DRIVER BEHAVIOR AND POLLUTANT EMISSIONS ON ISOLATED ROAD HUMPS

J. CRUZ da SILVA
Department of Civil Engineering, Polytechnic Institute of Leiria, Portugal
JPSILVA@IPLEIRIA.PT
A. SECO & A. BASTOS SILVA
Department of Civil Engineering, University of Coimbra, Portugal
ASECO@DEC.UC.PT & ABASTOS@DEC.UC.PT
M. PESTANA
Department of Quantitative Methods ISCTE, University Institute of Lisbon, Portugal
MHPP@ISCTE.PT
A. VASCONCELOS
Department of Civil Engineering, Polytechnic Institute of Viseu, Portugal
VASCONCELOS@DCIVIL.ESTV.IPV.PT

ABSTRACT

Road Humps are a particular type of traffic calming devices that are generally used in critical locations of the road where traffic speeds are high. Therefore they perform an important safety role. This particular measure is widely used in several countries. Generally they are selected due to their effectiveness and ease of implementation. Other factors such as the consequences on emissions are normally not considered. While in the past this procedure was standard nowadays there are tools that allow a broader approach to the problem. The knowledge of the resulting speed profiles is also crucial to ensure that the measure originates the appropriate speed reduction.

This paper will present a research study that was supported by an extensive data collection campaign using an instrumented vehicle. The data collection involved 18 drivers and 34 road humps. Through the use of an instantaneous pollution emission model pollution levels were calculated. These values are essential for the evaluation of the environmental aspects of this traffic calming device thus enabling a better understanding of the relationships between road infrastructure characteristics and pollution levels. They also allow the analyses of the relationships between driver behavior and the pollution levels which are discussed in this paper.

1. INTRUDUCTION

More than a century ago humanity saw the birth of an invention that would have a decisive influence on the course of modern civilization and more specifically to our contemporaneous way of life. That invention was a self powered vehicle usually known as the automobile or car. The benefits such machine had were too obvious to be ignored. The travel freedom was much valued. Initially only accessible to the wealthier automobiles soon became cheaper, better and easier to use and therefore accessible to a wide range of the population.

Fast forward to actual times and we are dealing with several issues that arise from the widespread of cars. These issues are can be divided in several areas going from land planning aspects, environment issues and safety concerns. The latest aspect usually is normally the result of inadequate speeds. One way to minimize this issue is to design the infrastructure using techniques that mitigate these situations. These techniques are commonly known as traffic calming measures.

Thus traffic calming measures are mainly applied in critical locations of the road infrastructure where there is a need to assure that vehicle speeds are low or to reduce traffic demand such as in residential areas. As a result they perform an important safety role which is beneficial in many aspects namely in creating a safer road environment for all users and in improving the livability of the urban area.

Generally the traffic calming measure selection process is based on the desired level of speed reduction. Other factors such as the consequences in noise levels or air pollution are normally unconsidered or minimized. Consequently the evaluation is incomplete which can result in a biased evaluation. While in the past this procedure was standard nowadays it can be dealt in a broader manner. In fact due to the consequences of air pollution to human health, the environment and fossil fuel usage the development of evaluation procedures that can account for this vital aspect are essential.

In this context this paper will present a research work that had the objective of improving the knowledge of the driver behaviour and its consequences a particular type of traffic calming device: Road humps. This particular measure, which is typically very effective in curbing traffic speeds, is broadly used around the globe [1]. To support the research real life data was collected using an instrumented vehicle. The vehicle had several instruments that gathered information on the speed, acceleration (in the 3 axes), pitch, roll and yaw as well as its position using a GPS (Global Positioning System) tracking device. The vehicle also had three cameras which recorded images of the vehicles surrounding. The data collection involved 18 drivers which passed approximately 18 times in a set of 34 road humps in 3 different locations. The humps had different geometric characteristics although within normally acceptable values according to the generally accepted technical references.

All this information will be used in improving the actual knowledge on the relationships between speed and the geometric characteristics of road humps. It will also have another important application which is addressed in this paper. Through the use of instantaneous emissions models it is possible to calculate instantaneous pollution levels. In the case the model selected was the Comprehensive Modal Emissions Model (CMEM) which gives second by second values of emitted values of CO_2, CO, HC, NO_x and consumption [2]. These values are the basis for the evaluation, done in this paper, of the implications of driver behaviour on the level of pollutant emissions when using this particular traffic calming measure.

