EVALUATION OF THE PERFORMANCE OF LIGHT SPEED ENFORCEMENT SYSTEMS

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ABSTRACT

Road accident rates in urban areas are still a serious problem, and speeding continues to the leading factor for this situation. To tackle this problem a number of mitigation measures have emerged over time aimed at reducing circulation speeds, among which are included the Red-light enforcement systems. The implementation of such systems has become common practice in Portugal, given the ease of installation and effectiveness demonstrated in reducing speed. Consequently, this type of systems has expanded rapidly across the country with applications covering both the urban and rural areas. They sometimes have some popular opposition, but have gained a great level of acceptance by road management authorities. Therefore, this paper focuses on evaluating the effectiveness of these speed control systems. The assessment is supported by a real database actual achieved by taking the speed distribution at three sites that had these type of systems, accompanied by the registration of video images. The analysis of data collected allowed, firstly, to assess the differential variation of the speeds associated with the system, the non compliance rates and, moreover, to perceive the behavior patterns of drivers due to the presence of the system.

Keywords: controlling speeds; traffic calming; driver behaviour.

INTRODUCTION

Traffic accidents resulting in deaths are one of the most worrying problems in the Portuguese society. Even if recent statistics show that the number of accidents and fatalities has been dropping since 1997, the problem still remains a priority. Actually, 71% of the accidents in Portugal, occur in urban areas (ANSR, 2009), and roadkilles account for 17% of the deaths. The news and the official entities present almost daily records of excessive speeding as one of the main causes of accidents.

In response to this issue, strategies aiming to tackle drivers' behavior have been defined. These strategies focus on several different measures that range from promoting awareness campaigns and increasing law enforcement to the implementation of physical restrictions in the road. Red-light enforcement systems to control excessive speed present themselves as one of the most used systems in Portugal, both in urban and semi-urban areas.

These systems have assumed a high level of technical acceptance being increasingly used as mean to solve occasional problems (accidents at intersections, pedestrian crossings, pedestrian sense of insecurity related to the practice of excessive speeds, etc..) since the they are associated with high levels of speed reduction. The systems have been applied in isolation, in systems that also regulate traffic or in pedestrian crossings, currently covering urban and rural areas.

Bearing this scenery in mind, this paper focuses initially in presenting the different approaches types of light enforcement equipments to control speed in order to provide a more detailed analysis of their application field, main characteristics, weakness and potentialities. In fact, light speed enforcement systems in Portugal are a most common tool, leading to quasi-immediate results. However, a few problems remain, regarding disobedience of the system and the reduction of levels of service when the lights are applied without coordination.

The evaluation of the performance of the light speed enforcement system was centered in two independent levels although complementary. On one hand the behaviors adopted in the approach and section crossing was accessed using video. This analysis enabled the quantification of the level of illegal passing's as well as the strategies used by drivers to avoid the systems' activation. A second analysis consisted in evaluating the differential variation of speed between the approach and the crossing zones. This was carried out using a real data base collected by standing radars strategically located.

THE SPEED CONTROL SYSTEMS

Concept and Operation Mode

Red-light enforcement systems are a device that is monitoring vehicles speed and penalizing vehicles operating at a speed higher than the one programmed in the control system using a red light. Whenever the vehicle is detected moving at a speed higher than the pre-established, the system acts by activating a period of steady yellow, followed by a red stage, forcing the vehicle to stop.

Types of Systems and Corresponding Operating Mode

These systems consist of instantaneous vehicle speed detection devices, which may be based on electromagnetic induction coils embedded in the pavement or Doppler effect radar.

In terms of action it is possible to identify two types of systems (Faulhaber, 1998). One works by calculating the average vehicle speed and the other monitors its instantaneous speed. The choice of one or the other type does not obey any specific criteria, depending mainly of the cost of the system (Seco et al., 2005).

Average speed systems

This type of systems relies on sensors and is commonly used in Spain. The most common application is based on the placement of magnetic coils (usually known as loops) in the pavement on the section preceding the lights. After a vehicle is detected speeding by the loop, the signal turns red during the period of time the vehicle takes to reach the light after a usually short period the light turns green. Therefore any vehicle traveling below the established speed will have a green signal when it reaches the traffic light.

