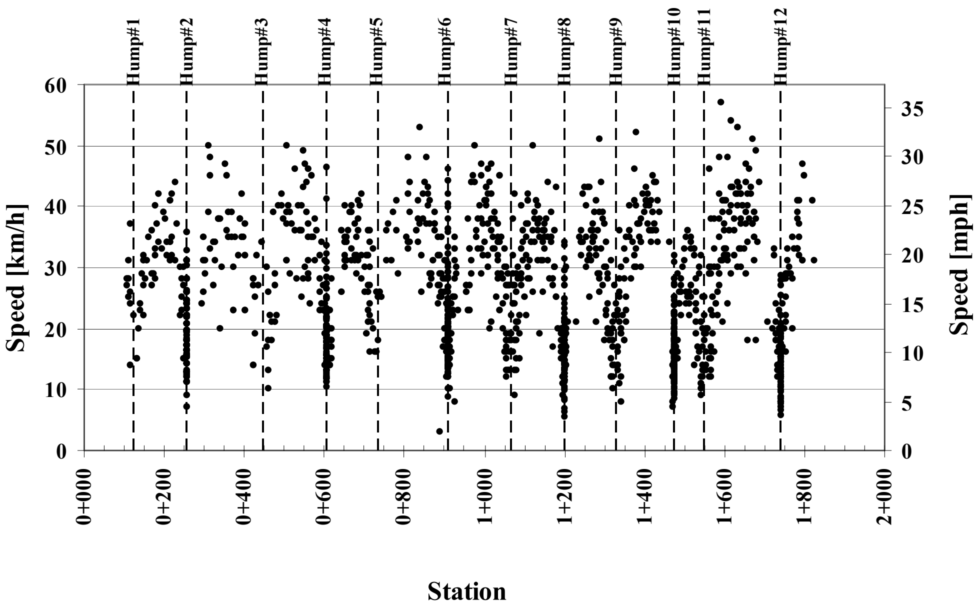
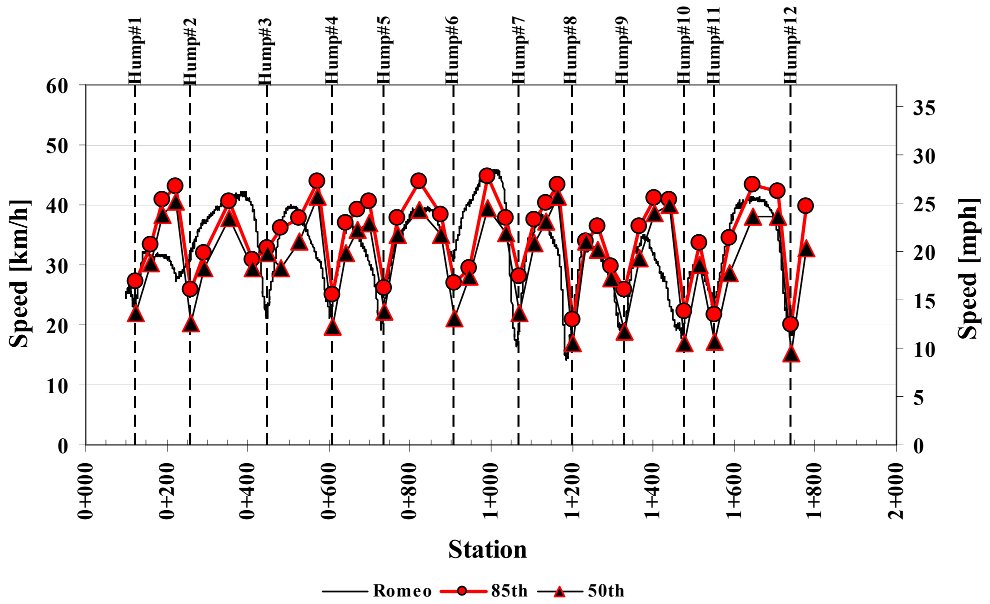
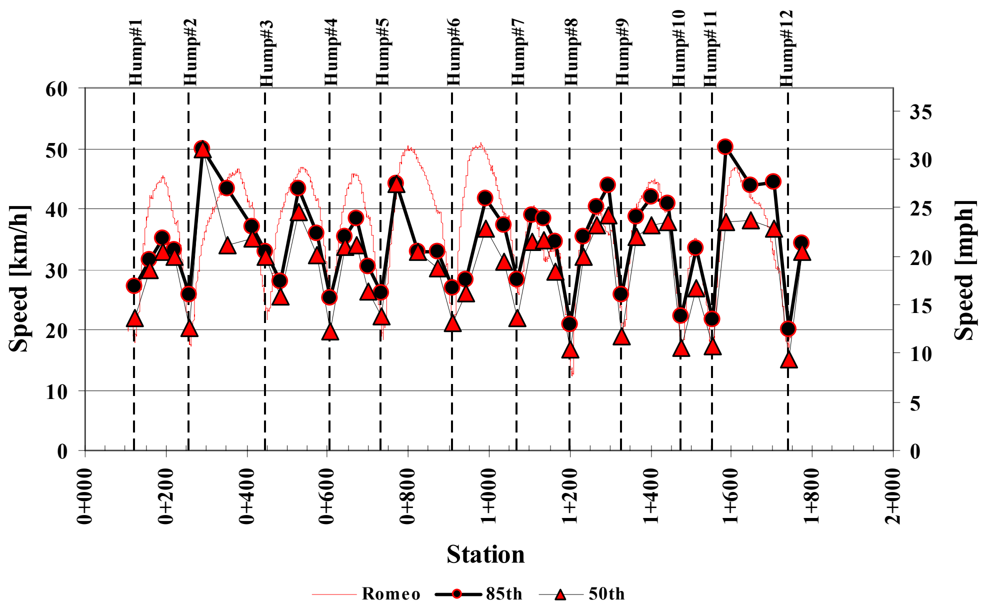