2. ROAD HUMPS

Road Humps are a popular traffic calming device that consists in a transversal elevation of the road’s pavement. They are one of the most used traffic calming devices not only for their low cost and ease of implementation but also for being highly effective in reducing traffic speeds. Their efficiency results from the discomfort that drivers feel due to an increase in the vertical acceleration values when they are crossed above their specific design speed [3, 4]. Road elevations are generally divided in two groups according with their length [5]. The first group usually known as speed humps has an elevation between 5 and 12 cm, 3 to 12 m of length and generally has a circular or trapezoidal section. The second group is known as speed bump and has usually 5 to 15 cm in height and 0.3 to 1.0 m in length. Figure 1 illustrates these two types.

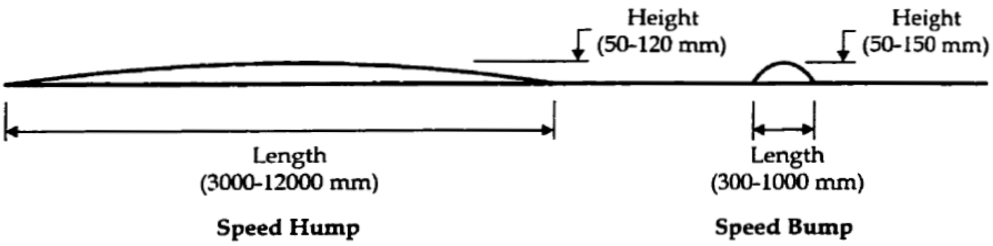

Figure 1 – Speed hump and speed bump [5]

This research was centered in speed humps. One of the most common profiles is known as the Watts profile and was developed in the 1970’s by G.R. Watts in the Transport and Road Research Laboratory (TRRL) in the United Kingdom [3]. It is a section of a cylinder with 3.7m of length and 75 to 100 mm in height transversely placed on the road. This profile can be crossed by the majority of vehicles with speeds between 25 to 30 km/h and was adopted by several countries [4, 6, 7] including Portugal [8].

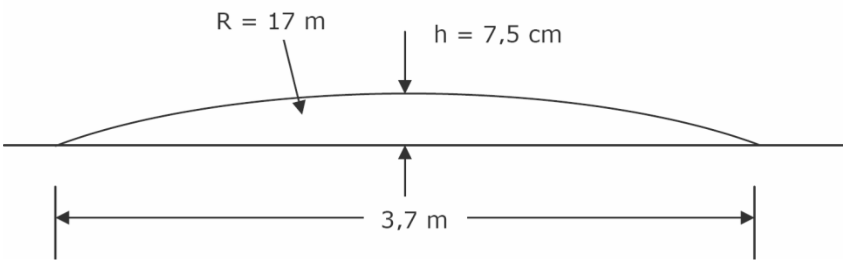

Figure 2 – Watts hump profile [8]

Other configurations were developed that vary in length, height and cross section. Among these we can find the Seminole speed hump developed in Seminole County, Florida [9]. In this solution a straight section is added resulting in an increase in the total length. The speed hump can, in this case, also be known as a speed table and can be used with a pedestrian crossing [1].

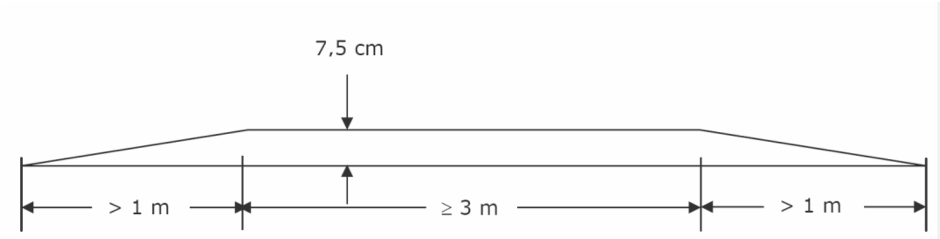

Figure 3 – Trapezoidal or Seminole County speed hump [8]

The underlying principle of a speed hump results from the transfer of a vertical force to the vehicle and its passengers as it crosses the speed hump [10]. This force provokes vertical acceleration and induces a rotation movement on the vehicle [11]. As the vehicles travelling speed increases so thus the magnitude of the acceleration, rotation and vertical displacement. The discomfort has been associated with higher vertical accelerations in numerous studies [5, 12].

