INFLUENCE OF TRAFFIC FACTORS IN THE SLOPE DESCRIPTOR

ERNESTO ACCOLTI [1,2], LUIGI MAFFEI [1] AND FEDERICO MIYARA [2]

[1] Built Environment Control Laboratory, Second University of Naples, Aversa (Ce), Italy,
lab.rias@unina2.it
[2] Grupo Ruido and Laboratorio de Acústica y Electroacústica, Universidad Nacional de Rosario, Argentina.
eaccolti@fceia.unr.edu.ar, fmiyara@fceia.unr.edu.ar

Abstract – *The Slope descriptor aims to describe effects of noise that are not dealt with by classical energy descriptors currently used in normative and legislation. This descriptor is in state of development and currently has important empirical support that relates it to subjective parameters such as quietness and noisiness. In this article a model for the controlled combination of sound events is used to study the relation between traffic parameters such as flow and percentage of heavy vehicles with the above descriptor for uncongested road traffic. The results may be important for city planning tasks and the method could be applied for studying diverse descriptors responses related to diverse kind of sounds and parameters.*
Keywords: Slope descriptor, music likeness, road traffic, ecological psychoacoustics, soundscape.

Resumen – El descriptor llamado Pendiente busca describir efectos del ruido que no son tratables a través de los descriptores clásicos basados en criterios energéticos como los usados actualmente en normativas y legislación. Este descriptor está actualmente en desarrollo y cuenta con importante apoyo empírico que lo vincula con parámetros subjetivos como tranquilidad y ruidosidad. En este artículo se estudia la respuesta del descriptor frente a parámetros del tráfico rodado sin congestión como flujo y porcentaje de vehículos pesados mediante un modelo de composición controlada de sonido ambiente a partir de eventos sonoros. Los resultados pueden ser interesantes para tareas de planeamiento urbano y el método puede ser aplicado en la investigación de diversos descriptores en relación a diversos tipos de sonidos y parámetros.
Palabras clave: Tráfico rodado, psicoacústica ecológica, paisaje sonoro.

1. INTRODUCTION

The energy descriptors such as A-weighted sound pressure levels are nowadays widely used in normative and legislation in many countries [1,2]. These descriptors can predict a large part of the human response to environmental noise but the remaining variance can also be large in many cases even if the well known corrections for tonality, impulsiveness and low frequency content are used. Psychoacoustic parameters such as loudness, roughness and sharpness [3] are more accurate for estimations of the human responses to noise because they take into account the physiological response. However many psychological factors are also influencing the response and avoiding them causes large dispersion in many cases.

Both physiological and psychological factors are related to the perceptual organization, grouping and selective attention [4] in turn related to the predictability of the time structure of sound. Nowadays effort to understand these structures are addressed by auditory scene analysis and ecological psychoacoustics approaches. The stream segregation in the human system is influenced by both physiological and cognitive levels [4] and the perception of the time structure of sounds may also depend on the time patterns of the different streams. Also the articles referenced in [4] prove that the perceptual organization, grouping and selective attention are mainly related to different levels but some interaction occurs.

Traffic noise is one of the most salient sources of environmental noise in many cities and current developed methods are used to predict energy descriptors [5-7] from the flow rate and the percentage of heavy vehicles among other variables.

The Slope descriptor [8] is an estimation of how the time gaps between consecutive events are distributed. The basis of this descriptor has been related to the self-organized criticality (SOC), brain activity and music likeness, see references in [9] for details. This descriptor has been suggested as estimation of how pleasant or boring is perceived the Soundscape and, based on empirical data, hierarchical clustering techniques have been validated for categorizing places from quiet to disturbed using as characteristic vectors a set of descriptors that include both energy and Slope descriptors [8].

Prediction models of the Slope values from traffic flow data could improve city planning tasks. Furthermore, including the current developed energy descriptors could allow the categorization of different sound environments in order to identify sensible areas even modified areas before modifications were made.