In case the vehicle is traveling in a platoon, the system only evaluates the average speed of the first vehicle, extending the green for the vehicles that follow, regardless of their speed. If the distance between two vehicles in the queue is significant, the system assumes the definition of a new group and can activate the red, thus controlling independently the different platoons formed.

These systems are often are associated with the placement of an additional loop for infringements detection (vehicles that do not stop at a red light) in order to activate a camera, a buzzer or a light that can be only be a warning without penalty, or can have a punitive fines. Examples of this type of activity are seen, for example, in Brazil and Spain. They are not actually used in Portugal.

Instantaneous Speed Systems

The instantaneous speed systems have an operation logic that measures the vehicles' speed in at least one point of a road section, enabling the red if the speed exceeds the pre-established one. Otherwise it remains green.

Simply put, there are two solutions to measure instantaneous speeds: solutions based on detection by electromagnetic coils embedded in the pavement and radar or infrared based systems. When these systems began to be implemented in Portugal, the technology most commonly used was based on detection by electromagnetic detection, although nowadays by radar or infrared systems are more common.

The most advanced and flexible systems use more than one loop with the second one being placed in a point between the first loop and the traffic lights. This type of solution provides an optimization of this system operation as it allows, a very close vehicle monitoring along the circuit, and avoiding, in some cases, the early activation of the light. Systems with speed detection by radar or infra-red and do not limit the speed control of a section, it is possible to

extend it to a section more or less elongated. They are extremely easy to install, particularly when compared with the other loop based systems.

Their main weakness lies in the failure of the system to distinguish the direction in which the vehicle is traveling, and, if the system is installed in a curve, it can be difficult to correctly point it only to one direction. Infrared systems have as main weakness the detection of dust and birds not being able to distinguish them from vehicles. Some in situ observations showed that the infrared systems have difficulty detecting vehicle groups, which may be related to the excess of information supplied to the system simultaneously.

Preferential implementation conditions

Although red-light enforcement systems are not considered by most authors, traffic calming measures (see Brooks, 1996; Ministry of Transport, 1992), since they do not impose any physical change to the infrastructure, however they are recognized as being extremely punitive for high speeding vehicles. It should be noted that the systematic use of this type of device in a specific route, is translated, usually a significant drop in the level of service, so its use should be localized and used to mark the change of road environments.

Its application field is relatively limited, and its implementation recommended in the following circumstances (DGV, 2005):

- On town entrances, alerting the driver to the change in the road environment;

- In the transition between roads types, enhancing the driver behavior change in the passage of a collector to a distributor road alerting the driver to the need to adjust the speed to the new conditions;

- When combined with traffic light controlled intersections or pedestrian crossings, providing greater credibility to the system;

- When not combined they must be separated from the intersections at least 25 meters, in order to avoid driver misunderstandings;

- They should be avoided in stretches of roads characterized by high longitudinal gradients (9% or even higher), since they usually have high speeds. The situation is particularly aggravated when that road or street has vulnerable users, particularly pedestrians either in sidewalks, or in crosswalks.

From the a constructive point of view, it should be noted that whenever proves necessary for the placement of speed control systems related to the two directions of traffic, the supporting posts should not be installed in the same section but should be spaced by at least 30m. When the speed control systems are associated traffic control lights at a pedestrian crossing or an intersection, if a vehicle is detected traveling at a speed higher than the legally established one, the system must act in both movement directions simultaneously in order to prevent a pedestrian to interpret the first stop of the vehicle as a signal that it is safe to cross.

EVALUATION OF THE EFFECTIVENESS OF THE RED-LIGHT ENFORCEMENT SYSTEMS

Working methodology

The development of the study was supported by a real database, which consisted in collecting data from three sites located in the city of Coimbra or in its vicinity. The data collection was carried out outside the peak hours in order to safeguard that most of the patterns observed corresponded to free flow conditions with video images used to ensute this. Data collection was always done in daytime, mostly between 10:00 and 12.00 AM.