3. INSTRUMENTED VEHICLE

The vehicle instrumentation resulted from a joint effort from the University of Oporto, the University of Coimbra and the Polytechnic Institute of Leiria. It is the second successful experience in vehicle instrumentation for driver behavior studies of this team [13].The vehicle used was a Volvo V40 station wagon (model year 2000) with a 1.6 liter gasoline engine. It was assumed that its handling conditions and power to weight ratio are a fair representation of the average Portuguese car which should also be true at least in western countries.

Two independent systems were installed in the car. One had the task of gathering the dynamic variables associated with the cars movement the other would record video images of the traffic conditions surrounding the car while it was collecting data.

The dynamic variable system selected was the Maxqdata MQ 200 RT [14] which was originally developed for car competitions. It has a 3 axis accelerometer, a 3 axis gyroscope, a GPS and also the possibility to connect to the vehicle's OBD (On Board Diagnosis System). The variables recorded for this study were the following:

- Longitudinal, lateral and vertical accelerations (with a 20 Hz frequency);
- Pitch, roll and yaw (see Figure 4) recorded at 20 Hz;
- Vehicle position, speed, longitudinal and lateral accelerations from the GPS unit recorded at 5 Hz.

The MQ 200-RT unit was mounted under the passenger seat since there was not enough space under the driver seat because it was adjustable in height. This location ensured that the accelerations recorded were the same as the ones felt by the driver (Figure 5a).

The MQ 200 RT unit transmitted all information in real time using the Bluetooth protocol which is quite reliable [15] to a PDA (Personal Digital Assistant) which recorded it (Figure 5b). One of the advantages of this system was that all the information collected was recorded in a single file and hence had the same timestamp which was given by the GPS standard time.