This article addresses a pilot study of how the Slope descriptor depends on the flow and percentage of heavy vehicles for a road traffic stream. This first study does not solve the grouping and selective attention problem but, as a first study, is advantageous assessing only one stream. Even though the stream segregation has a subjective component, traffic noise is widely treated as a category and the subjective streaming can be studied at different levels of meaning transferred by subgroups within a class of sound sources (or a stream). In order to control the traffic variables and avoid sounds from other semantic classes in the sound signals an algorithm for the controlled composition of environmental noises [10-12] is used.

It must also be advised that noise mapping with prediction methods appear not fully realistic in some urban districts if only traffic noise on the main roads is considered [13], instead other streams than just traffic noise sources should be included in future work.

2. RELATED WORK

2.1 Slope descriptor

In general terms, the Slope descriptor [8], similar to the music likeness descriptor [9], is estimated as the slope resulting from a linear regression fit of the log-log spectrum of the energy envelope of a sound. Also psychoacoustic descriptors such as loudness and pitch are used instead of the energy envelope. The model that fits the spectrum *G(f)* of the energy envelope or a psychoacoustic parameter is shown in equation (1)

$$G(f) = A \cdot f^{B} \tag{1}$$

where *A* is the intercept and *B* the Slope.

The useful frequency range current has not reached a consensus. In [8] the range I_1 = [0.02 Hz, 0.2 Hz] is used and in [9] 3 different ranges are used: I_2 = [0.002 Hz, 0.2 Hz], I_3 = [0.2 Hz, 5 Hz] and I_4 = [0.002 Hz, 5 Hz].

The Slope of -1 has been suggested as an optimal condition because it is related to the Slope of music as well as the Slope of SOC systems. In section 3.2 an algorithm for the estimation of the Slope is described.

2.2 Controlled composition of environmental noise

The controlled composition algorithm developed in reference [12] was used to obtain wave files containing traffic noise with different fixed levels of both the flow and percentage of heavy vehicles factors.

This algorithm can be separated into 3 main blocks named semantic content (SC), time structure (TS) and spectral content control. In this article only the SC and TS blocks are used.

The SC control is achieved by choosing a stream from a hierarchical categorization structure. Figure 1 shows a brief of the structure used.

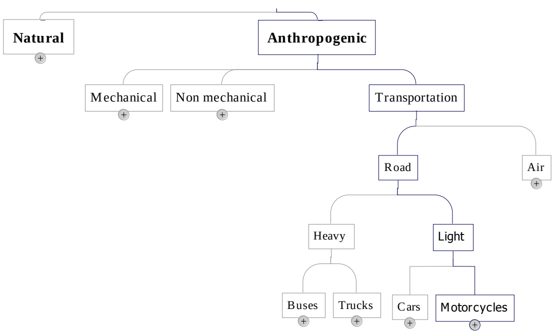

Figure 1: Hierarchical categorization structure
(some categories were removed due to illustration purposes)

The structure continues with the next levels: Mark and model (i.e. some categories are: Chevrolet Cutlass, Honda 125), age, kind of event (e.g. **passby**, door close, etc.), velocity and finally filenames. Each element in the bottom levels of this structure is connected to a sound event that is represented in a wave files database by at least 3 instances. Then the semantic control can be achieved by restricting the database just to the wave files that are below a desired category *C* at any desired level. Also the percentage of events from the categories below category *C* can be fixed using an index vector that points to the desired percent of events of each subcategory in a random basis. Furthermore, the SC system allows adding constrains at any level by choosing the files that belong to an intersection of categories at different levels.

The TS control is achieved by fixing the distribution parameters of the composition for each stream. The composition places a random chosen event *i* (from the group) after a random time interval t_i according to a specified probability density function (PDF) *f* that has a cumulative density function (CDF):

$$F(h_0) = P(h \le h_0) = \int_0^{h_0} f(h)dh \tag{2}$$

Thus, assuming a uniform distributed variable u with probability as in equation (3) in the interval [0, 1],

$$P(u \le u_0) = u_0 \tag{3}$$

equation (4) can be obtained

$$P[u < F(h_0)] = F(h_0). \tag{4}$$

Since F is monotonically increasing, equation (5) can be obtained,

$$P[F^{-1}(u) < u_0] = F(u_0) \tag{5}$$

which proves that $F^{-1}(u)$ has the same CDF and, as predictable, the same PDF of the previously specified f. Then the variable t is easily estimated implementing F^{-1} over a variable u estimated using a random number generator.

