EVALUATION OF THE EFFECTS OF ROAD HUMPS ON POLLUTION EMISSIONS

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ABSTRACT

Traffic calming devices and strategies are generally used in critical locations of the road infrastructure where there is a need to assure that traffic speeds are low or to reduce its demand such as in residential areas. Traffic calming devices perform therefore an important role in assuring not only the safety of all road users but an appraisable and friendly urban environment.

In general terms the selection of the type of measure to be applied is based on the desired level of speed reduction. Other factors such as the consequences in noise levels or air pollution are normally not considered or are relegated to a secondary role. Consequently the evaluation is incomplete which can result in solving one aspect of the problem but aggravating other essential issues. While in the past this procedure was standard and acceptable nowadays it is becoming outdated and there are tools that allow a broader approach to the problem. In fact due to the consequences of air pollution to human health, the environment and global warming, the development of evaluation methodologies that incorporate this vital aspect are essential.

This work will present an ongoing research that has the goal of improving the knowledge on a particular type of traffic calming device: Road humps. This particular measure, which is usually very effective in reducing traffic speeds, is widely used in several countries.

In order to support the research an extensive data collection campaign was done using an instrumented vehicle. It was provided with several instruments that gathered information on the vehicles speed, acceleration (in the three usual axes), pitch, roll and yaw as well as its position using a GPS tracking device. The vehicle also had three cameras installed linked to a computer which recorded images that would allow further evaluation of traffic conditions and therefore recognize free flow conditions from conditioned ones. The data collection, which is now complete, involved eighteen drivers which passed about eighteen times in a set of seventeen road humps in three different locations. The humps were selected for having different geometric characteristics although they were all within normally acceptable values according to the generally acknowledged references on this matter.

Through the use of instantaneous emissions models it is possible to apply instant speed and longitudinal acceleration to calculate instantaneous pollution levels. These values are

essential in evaluation the environmental aspects of using this specific traffic calming device and enable a better understanding of the relationships between road infrastructure characteristics and pollution levels.
This paper will present the methodologies and equipments used on the data collection and treatment phase of this research as well some results showing the speed profiles on the hump surrounding as well as some of the calculated pollution values that characterize the impact of use of road humps.

Keywords: Traffic calming, Road humps, Instantaneous emissions, Air pollution

INTRODUCTION

In the late XIX century 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 using a gasoline engine usually known as automobile. Initially its use was far from practical and it the advantages it had compared to animal powered vehicles were limited. However the fast pace of the technological development quickly changed this situation. The benefits became too obvious to be ignored. The travel freedom it brought was much appreciated. Initially only accessible to the wealthier automobiles soon became cheaper and therefore accessible to a wide range of the population mainly in the North America and Europe.
Fast forward to our days and we find ourselves confronted with several issues that arise from the widespread use of private automobiles. These issues are can be divided in several areas going from land planning aspects, environment issues and safety concerns. The latest aspect usually is caused by the adoption of inadequate speeds by drivers. Therefore the infrastructure has to be designed in order to cope and minimize such situations. In urban areas this is commonly dealt with traffic calming strategies and devices.
As a consequence traffic calming techniques are generally used in critical locations of the road infrastructure where there is a need to assure that vehicles speeds are low or to reduce traffic demand such as in residential areas. They perform therefore an important role in assuring the safety of all road users by making car drivers adopt safer speeds. This is beneficial in many aspects namely in creating a safer road environment for all users and therefore improving the livability of the area where these techniques are applied.
In general terms the selection of the type of traffic calming measure to be used is based on the desired level of speed reduction. Other factors such as the consequences in noise levels or air pollution are normally not considered or are relegated to a secondary role. Consequently the evaluation is incomplete which can result in solving one aspect of the problem but aggravating other essential issues. While in the past this procedure was standard and acceptable nowadays there are tools that allow a broader approach to the problem. In fact due to the consequences of air pollution to human health, the environment, global warming and energy usage the development of evaluation methodologies that incorporate this vital aspect is considered crucial.
The following chapters of this paper will present an ongoing research that has the objective of improving the knowledge on a particular type of traffic calming device: Road humps. This particular measure, which usually is very effective in reducing traffic speeds, is widely used in