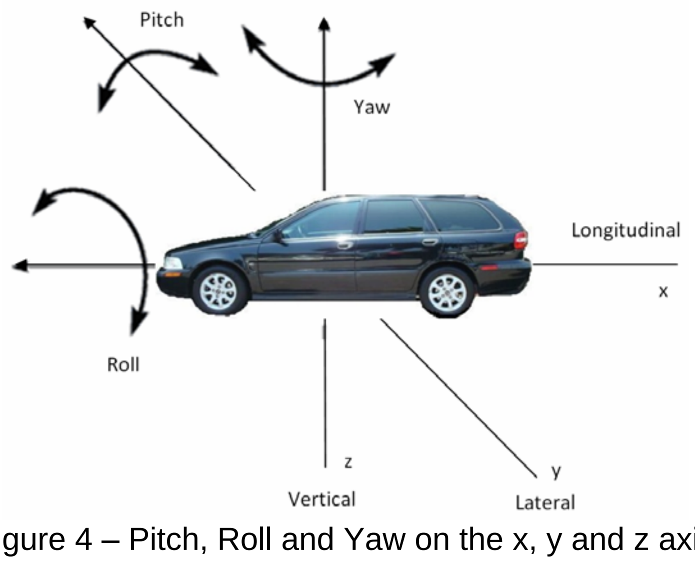

Figure 4 – Pitch, Roll and Yaw on the x, y and z axis

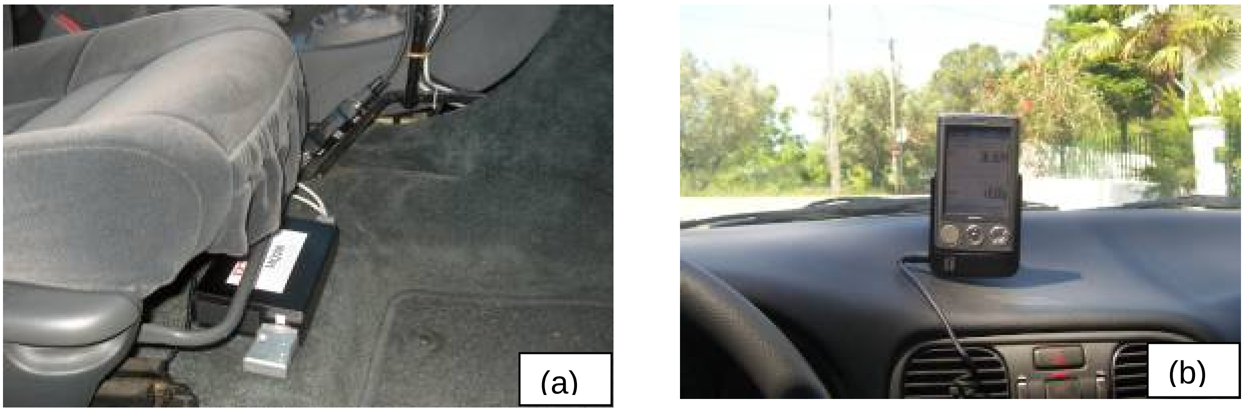

Figure 5 – MQ 200-RT unit (a) and PDA for data visualizing and recording (b)

The image recording system has three cameras strategically positioned in the car. They captured the front, rear and left side view from the car thus enabling the assessment of road traffic conditions. The images were recorded in a computer installed in the trunk of the car. This computer had a Geovision GV800-4 video capture card [16] installed which enabled the recording of the images (recorded at 30 frames per second) from the three cameras along with a date and time stamp. The time was given by the computer’s operating system which was periodically set and verified to be in accordance with the GPS time. This was an important aspect in order to assure that the data collected by the MQ 200-RT could be easily and accurately identified with the corresponding video images. The following figures show some views of this equipment.

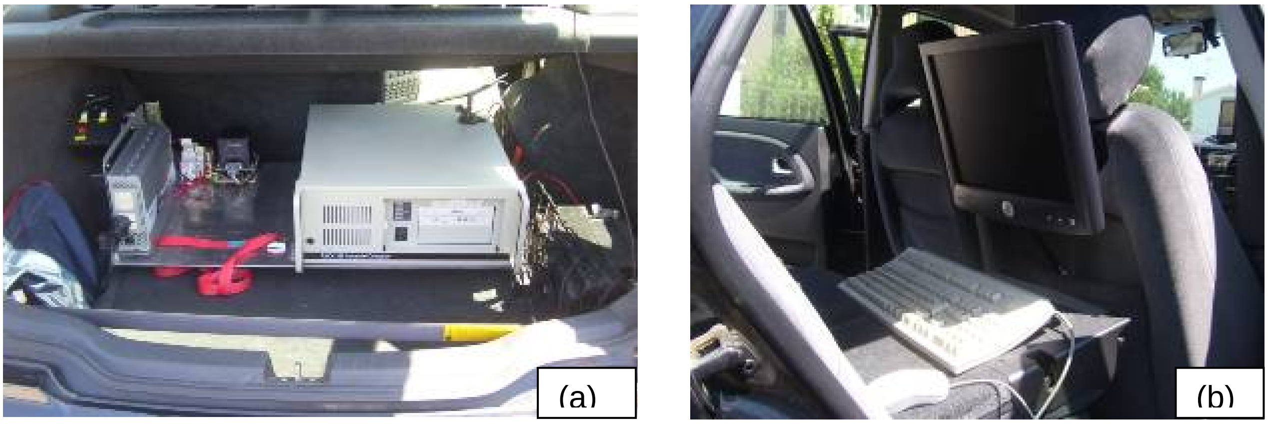

Figure 6 – Computer and support systems in the vehicle trunk (a); interface (b)