FIGURE 4 Recorded speed data

Average and 85th percentile values are shown in Figure 5 together with those retrieved from the Romeo system. A good agreement between the various types of measurement can be observed. However, in one direction (from "Corso Belgio" to "Corso Tortona" – Figure 5-b), some differences are noticeable. It was observed that this occurs where the number of available data decreases substantially and therefore, for a matter of reliability, corresponding average and 85th percentile values were neglected in the following analyses (see Figure 5-b). Accelerations (and decelerations) were determined from the average curves and from the 85th percentile ones.



(a)



(b)

FIGURE 5 Average and operating speeds compared with Romeo speed records. (a) Corso Tortona – Corso Belgio. (b) Corso Belgio – Corso Tortona.

RESULTS AND DISCUSSION

In order to define a model to fit the experimental data, various options were considered, including linear and exponential models. However, since the differences between these two models were only minor, the linear model was chosen due to its simplicity. The experimental speed data, expressed in terms of the 85th percentile of the speed measured at the midpoint between two consecutive humps ($V_{85,mp}$), was thus related to hump spacing (S) by means of the following equation:

$$V_{85,\mathrm{mp}} = a + \mathrm{b} \cdot S$$

where a = 27.7 km/h (17.2 miles/h) and b = 0.090. The corresponding plot of the experimental data and of the regression equation is shown in Figure 6.

The soundness of the model is proven by the good agreement which is obtained when comparing the intercept value of the equation (speed equal to 27.7 km/h for an ideal spacing of 0 m) with the average value of speed measured across the humps (equal to 25.2 km/h – 15.6 miles/h). The dispersion of the data however, proves that other factors clearly affect, at least for the considered case, the relationship between speed and spacing. No differences were observed when analyzing separately the data recorded in the two directions of travel, thus indicating that the different organization of margins (presence of linear parking or of sidewalks) is not a relevant factor.