several countries. In order to support the research data was collected using an instrumented vehicle. It was provided with several instruments that gathered information on the vehicles speed, acceleration (in the three axes), pitch, roll and yaw as well as its position using a GPS (Global Positioning System) tracking device. The vehicle also had three cameras installed linked to a computed which recorded images surrounding the vehicle and allowing further evaluation of traffic conditions and therefore distinguish free flow conditions from conditioned ones. The data collection, which is now complete, involved eighteen drivers which passed around eighteen times in a set of seventeen road humps in three different locations. The humps were selected for having different geometric characteristics although they were all within normally acceptable values according to the generally accepted references on this matter.

All this information will be used in improving the actual knowledge on the relationships between speed and the geometric characteristics of road humps, the road and its surroundings. It will also have another important application. Through the use of instantaneous emissions models it is possible to apply instant speed and longitudinal acceleration to calculate instantaneous pollution levels. In the case the model selected was the CMEM (Comprehensive Modal Emissions Model) which gives second by second values of emitted values of CO_2, CO, HC, NO_x and consumption (Barth, Feng An et al., 2000). These values are essential in evaluation the environmental aspects of using this specific traffic calming device and enable a better understanding of the relationships between road infrastructure characteristics and pollution levels.

ROAD HUMPS

Road Humps are traffic calming devices that consist in a localized transversal elevation of the road's pavement. They are designed with the aim of changing driver behavior and speed adopted in a particular location. They should be visually conspicuous so that drivers can react accordingly to their presence. They are one of the most used traffic calming devices not only for their low cost and easy implementation but also for being highly effective in reducing traffic speeds and consequently the number and severity of accidents. Their efficiency results from the discomfort that drivers feel due to a severe increase in the vertical acceleration values when they are crossed above their specific design speed (Watts, 1973). Road elevations are generally divided in two groups according with their length (Weber, 1998). The first group usually known as Speed Humps has an elevation between 5 and 12 centimeters and lengths in a 3 to 12 meters range and they can have a circular or trapezoidal section. The second is known as speed bump and has usually 5 to 15 centimeters in height and 0.3 to 1.0 meters in length. Figure 1 illustrates these two types.

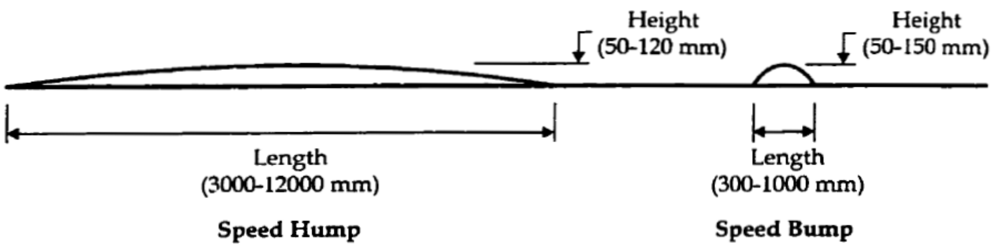

Figure 1 – Speed hump and speed bump (Weber, 1998)

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 (Watts, 1973). It is a section of a cylinder with 3.7m of length and 75 to 100mm in height transversely placed on the road. This profile can be crossed by the majority of vehicles with speeds in the 25 to 30 Km/h range and was adopted by several countries (ITE, 1993; TAC, 1995) including Portugal (DGV, 2004).