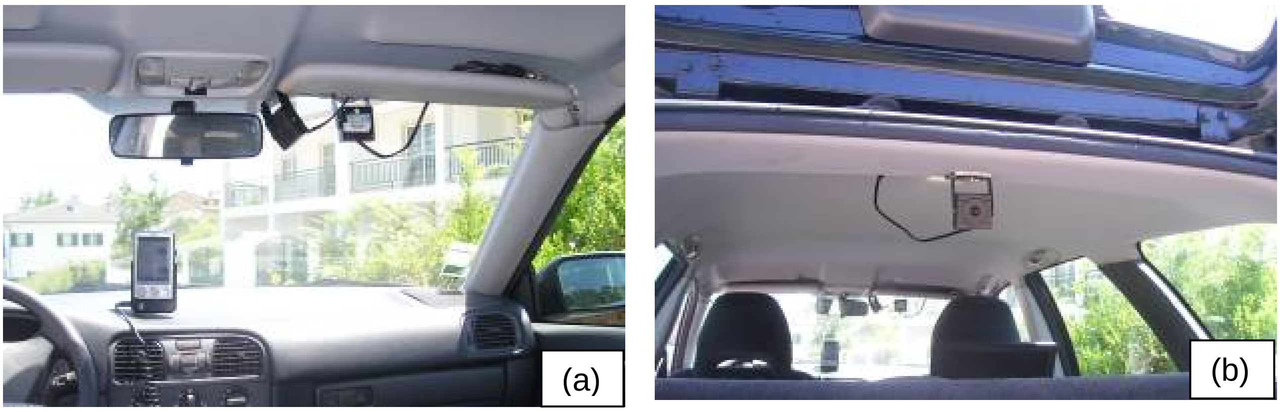

Figure 7 – Lateral and front view cameras (a); rear view camera (b)

All the systems described previously operated in a very reliable way enabling the collection of a great amount of data in a relatively short period.

4. DATA COLLECTION

An extensive search for speed humps was done previously to the data collection in the central region of the country (due to logistic reasons). The speed humps had to comply to with several requisites to ensure that their geometric characteristics were acceptable and in accordance with the national standards [8] and also that their location was appropriate. Three locations were selected and identified by local landmarks. One of the locations "Casal do Barril" had four speed humps with a Watts type profile with maximum between 0.075 and 0.080 m. The other two locations identified as "Porto de Mós" and "N110" had a total of thirteen speed humps using the trapezoidal profile. Most of these speed humps were associated with pedestrian crossings. In these cases the height of the traffic calming device had a minimum of 0.05 m and a maximum of 0.095 m. The total length went from 3.7 to 11.4 m and the entry and exit ramps were always 1 m long.

Following this phase a total of 18 drivers were enrolled to conduct the onsite data collection. They all had at least two years of driving experience, did on average a minimum of 10000 km driving per year and had ages between 24 and 29 years. The group was mainly formed by male drivers but also had five female drivers among them. Similar criteria's were also adopted in other analogous studies [17].

The drivers all had the opportunity to get fully acquainted and comfortable with the vehicle's handling characteristics as they all had the opportunity to drive it freely through a period of time they considered sufficient. On each test site they also drove one or two laps to know the location of the speed ramps as well as the inversion and data retrieving points.

The methodology adopted in the sessions was the following: two drivers would be present at each session and each of them drove continuously for a maximum of half an hour. At the end of this period there was a switch in drivers and new logging files were started. This procedure had two main purposes. On one hand the drivers could rest and therefore minimize eventual driver behavior alterations due to fatigue and on the other hand the size of the collected files was kept low which aided the subsequent data treatment. Each speed hump was crossed 16 to 18 times by each driver.

Figure 8 – Instrumented vehicle collecting data

5. DATA ANALISIS

After completing the data collection all the information was restructured to enable the next steps. This task was accomplished firstly by exporting the dynamic variable to a spreadsheet format and afterwards using a set of Visual Basic customized developed applications used essentially to identify and isolate the relevant data.

The next step was to review all the video images and to verify, for each speed hump crossing, what were the traffic conditions ahead of the instrumented vehicle. Every time the driver was conditioned by a slower vehicle in front of him, a pedestrian crossing or any other situation that inhibited him from freely selecting his desired travel speed meant that free flow conditions were not confirmed and therefore that particular crossing had to be rejected and suppressed from the final data base. Although tedious and time consuming this was an important phase to ensure the quality of the data used in the next stages.

After that phase the environmental data was calculated using the CMEM software which is an instantaneous emissions model. It was developed by the University of California-Riverside, the University of Michigan and the Lawrence Berkeley National Laboratory [2]. It determines the second by second tail pipe emissions in different driving modes (idling, accelerating, cruising and decelerating) for several different types of light duty vehicles. Its validity and usefulness in this type of analyses has been tested and used in other researches studies [18, 19]. In practical terms this model works by initially setting the relevant characteristics of the vehicle such as its engine type, capacity and power, the vehicle weight and its anti pollution technology and use these parameters along with the instant speed and longitudinal acceleration to calculate the instantaneous vehicle's pollution values namely the CO_2, CO, HC, NO_x and fuel consumption on a second by second basis. This procedure allows several important analyses such as comparing the effects of driver behavior and road characteristics and quantity of pollution gases emitted by the vehicle [18, 20].