A Poisson process was implemented to model traffic without congestion because it may explain random intervals between independent events within a class having a time homogeneous events rate λ. Actually some correlation does exist in real traffic even when no congestion occur and can be incorporated also using experimental PDFs. The correlation frequently is a consequence of the existence of a minimum time interval between consecutive events. Thus a modification of the Poisson PDF allows taking into account the minimum time interval t_s between events. The elements $t_i \mid (t_i < t_s)$ (i.e. elements lower than t_s) are replaced by $t_s \pm \delta_s$, been δ_s a random Gaussian variable with a little variance in comparison with t_s.

3. METHODS AND EXPERIMENTAL SETUP

3.1 Control of factors levels

A total of 80 road traffic signals were composed using the tool described in section 2.2 for studying each parameter resulting in 3 sets of 20, 30 and 30 signals each set. The time length of each signal was 16 minutes in order to estimate the spectrum of the envelope at very low frequencies (about 0.001 Hz).

The first set was composed to study the effect of the percentage of heavy vehicles (PHV), fixing $\lambda = 600$ vehicles/hour, $t_s = 0.3$ s and $\delta_s = 0$ s. The PHV was varied at 4 levels (10, 20, 30 and 40) and 5 replicates were generated. A total of 20 signals composed the first set.

The effect of the events rate was studied at 5 levels (i.e. in vehicles/hour: 260, 545, 830, 1115 and 1400) with 6 replicates giving a total of 30 signals. The remaining parameters were fixed at $PHV = 20$ %, $t_s = 0.3$ s and $\delta_s = 0$ s.

Finally, the effect of t_s was studied at 5 levels (i.e. in seconds: 0.16, 0.65, 1.14, 1.64 and 2.13) with 6 replicates giving a total of 30 signals, fixing $\lambda = 830$ vehicles/hour, $PHV = 20$ % and $\delta_s = 0$ s.

3.2 Slope descriptor

An algorithm that estimates the Slope descriptor (see section 2.1) was implemented for evaluating each signal. Figure 2 shows the block diagram of the algorithm. At first, the time history of the signal is energy averaged in time using an envelope extractor implemented by a first order bass pass filter, with time constant $\tau = 2$ ms, over the square of the signal. In the next step a downsampling procedure decimates the envelope in order to reach a sample rate $F_s = 500$ Hz. The spectrum of the downsampled envelope is estimated using a Fast Fourier Transform algorithm. Finally a linear fit procedure gives the slope and other parameters of interest. The linear fit is implemented over 5 different frequency ranges I_1, I_2, I_3, I_4, and I_5 = [0.02 Hz, 5 Hz].