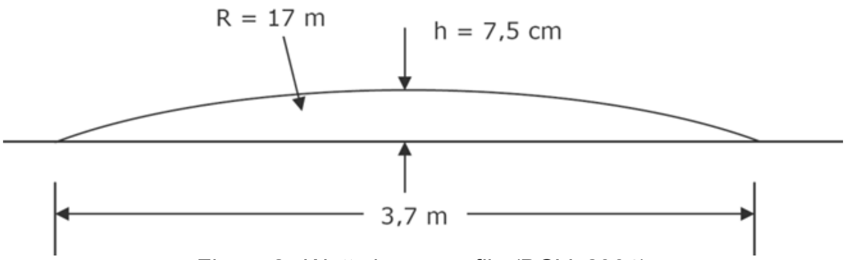

Figure 2– Watts hump profile (DGV, 2004)

This fact has allowed its use with speeds up to 50 Km/h. Since the Watts profile can be too harsh for trucks or higher speeds 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 (Nicodemus, 1991). In this solution a straight section was 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 associated with a pedestrian crossing. In these cases the height of the speed hump is similar to the sidewalk resulting in an added comfort for pedestrians and reinforcing the idea that pedestrians are the preferential users of the urban space and therefore vehicles have to adapt to that reality.

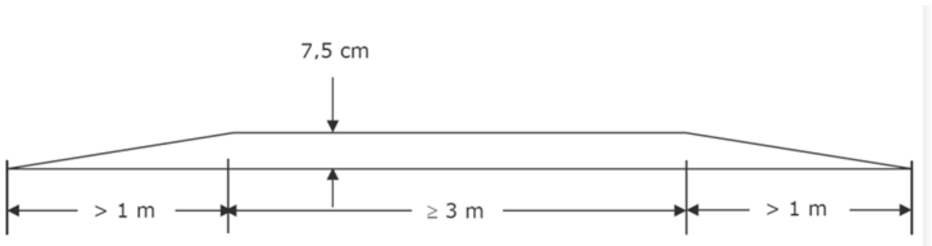

Figure 3 – Trapezoidal or Seminole County speed hump (DGV, 2004)

Several other configurations have been proposed and should be used according to local constraints and the main goal of the traffic calming device.
The functioning 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. This force provokes vertical

acceleration and induces a rotation movement on the vehicles when these have a similar inter axis distance to the speed hump length (Jarvis, 1980). 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 most of the research works.

INSTRUMENTED VEHICLE

In order to gather the data for the research the decision was taken to instrument a vehicle with the appropriate data collection equipment. The instrumented vehicle resulted from a joint effort by 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 (Silva, Bastos Silva et al., 2002).The vehicle used for this task 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. Two independent systems were installed in the car. One had the task of collection the dynamic variables associated with the cars movement the other would record video images of the traffic conditions surrounding the car while it is moving.
The dynamic variable system selected was a Maxqdata MQ 200 RT (Maxqdata, 2007). Briefly this system, which was originally developed to support car competitions, had a collecting unit with a built in three axis accelerometer, a three axis gyroscope, a GPS unit and a connection the vehicle's OBD (On Board Diagnosis System). The variables recorded were therefore the following:

- Longitudinal, lateral and vertical accelerations from the built in accelerometers recorded with a 20 Hz frequency;
- Pitch, roll and yaw (Grewal, Weill et al., 2007) recorded at 20 Hz from the gyroscope;
- Vehicle position, speed, longitudinal and lateral accelerations from the GPS unit recorded at 5Hz;
- Engine RPM (Rotation Per Minute) and throttle position recorded from the OBD. This recording frequency depended on the vehicle's ECU (Engine Control Unit) response which was in the 2 to 3 Hz range (it was not constant).

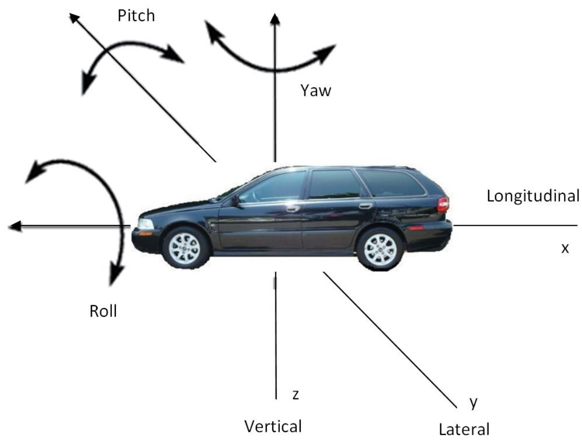

Figure 4 – Pitch, Roll and Yaw on the *x*, *y* and *z* axis

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 (or at least very similar) to the ones felt by the driver. Figure 5 shows the MQ 200-RT unit mounted in the car.