Driver behavior near a speed hump is generally characterized by a decrease of speed on its approach followed by acceleration after crossing it as the driver tries to regain speed. This situation is illustrated in Figure 9 that shows the speed profiles of four different passages on the same speed hump. The profiles in green and purple represent situations in which the driver had his behavior conditioned on the exit due to the presence of slower vehicles. As stated previously these cases were erased from the final data base. The blue and red profiles represent normal unrestricted behaviors. The two main phases of braking and acceleration after speed hump are clearly visible. Other relevant aspects can be noted as well such as the fact that the braking deceleration is much higher than the rate of speed gain. Although drivers start losing speed before, the final braking area has approximately 25 m in length and to recover the initial speed approximately 140 m are required.

This originates two distinct phases that also have very different implications in terms of pollutant emissions. The first phase (before the speed hump) is not very relevant because, normally, the vehicle engine is not producing any significant power output but is idling which implies very low (or zero in some recent vehicles) emissions [21]. However the second phase, after crossing the speed hump, is crucial because the engine is forced to work in order to make the vehicle regain kinetic energy. This implies fuel consumption and therefore an increase in pollutant emissions. According to the literature, higher rates of acceleration result in greater quantities in terms of pollutant emissions [20-22]. As a result aggressive drivers should have higher emissions. The approach speed is also important since it was observed that drivers tended to regain their normal speed after the speed bump. Therefore higher approach speeds usually resulted in greater or longer periods of acceleration after the speed hump.

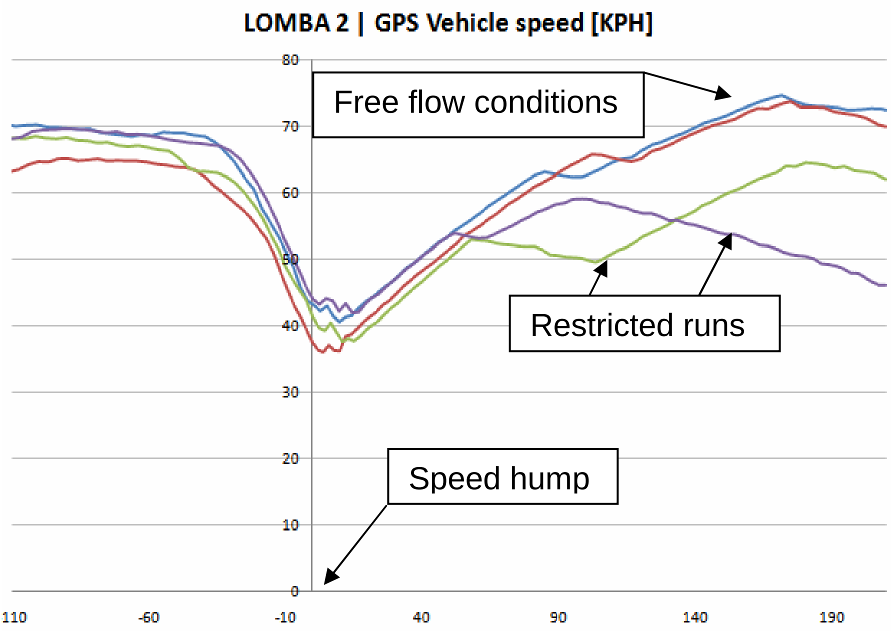

Figure 9 – Speed profiles while crossing a speed hump

In order to evaluate the validity of the preceding hypothesis the total value of CO_2 generated on average by each driver considering all 34 speed humps was calculated. These values were obtained using the previously described methodology and considering a road sketch of 75 m before the road hump and 150 m after it totalizing 225 m. These values were adopted after an extensive review of the speed profiles showed that the influence of the traffic calming measure would normally be restricted to those limits. The values are shown in Table 1.