It was observed that the 5 data points clearly out of trend in Figure 6 were collected in sections with a different lane width (W_L). This variable was therefore considered significant and explicitly introduced in the improved version of the model which can be written as follows:

$$V_{85,\mathrm{mp}} = a' \cdot W_L + \mathrm{b}' \cdot S$$

where a' = 8.685 and b' = 0.082, with W_L and S in meters. It was thus found that by explicitly taking into consideration the effects of lane width the model is characterized by a higher reliability, with a high correlation coefficient with the measured data. Table 2 reports the summary output of the multiple linear analysis. It can be observed that the p-value of the independent variables of the model are less than 0.05, which indicates that the control variables affect significantly the operating speed in the middle point between two successive humps. Figure 7 shows the design graph in which the relationship between spacing, lane width and operating speed is summarized.

In the case of acceleration and deceleration values, no specific trend was observed and in some cases 85th percentile speed values were found to be greater in the sub-sections leading to and away from the humps when compared to central sub-sections. In such cases acceleration and deceleration values were significantly different from those of other TSH's and were therefore treated separately in the analyses.

TABLE 2 Summary output of multiple linear regression analysis

Statistical parameter	Values
R	0,998
R^2	0,996
Adjusted R^2	0,945
Standard Error	2,78
Observations	22
p-value of variable S	0,0002
p-value of variable W_L	$1{,}46 \cdot 10^{-9}$

The final result of data treatment yielded acceleration and deceleration values which for the type of TSH considered in the study were characterized by the same mean absolute values (± 0.8 m/s^2 – 2.62 feet/sec^2) and standard deviation (± 0.4 m/s^2 – 1.31 feet/sec^2).