Figure 5 – MQ 200-RT under the passenger seat

The MQ 200 RT unit transmitted all information in real time using the Bluetooth protocol which is quite reliable (Prabhu and Reddi, 2006) to a PDA (Personal Digital Assistant) which recorded it. 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 6 – PDA for data visualizing and recording

As for the image recording system it has three cameras that are strategically positioned inside the car. Basically 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 powered by the car´s electrical system (it needed an extra battery and a power inverter) installed in the trunk of the car. This computer had a Geovision GV800-4 video capture card installed (www.geovision.com) which enabled the recording of all the images (images were 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 the location of the cameras and the computer.

Figure 7 – Computer and support systems in the vehicles trunk

Figure 8 – Computer interface in the back seat of the vehicle

Figure 9 – Lateral and front view cameras

Figure 10 – Rear view camera

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.

THE DATA COLLECTION PHASE

Before starting with the data collection sessions an extensive search for speed humps was made in the central region of the country (due to logistic reasons). The speed humps had to comply to with several requisites that were defined to ensure that their geometric conditions were acceptable and in accordance with the national standards (DGV, 2004) and also that they were appropriately located in the road infrastructure. After this process three locations were selected and identified by local landmarks. One of the locations "Casal do Barril" had four speed humps constructed using a Watts type profile with maximum heights between 0.075 and 0.080 meters. The other two locations identified as “Porto de Mós” and “N110” had a total of thirteen speed humps using the trapezoidal profile showed in Figure 3. Most of these speed humps were associated with pedestrian crossings. In these cases the height of the device had a minimum of 0.05m and a maximum of 0.095m. The total length went from 3.7 to 11.4m and the entry and exit ramps were always 1 meter long.

Figure 11 – Selected test locations

Following the site selection phase a total of 18 drivers were enrolled to conduct the onsite data collection sessions. All subjects 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 three female drivers among them. Similar criteria’s were also adopted in other similar driver behavior studies (Bastos Silva, 2004).

The drivers all had the opportunity to get fully acquainted and comfortable with the instrumented 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 u turn 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 (dynamic variables and video images) 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 in both directions. In total the instrumented vehicle travelled more than 5500Km collecting data.

Figure 12 – Instrumented vehicle collecting data

DATA TREATMENT AND RESEARCH METHODOLOGY

After the data collection phase it was necessary to organize all the files and structure them in a way that allowed and enabled the next steps of the study. This task was accomplished firstly by exporting the dynamic variable data from its native format to a spreadsheet format and afterwards using a set of Visual Basic customized developed applications to reorder and isolate the relevant data.

The next step was to review all the images gathered 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 verified and therefore that particular crossing had to be rejected and suppressed from the data base. Although tedious and time consuming this was an important phase to ensure the quality of the data used in the following stages.

After that phase the environmental data was calculated using the CMEM (Comprehensive Modal Emissions Model) 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 (Barth, Feng An et al., 2000). It has the ability to determine 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 (Tate, Bell et al., 2005). 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 (Höglund and Niittymäki, 1999).
After the pollution data was calculated a video data merging software TrackVision 1.2 (www.trackvision.net) was used to merge some selected data with the video images resulting in a new video which can be useful to aid the analyses since it shows a combined view of the road and the selected relevant parameters. Figure 13 presents an example of this. Since the vehicle's position is also available (recorded by the GPS) using a Geographic Information System (GIS) software it is also possible to visualize anyone of the variables originally collected or calculated by the CMEM instantaneous emission model (see Figure 14) in a color code scale. This is also a useful aid for data analyses.