Data collection was done using a "Viacount II" radar which has a Doppler sensor working at 24.165GHz, a RAM Flash Memory, an integrated real time clock, serial data port type RS232 and a 12 volts battery. The speed distribution was recorded in two fundamental points: the approach to the control system to characterize the cruise section on the approach to the device (Site 1) and near the system (Site 2) to assess the actual effect on speed variation.

Additionally video footage was used to identify wrong behaviors and, in particular, the rate of red light violations.

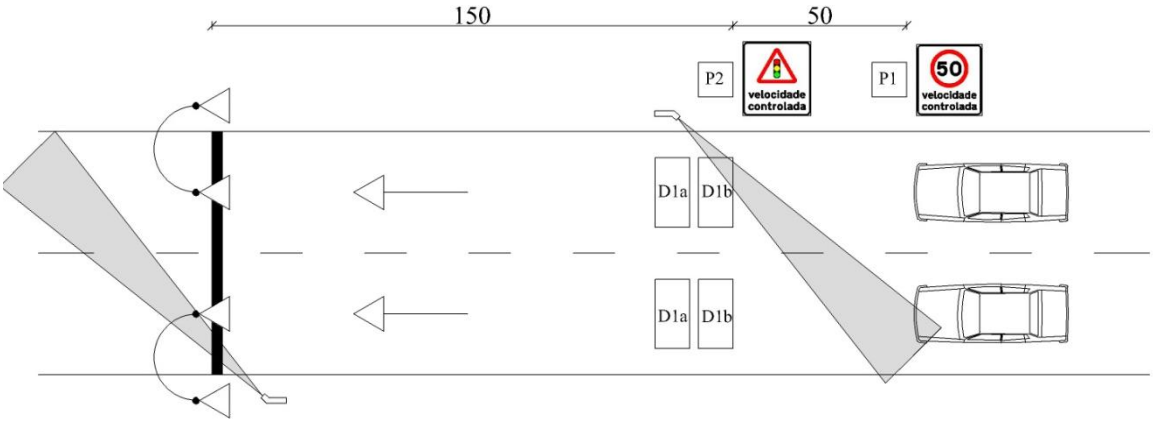

Figure 1 – Equipment scheme

The evaluation of the effectiveness of the systems was done using three performance indicators: (i) differential variation of the average instantaneous speeds recorded in the section next to the last speed limitation sign (signal P1 in Figure 1) and the section near the traffic light control, (ii) percentage of red light violations, and (iii) the proportion of vehicles speeding in the two sections where the sensors were installed.

Case studies selection

For logistical reasons the site location selection was limited to the city of Coimbra and surrounding areas, and the analysis was limited to three sites. Firstly, sites with different technological systems were selected, and then roads with different environments. As a consequence two systems highly integrated in urban environment (*Avenida da Lousã* and

the *Avenida Elísio de Moura*) were selected as well as one site integrated in a peri-urban environment (*N111-S.Silvestre*).

The *Avenida da Lousã* - case study 1 (Figure 2 (a)), is characterized by having a very straight line layout and having low gradient changes. Therefore it's design is propitious to high speeds.

Figure 2 – Case studies selected (a) Av Lousã; (b) Avenida Elísio de Moura; (c) S. Silvestre – N111

The system installed in *Avenida da Lousã* measure the instantaneous speed and is actuated by an electromagnetic sensor embedded in the pavement and installed 120m before the traffic lights. The traffic count survey conducted at that avenue showed that, even outside the peak period, demand levels are significant, approaching the 800 vehicles / h with about 9% of heavy vehicles and 2% of motorcyclists.

The Avenida Elísio de Moura (case study 2) - Figure 2 (b) is part of the structuring network of Coimbra integrating the ring road that circles the city, ensuring regional and urban traffic connections. It has 850m straight and a typical 2x2 cross-section. The gradient is 6.5%, which, in its downward direction, is propitious to high speeds. The Red-light enforcement system is installed in the downhill direction and measures instant speeds. It has an infrared sensor mounted above the traffic lights. During the period under review hourly an average traffic of 635 vehicles was recorded with about 18% of heavy vehicles and 2% motorcyclists.