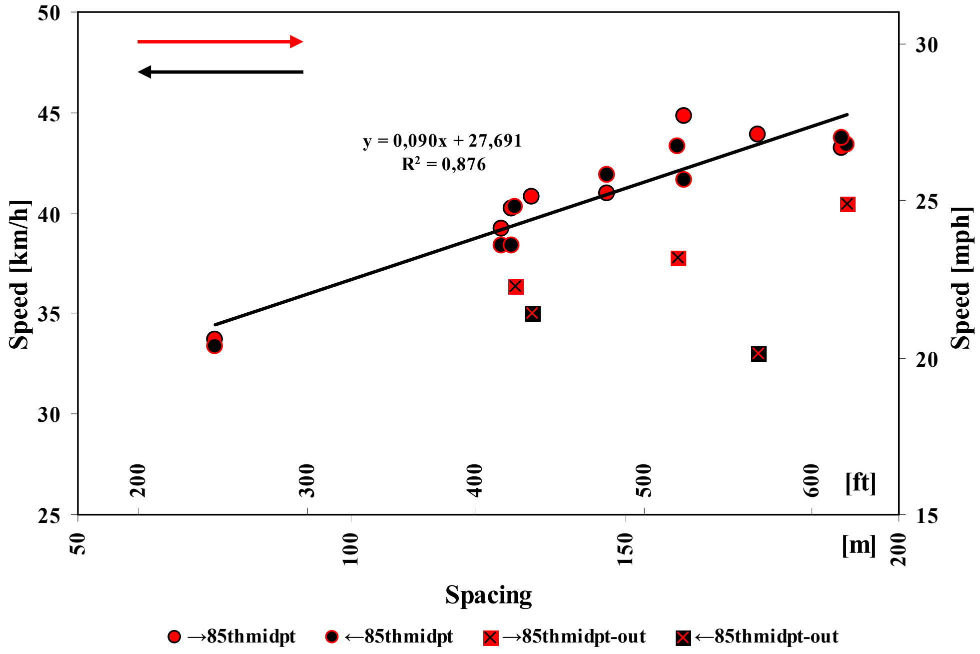


FIGURE 6 Relationship between operative speed and spacing between humps

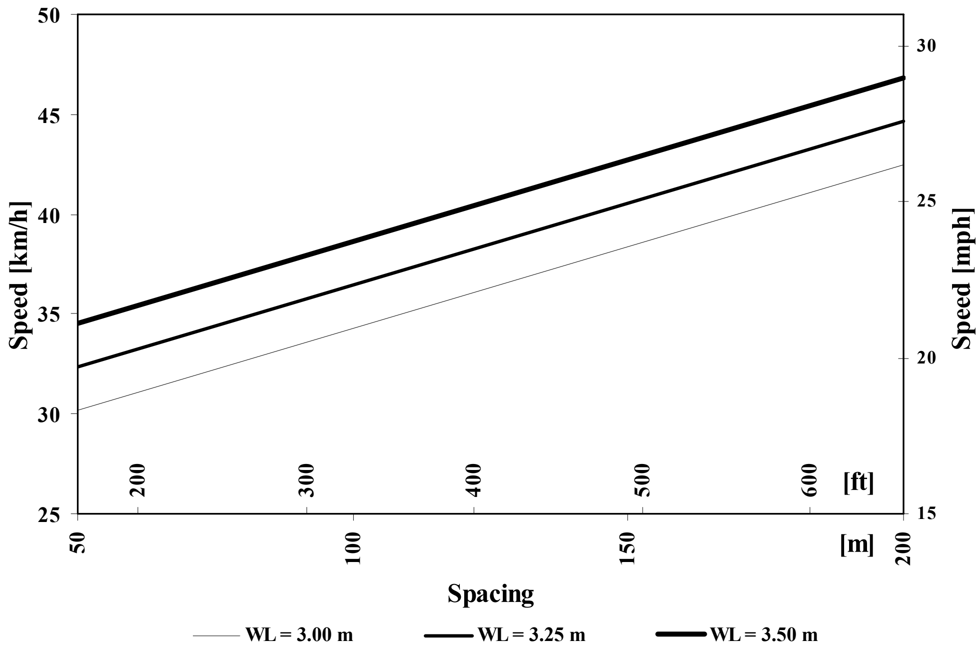


FIGURE 7 Relationship between spacing, lane width (LW) and operating speed

CONCLUSIONS

The investigation described in this paper focused on the assessment of vehicle speeds along a residential urban street (1.8 km long) where a series of trapezoidal speed humps (TSH) were installed as a traffic calming system (TCS). Field measurements were carried out by employing an array of instruments including a laser speed gun, a digital videocamera and an instrumented vehicle.

Results proved to be coherent with available literature since it was observed that TSH cause a significant reduction of speed for extended stretches of the infrastructure. This clearly has a benefit in terms of road safety and security (perceived level of safety) in a very sensitive area where there is a non-negligible presence of vulnerable road users (i.e. pedestrians and bicyclists).

The major focus of the investigation was the assessment of the effects of TSH spacing on operative speed. Speed profiles were derived by considering isolated vehicles since operative speeds by definition can be assessed only in the case of unconditioned travelling situations. The 85^{th} percentile of a sample of unconditioned speeds is a good estimate of operating speed in a specific location.

As a result of the analysis of speed profiles, an original relationship that links operating speed to hump spacing and lane width was proposed. It is interesting to note that the model indicates that the effectiveness of vertical measures such as TSH's is influenced by lane width, thus suggesting non-negligible physical and psychological effects on drivers. However, the lane width of the investigated street is quite high when compared with similar streets or to Italian standards (3 m); thus, it cannot be excluded that when smaller lane widths will be considered, the effect of margin organization could be more important and therefore to be included in the model. For the specific site herein considered it was observed that intersections do not affect operating speed: this is due to the fact that they are located very close to the TSH's.

This result represents a tool for the validation of speed profiles that would be considered by designers when making choices for the installation of speed humps. Although the model is clearly referred to a single specific situation, it should be noted that the equation was derived by considering modern vehicles that are characterized by high performances in terms of speed and comfort. In fact, many of the circulating cars which belong to the new generation of vehicles have efficient suspensions and continuous damping control systems, while most of the data and models available in literature refer to outdated car models.

The extension of this investigation to other traffic control devices is one of the aims of the Authors in order to compensate for the lack of tools and equations useful in the rational design of Traffic Control Systems.

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