Figure 13 – Data and video image merged

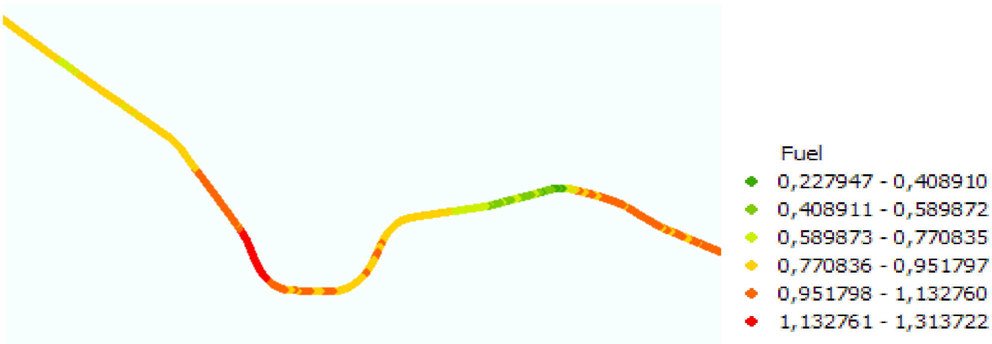

Figure 14 – Fuel consumption along the vehicles path

The next figure illustrates the speed and longitudinal acceleration profiles relative to four passages on the same speed hump. Especially in the speed profiles it is clearly visible that in two passages the driver had its behavior conditioned on the exit. As for the spatial influence of the speed hump the 25 m region before the traffic calming measure seems to be the usual region where the speed reduction starts. Crossing speeds were in this particular case in the vicinity of 40 Km/h. the longitudinal acceleration reached -0.4g on the before the speed hump and climbed to values above 0.1g on the exit.