The third site (case study 3) S. Silvestre-N111 - Figure 2 (c) is one of the major roads in the region of Coimbra, being responsible for connecting Coimbra to Figueira da Foz, with daily average traffic of about 10 000 vehicles. Its layout is generally quite rectilinear with low gradients. Therefore it has good conditions for high speeding. This has led to the installation in recent years of several Red-light enforcement systems, mainly to mark entrance of localities. The site selected is the entrance to the village of São Silvestre, although the urban area is developed outside the road being analyzed, which also contributes to the practice of high speeds. The system is integrated in a traffic light controlled intersection with physical channeling, a speed radar the main road and sensors to detect vehicles on the secondary roads. The solution is, therefore, semi-actuated, with speed measurement. During the period under review an hourly average traffic of 225 vehicles was recorded, with about 12% of heavy vehicles and 3% of motorcyclists.

Speed distribution Characterization

Table 1 outlines the average speeds recorded, as well as other dispersion indicators.

Table I – Average speed and speed dispersion indicators (km/h)

Case study number	Section	Average speed	Minimum speed	Maximum speed	Standard deviation	Percentiles		
						25th	50th	75th
1	Section 1	48,24	16	121	9,66	42	47	53
	Section 2	32,06	12	77	10,3	23,25	34	39
2	Section 1	65,11	5	132	15,65	54	64	74
	Section 2	39,39	6	82	10,7	30,75	40	47
3	Section 1	55,72	13	96	14,82	46	57	66
	Section 2	35,67	9	101	15,63	24	32	44

As would be expected the higher average values are recorded in Avenida Elísio de Moura, given the high descendent gradient on the approach followed by S. Silvestre-N111, quite possibly because it is a sub-urban area. These are also the locations where there is a greater dispersion of the speed distribution, and this aspect is clear either using a standard deviation analysis or using the amplitude between the maximum and minimum speed.

It is still worrying to note that the peak values recorded reach extremely high values, especially if we take into account that the locations are subject to a 50km/h speed limit. These same results are visible in Figures 3 and 4.

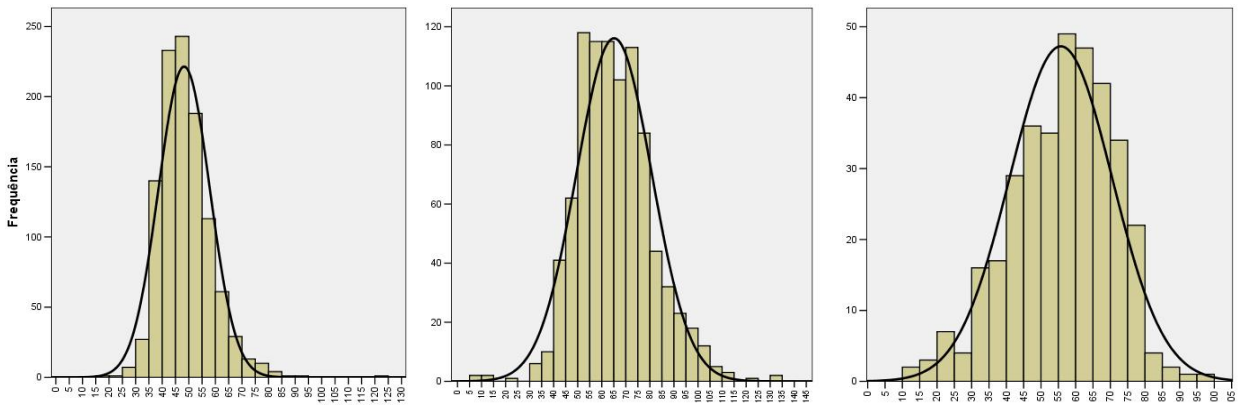

Figure 3 – Speed histograms at section 1: (a) case study 1; (b) case study 2; (c) case study 3