Table 1 – Calculated CO_2 values by driver

Order	Driver nº	Total CO_2 (gram)
1	**13**	56,6
2	**10**	55,7
3	**18**	54,2
4	**11**	52,4
5	**9**	50,5
6	**14**	47,9
7	**1**	47,5
8	**6**	47,3
9	**15**	47,1
10	**2**	46,8
11	**7**	46,7
12	**5**	45,8
13	**12**	45,7
14	**17**	45,2
15	**4**	44,4
16	**16**	44,4
17	**3**	43,5
18	**8**	40,7
average value	*47,9*	

The previous table shows that driver nº 13 is on average the biggest polluter (56.6 g) and that driver nº 8 has the most environmentally conscience behavior with 40.7 gr. the average is 47.9 g and the percentage variation between these extreme values is almost 40%. This latest value is certainly high as it is only explained by the driving style differences among the drivers tested. Also worth noting is that these values represent the average of all runs in all speed humps and therefore extreme behaviors that can cause even greater differences are dimmed. These results are also within the range suggested by several EcoDriving organizations [23-25].

Table 2 resumes the relative qualitative performance of the drivers in terms of approach speed, exit acceleration and pollution levels. This analysis was used to evaluate the eventual existence relationships among these variables. Accordingly observing the table it is quite clear that there is a matching tendency of high speed and particularly high acceleration levels with high levels of CO_2 emitted. The opposite situation is also identifiable. Therefore all drivers that have high acceleration levels also have high CO_2 values. On the other hand almost all drivers with low acceleration levels also have low CO_2 emissions with the exceptions to these cases having average levels. Regarding the speed the parallelism is not so notorious but nevertheless there is a propensity towards higher speeds being less environmentally friendly. Therefore it is quite clear that the driver behavior plays a major role in the level of pollutants emitted by mainstream cars equipped with the normal internal combustion engine.

Table 2 – Qualitative driver behavior and calculated CO_2 values by driver

Driver nº	Driver behaviour		Total CO_2 (gram)
	Aproach speed	Exit acceleration	
1	high	low	average
2	average	average	average
3	average	average	low
4	average	low	low
5	high	low	low
6	high	low	average
7	low	average	average
8	low	low	low
9	high	average	average
10	high	average	high
11	average	high	high
12	low	average	low
13	high	high	high
14	high	low	average
15	high	low	average
16	average	low	low
17	average	low	low
18	average	high	high

A log-linear analysis was conducted in order to verify the validity of the previous findings. It confirmed, as expected, the high level of positive association between the acceleration and CO_2 emitted. As for the speeds and CO_2 levels a connection is also present although with less strength.

CONCLUSIONS

Traffic calming techniques are currently extensively used in many countries by road management authorities especially in urban areas. Their main goal is usually to persuade drivers to adopt their travelling speed accordingly to the road environment conditions and therefore create a better and safer environment for all users. Road humps are one of the most common traffic calming devices. They are generally very effective in reducing speeds and are also inexpensive and easy to implement when compared with other alternatives.

Normally the traffic calming device selection procedures don't take in account the environmental factors. As a consequence the traditional evaluation systems may be incomplete and leave out of the equation one important aspect of the global problem. In this context this paper briefly presents the methodology and some preliminary findings of a research work that has the aim of improving the current understanding of driver's behavior when crossing speed humps and also determining the environmental consequences of the implementation of this particular type of traffic calming device.

The research is based on a data base gathered in real conditions using an instrumented vehicle that recorded dynamic variables as well as video images. It was driven by a set of 18 drivers that passed several times and in both directions trough a selection of 34 speed humps in three different locations. After completing the data collection the environmental variables namely the CO_2 emitted were calculated using an instantaneous emission model. This enabled the analysis of the relations between road infrastructure characteristics and induced pollution levels.

Results presented in this paper showed a clear influence of the driver behavior on the level of tailpipe emissions when crossing a speed hump. In fact it was notorious that the acceleration levels after the traffic calming are highly correlated with the amount of CO_2 emitted. It was shown that on average aggressive drivers can originate emissions almost 40% higher than the ones produced by calmer or more environmentally conscious drivers.

It is also worth mentioning that this evaluation methodology can be easily replicated for other specific road characteristics or changes in road design allowing as a consequence a broader understanding between the road and the environmental issues that nowadays assume a very important role in the road design processes.