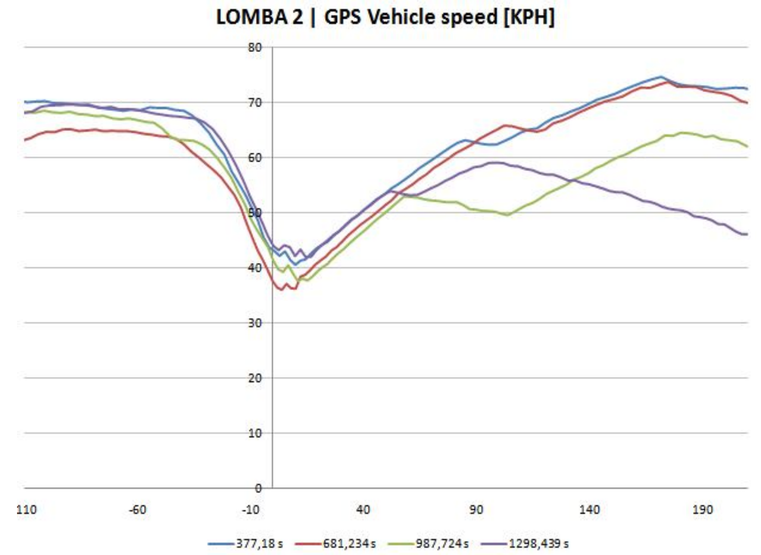

Figure 15 – Speed profiles while crossing a speed hump

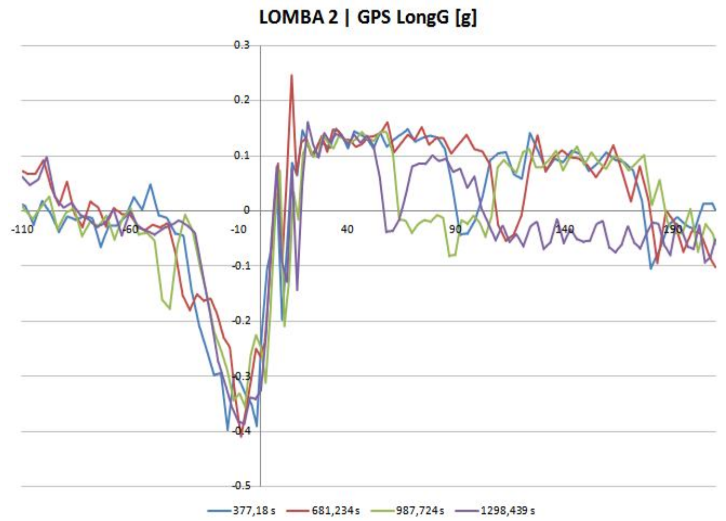

Figure 16 – Longitudinal acceleration profiles while crossing a speed hump

Figure 17 presents the pitch (which is the movement of the vehicle around its lateral axis, or a measure of the degree to which it tilts up or down longitudinally) as well as the CO_2. In the left side the influence of the speed hump is well noticed and manifests itself by a notorious and concentrated swing with similar values on the negative and positive sides of the scale. This is very similar to the behavior of the vertical acceleration. As for the CO_2 profiles they also present some interesting aspects. Firstly and starting from the left (approaching the speed hump) the values decrease and remain low until the speed hump. This is explained by the fact that the vehicle goes from cruising to braking (were the engine is idling) and therefore it's normal that CO_2 values decrease. After the speed hump the driver has a need to accelerate to regain its previous speed and therefore the fuel supply to the engine is increases notoriously and as a consequence so does the CO_2 emissions. In the 50 to 60 m region after the speed humps all passages show a momentary drop in emissions. This phenomenon is due to a gear shift from second to third gear and thus a momentary lack of longitudinal acceleration. As the vehicles moves away from the speed hump the acceleration decreases and approaches zero (cruising situation) and although the speed is higher the CO_2 emission are much lower then immediately after the traffic calming measure. Due to space restrictions the other main pollutants calculated by the CMEM model are not presented here. However they have very similar behaviors. This preliminary analysis clearly demonstrates that this specific type of traffic calming device induces a localized increase in tail pipe emissions which is obviously damaging for the environment. Understandably the global assessment of the speed hump should not focus solely on this aspect but must also take in account the advantages that made speed humps so popular around the globe namely their effectiveness in controlling vehicles speeds and ease of construction. What should be retained is that there is another relevant aspect that is worth considering when evaluating the specific design characteristics of a street or road section.