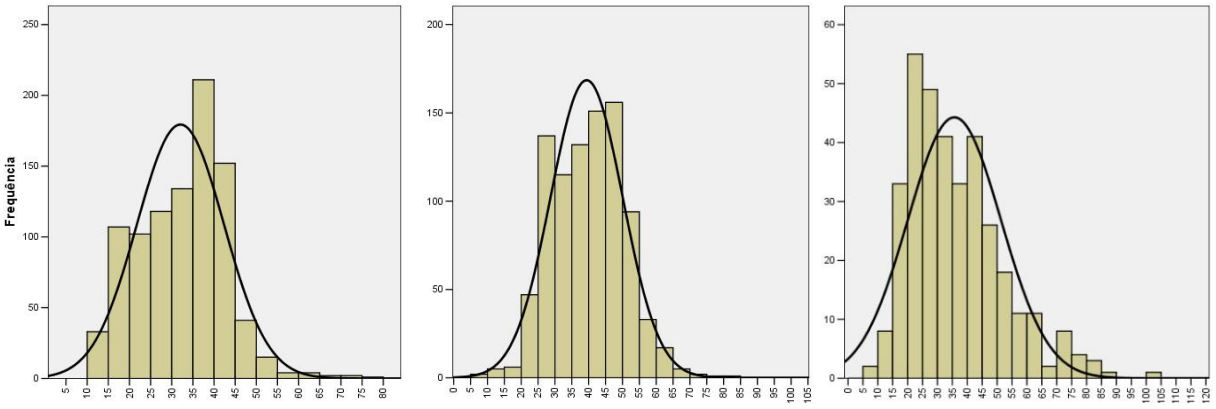

Figure 4 – Speed histograms at section 2: (a) case study 1; (b) case study 2; (c) case study 3

The analysis of the figures corresponding to section 1 (approach speeds), show some tendency to adjust to the normal curve, a characteristic that is lost in the section near the traffic light (section 2). This finding reveals a number of factors that are disturbing the normal behavior, which should be related with hesitations, different braking distances and different strategies for dealing with the system (maintaining a reduced speed on the section, braking near the traffic lights, etc.). As might be expected, the histogram in section 2 (traffic light) tends to suggest some asymmetry with a tail on the left (positive skewness coefficient) on *Avenida Elísio de Moura* in and *Avenida da Lousã* and a tail to the right (negative skewness coefficient) on *S. Silvestre-N111*. These results suggest that in *Avenida da Lousã* drivers try to respect the speed limits, whereas in *S. Silvestre-N111* there is a greater tendency to go through the traffic light at high speeds.

It is still possible to verify by the analysis of histograms and also from Table 1 that there was a significant decrease of the average and median speed values, between section 1 (approaching section) and section 2 (traffic light).

Red light Violations

Red light violations were quantified using the video recordings (Table 2).

Table 2 – Red light violation

Case study number	Red light compliance - section 2				Total	Drivers in excess speed at section 2				Total
	Pass the red light		Stop at the red light			Pass the red light		Stop at the red light		
	N	%	N	%		N	%	N	%	
1	17	1,60%	1056	98,40%	1073	17	70,80%	7	29,20%	24
2	7	0,80%	904	99,20%	911	7	5,20%	128	94,80%	135
3	5	1,40%	346	98,60%	351	5	8,90%	51	91,10%	56

Given the size of each sample red light violations are relatively low (between 0.8 and 1.6%). It is however expected that the degree of violation takes has higher values in inter-urban

areas and night periods, since supervision on those circumstances tend to be less probable. It is also important to see that all drivers that passed the red light were speeding. It is however noticeable that some drivers use strategies so that speeding vehicles don't pass the red light. Therefore heavy braking at control sections followed by accelerations are quite common.

Ability to control speeds

The ability to control speed was analyzed on two levels: (i) the proportion of vehicles speeding, (ii) the differential speeds variation between the approach and control section.