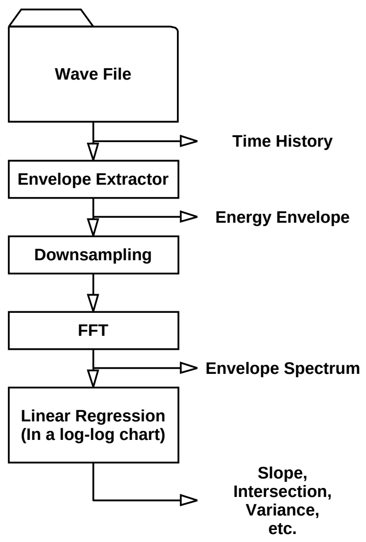

Figure 2: Block diagram of the slope estimation algorithm

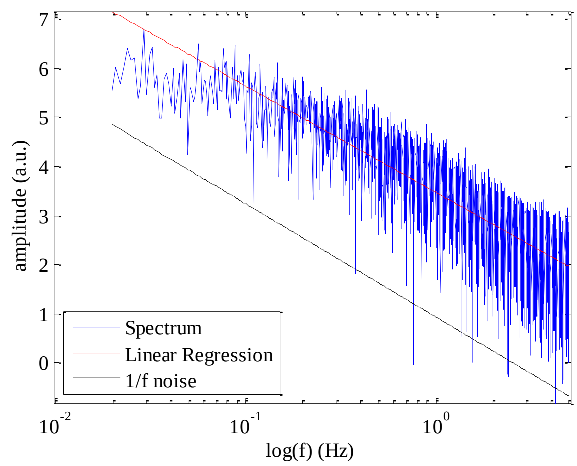

Figure 3: Partial outputs for I_5.

Figure 3 shows the partial outputs of this algorithm. The Envelope Spectrum for an arbitrary signal is shown in blue, the linear fit model in red and a linear model with the expected Slope for a SOC system in black. The Slope for this signal is -0.94, very similar to a SOC system as can be seen in Figure 3.

4. RESULTS

Any effect of the studied factors at the used levels was found for any of the responses (i.e. Slope descriptor at the 5 frequency ranges).

Figures 4-18 show the responses in a boxplot depicting with blue boxes the lower quartile and upper quartile. The black lines show the maximum and minimum. A red horizontal line shows the median where the blue boxes are thinner. The outliers are shown with a red plus symbol when the sample value is grater (or lower) 1.5 times the interquartile range from the upper (or lower) quartile. The black circles show the arithmetic mean and the green line that connects the boxes is a linear regression model estimated by the least squares method.

4.1 Percentage of heavy vehicles

Figures 4-8 shows the aforementioned boxplots for the Slope at I_1 to I_5 ranges, respectively. The varying parameter is the PHV.