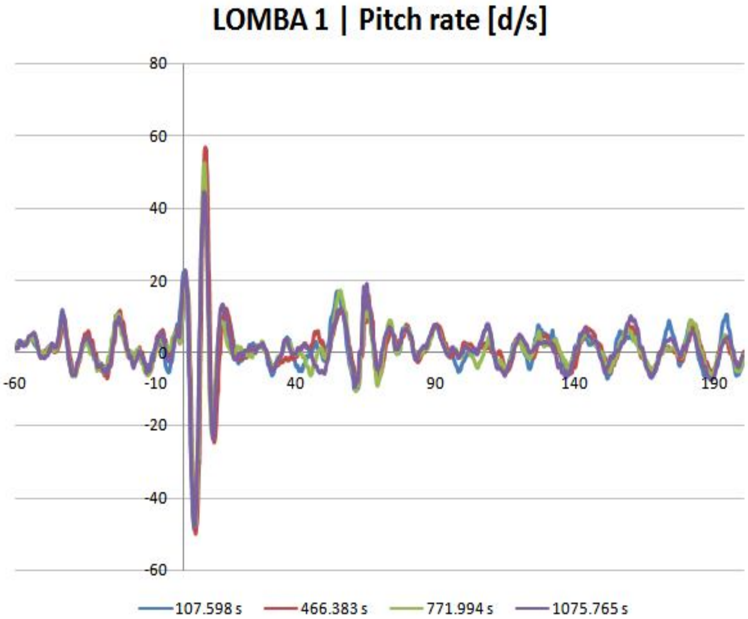

Figure 17 – Pitch rate while crossing a speed hump

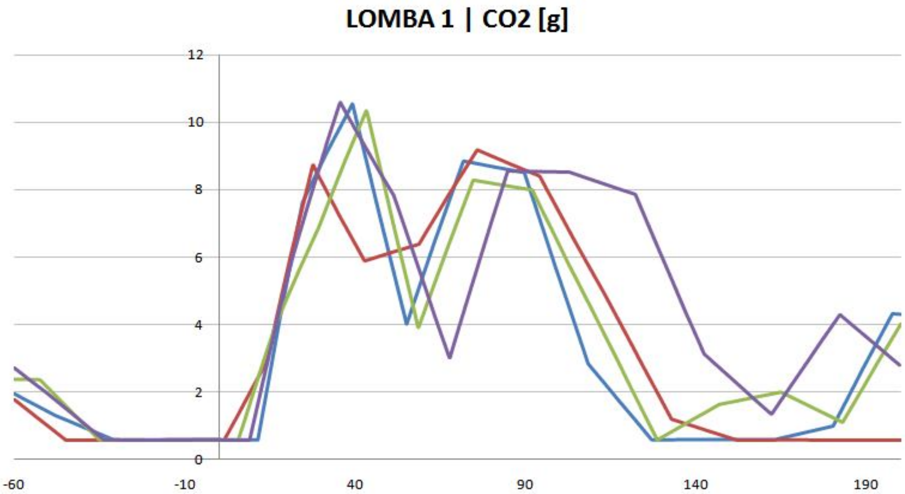

Figure 18 – CO_2 emission profiles while crossing a speed hump

This study is presently in a statistical analyses phase with the main goal of characterizing the driver behavior in the various types of speed humps. Relevant key parameters will be analyzed such as the point where drivers begin to slow down prior to the speed hump, the deceleration values, the crossing speeds, the vertical acceleration values, pitch values as well as the tail pipe emission quantities in the vicinity of the speed hump. These parameters will be compared with the speed hump geometric characteristics as well as relevant road characteristics such as its width, existence of sidewalk and sight distances. Driver behavior will be classified and grouped using variance tests and clustering techniques. Other key aspect of the research will be the development of speed models applied to speed humps which will aid the assessment of its applicability compared to other traffic calming solutions. These models will be developed using regression techniques (linear and non linear) and eventually time series. The environmental side of the equation which sometimes is disregarded will also gain from this study since it will bring new insights on the consequences of speed humps from an environmental perspective.

CONCLUSIONS

Traffic calming techniques are nowadays extensively used all around the globe by road managing authorities especially in urban areas. Their main goal is usually to coerce the drivers so that they adopt their travelling speed accordingly to the road environment conditions and therefore create a better and safer environment for all users in populated areas.

One of the most common traffic calming devices are road humps. This is justified by their effectiveness in achieving a speed reduction and also for being inexpensive and easy to implement. However the common traffic calming device selection procedures don’t take in account the environmental factors that arise after changing the road design. As a consequence the traditional evaluation systems are incomplete and leave out of the equation one critical aspect of the global problem.

In this context this paper presents the basic methodology adopted by an ongoing research work that aims on one hand in improving the current state of the arte concerning the effect of a speed hump on the driver’s behavior and on the other hand in 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 eighteen drivers that passed several times and in both directions trough a selection of seventeen speed humps in three different locations. After the data collection was complete the environmental variables associated with car use namely the CO_2 emitted were calculated using an instantaneous emission model. This is a significant aspect since it enables a better understanding the relations between road infrastructure characteristics and induced pollution levels. So far this methodology has been well adapted to the problem producing a valuable data base that will be essential for the successful fulfillment of the goals set for the next phases.

The research is now in the statistical analysis phase. This will include the improvement of the current knowledge regarding the existing relationships between the geometric characteristics of the speed humps and relevant parameters such as braking points, crossing speeds and vertical acceleration levels.

On the environmental side of the equation preliminary findings show a notorious increase in tail pipe emissions after the speed hump is crossed. This is obviously a negative implication and a setback for their use. However this fact should not be considered in an isolate manner. The assessment should be done considering all relevant implications such as the speed reduction and therefore increased safety levels they achieve. Therefore the current work has the goal to broaden this knowledge so that it can be used in future assessment methods used when evaluating the implementation of speed humps.

This 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 evaluation processes.

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