REFERENCES

1. Ewing, R. and S.J. Brown, (2010) U.S. Traffic Calming Manual, Washington, DC: American Planning Association.
2. Barth, M., et al., (2000) User's Guide: Comprehensive Modal Emissions Model, Version 2.0., National Cooperative Highway Research Program, Project 25-11.
3. Watts, G.R., (1973) Road Humps for the Control of Vehicle Speeds, Transport and Road Research Laboratory (TRRL) Report 597, Department of the Environment and Department of Transport: Crowthome, United Kingdom.
4. Ewing, R.H., (1999) Traffic Calming: State of the Practice, Institute of Transportation Engineers, Washington, DC, USA.
5. Weber, P.A., (1998) Towards a Canadian Standard for the Geometric Design of Speed Humps, in Department of Civil and Environmental Engineering. Carleton University, Ottawa, Ontario, Canada.
6. ITE, (1993) Guidelines for the Design and Application of Speed Humps, Technical Council Task Force on Speed Humps, Institute of Transportation Engineers, Washington, DC.
7. TAC, (1995) Urban Supplement to the Geometric Design Guide for Canadian Roads, Transportation Association of Canada, Ottawa.
8. DGV, (2004) Instalação e Sinalização de Lombas Redutoras de velocidade – Nota técnica, Despacho nº 109/2004, Direcção dos Serviços de Trânsito, Lisboa.

9. Nicodemus, D.A., (1991) Safe and Effective Roadway Humps: The Seminole County Profile, ITE Compendium of Technical Papers. Institute of Transportation Engineers: Washington, DC.
10. Blundell, M. and D. Harty, (2004) The Multibody Systems Approach to Vehicle Dynamics, Oxford, UK, Butterworth-Heinemann.
11. Jarvis, J.R., (1980) Legal Aspects of Round Humps on Public Roads, Research Report ARR No. 109, Australian Road Research Board (ARRB) Ltd., Victoria, Australia.
12. Bjarnason, S., (2004) Round top and flat top humps - The influence of design on the effects, in Department of Technology and Society, Lunds Tekniska Hogskola, Institutionen for Tecknik och samhalle: Lund, Sweden.
13. Silva, J.P.C., A.M.C. Bastos Silva, and A.J.M. Seco. (2002) Instrumentação de um veículo para apoio à análise comportamental de condutores. in XII Congresso Panamericano de Trânsito e Transportes. Quito, Equador.
14. Maxqdata, (2007) MQ200 User Manual, Maxqdata, Bellevue, Washington.
15. Prabhu, C.S.R. and P.A. Reddi, (2006) Bluetooth Technology and Its Applications with JAVA and J2ME, New Delhi, Prentice-Hall of India Pvt.Ltd.
16. Geovision. (2006) GV-800 Video Capture Card, [accessed 05/06/2006 from http://www.geovision.com.tw/english/index] Geovision Inc.
17. Bastos Silva, A.M.C., (2004) Definição de uma metodologia de concepção de cruzamentos giratórios, Departamento de Engenharia Civil, Universidade de Coimbra, Coimbra.
18. Tate, J.E., M.C. Bell, and R. Liu. (2005) The Application of an IntegratedTraffic Microsimulation and Instantaneous Emission Model to Study the Temporal and Spatial Variations in Vehicular Emissions at the Local-Scale. in Transport and Air Pollution, 14th International Symposium. Graz, Austria.
19. Chen, K. and L. Yu, (2007) Microscopic Traffic-Emission Simulation and Case Study for Evaluation of Traffic Control Strategies. Journal of Transportation Systems Engineering and Information Technology, 2007. 7(1), p. 93-99.
20. Höglund, P.G. and J. Niittymäki. (1999) Estimating Vehicle Emissions and Air Pollution related to Driving Patterns and Traffic Calming. in Urban Transport Systems, 2nd KFB-Research Conference. Lund, Sweden.
21. Int Panis, L., S. Broekx, and R. Liu, (2006) Modelling instantaneous traffic emission and the influence of traffic speed limits. Science of The Total Environment, 371(1-3): p. 270-285.
22. Boulter, P.G., (2001) The Impacts of Traffic Calming Measures on Vehicle Exhaust Emissions, Middlesex University, London.
23. ACEA. (2010) Eco-driving: Easy to apply, impressive results. [accessed 31/08/2010 from: http://www.acea.be/index.php/news/news_detail/eco_driving_easy_to_apply_impressive_results/] European Automobile Manufactures Association.
24. AAM. (2009) Ecodrivingusa. [accessed 10/09/2010 from http://www.ecodrivingusa.com/.]; The Alliance of Automobile Manufacturers.
25. ACAP. (2010) Eco-condução Portugal. [accessed 10/09/2010 from http://www.ecoconducao-portugal.pt/]. Associação Automóvel de Portugal.