The proportion of vehicles speeding was obtained through the number of vehicles detected in the two sections with speeds higher than 50 km/h (see Table 3) – legal speed limit law on the site. the results show that although when approaching the proportion of vehicles exceeding the legal speed is significant (35, 84 and 65% respectively in each of the sections), the system tends to be efficient, naturally leading drivers to respect it on the section near the traffic light. Comparing the data in Table 1 and 3 (confirmed by the video images) confirms that all vehicles that violated the red light were circulating over the speed limit.

Table 3 – Red light violation

Case study number	Section	Respecting the speed limit		Exceeding the speed limit		Total	Differential speed variation			
		N	%	N	%		mean	%	Max.	Min.
1	Section 1	697	65,0	376	35,00%	1073	15,98	0,34	71	-23
	Section 2	902	97,4	24	2,60%	926				
2	Section 1	143	15,7	768	84,30%	911	25,7	0,40	108	-34
	Section 2	769	85,1	135	14,90%	904				
3	Section 1	121	34,5	230	65,50%	351	19,85	0,36	75	-45
	Section 2	291	83,9	56	16,10%	347				

The same table shows that regardless of where the analysis is done the system achieves a quite significant speed reduction, reaching average reductions between 34 and 40%.

Assessment of the major and minor variation of the differential speeds at two of the sites shows that there are vehicles that reduce, while others opt to increase speed on the control section. Again these behaviors indicate the development of strategies to overcome the system without violating the red signal.

It should be noted that the number of vehicles speeding in Avenida da Lousã was much lower compared to the same section on the other test sites. This may be due to the fact that this system is embedded in the pavement, and the majority of drivers know the system, opting to reduce speed along the sensor, accelerating immediately after passing it.

It should be noted that the higher speed measured in S. Silvestre-N111 (101 km / h) is less than 30 km/h than the maximum speed registered within the city of Coimbra (131 km/h). One

possible justification for this difference is that police enforcement is usually present at S. Silvestre-N111 and are nor usually present in urban sections. These two observations may imply that even random surveillance contributes to higher compliance levels.

Identification of strategies for drivers to who "circumvent the system"

The video images show that, in general, most drivers respect the speed control system. In fact a significant group of drivers when seeing the system choose to reduce their speed pass with the green light. Another group, also significant, adopts the same behavior, but when they are close to the traffic light, they accelerate and pass under a yellow light.

It is however possible to identify a set of attitudes, aimed at overcoming the system, without its notice.

In significant numbers, one of the strategies found in cross sections provided with shoulders (*Avenida da Lousã*) is a path deviation avoiding the sensor embedded in the pavement, and thus they do not activate the system.

In *Avenida Elísio de Moura* (infrared radar), the escape strategy, that is repeatedly practiced, is to accelerate after the sensor and still manage to pass under the yellow light before the red one turns on. The most dangerous behavior detected (although there were very few cases) are drivers who opt for extremely high speeds, and that do not brake at all between the sections and therefore manage to go through with the green signal. Any of these strategies should be studied and it is essential to find ways to prevent such behaviors.

MAIN CONCLUSIONS

Accidents are still responsible for the death of about 750 persons annually in Portugal, and speeding to be one of the major factors underlying these numbers. In that sense, this study sought to realize in a sustained manner if the speed control systems are actually effective in reducing speed and if they are largely respected by the drivers or not.

The results showed that the red-light enforcement systems are quite effective, since that in the period observed, it appears that an almost negligible percentage of vehicles pass the red light. The proportion of vehicles speeding also seems to suffer a big reduction, coupled with a decrease in the average speed to values within the legal speed limits.

The video images observation allowed the show that most drivers comply with the system but some of them use strategies to drive threw without activating it. These situations are for instance driving on the shoulder when the speed sensor is on the pavement. Also, the adoption of extremely high speeds has been used as a way to overcome the system. It was also noticed that the driver's behavior is particularly sensitive to the presence of police enforcement.

Therefore red-light enforcement systems are quite effective in reducing speed in major distributor roads in cities and also town entrances. It should however be noted that this type of systems are primarily designed to change driver behavior in road environment transition zones. As a consequence their overall performance level will increase considerably when combined properly with other complementary measures such as traffic calming measures or other strategies that change the road environment. It is also essential to focus on enforcement actions, even if they are random.

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