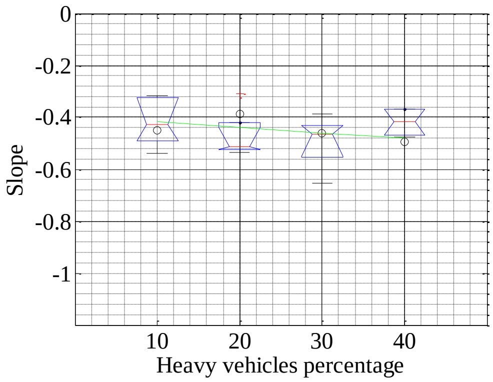

Figure 4: Response I_1 to PHV variations

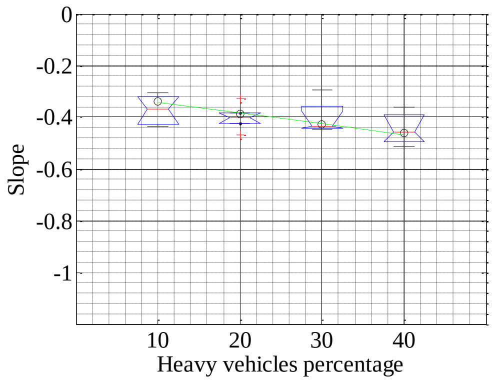

Figure 5: Response I_2 to PHV variations

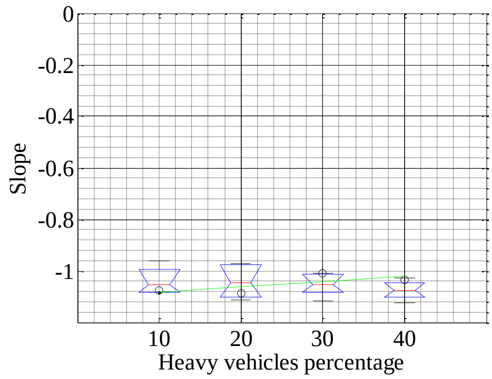

Figure 6: Response I_3 to PHV variations

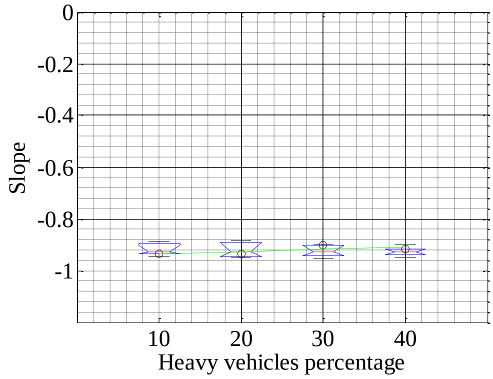

Figure 7: Response I_4 to PHV variations

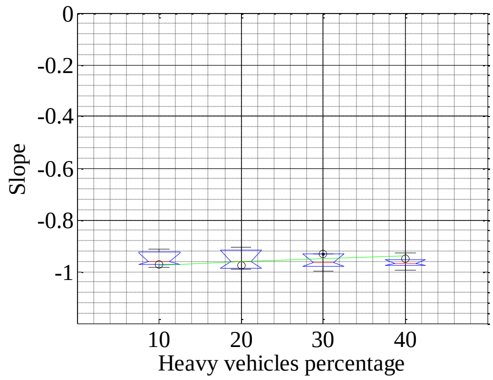

Figure 8: Response I_5 to PHV variations

Even though the model, the means and the averages for range I_2 (see Figure 5) show a little difference between the minimum and maximum levels, the variance is large revealing non statistical significant differences as can be seen from the interquartile boxes. This non significant differences are more evident in the remaining frequency ranges (I_1, I_3, I_4 and I_5).

4.2 Flow rate

Figures 9-13 shows boxplots for the Slope at I_1 to I_5 ranges, respectively. In this case the varying parameter is the flow rate. (Note that the unit is vehicles/second instead of vehicles/hour stated in section 3.1 but the levels are consistent)

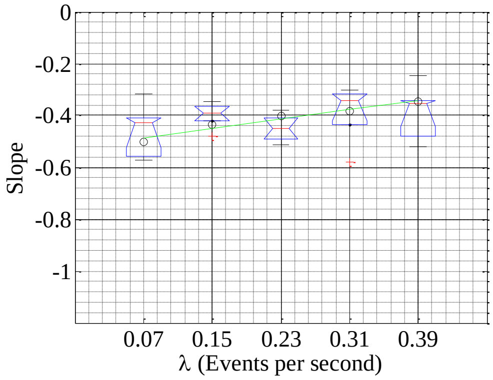

Figure 9: Response I_1 to λ variations

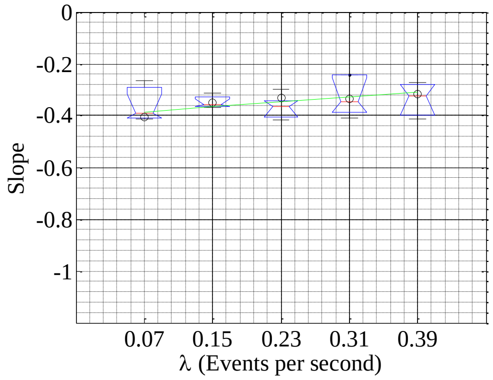

Figure 10: Response I_2 to λ variations

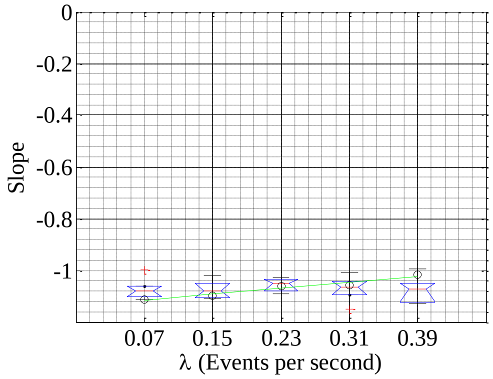

Figure 11: Response I_3 to λ variations

The little differences (particularly large for I_1) caused by varying the flow rate are not statistically significant once again for this parameter as it can be quickly seen from Figure 9-13 (particularly Figure 9).

The results for each range (I_1 to I_5) are not statistical different from the above case when varying PHV.

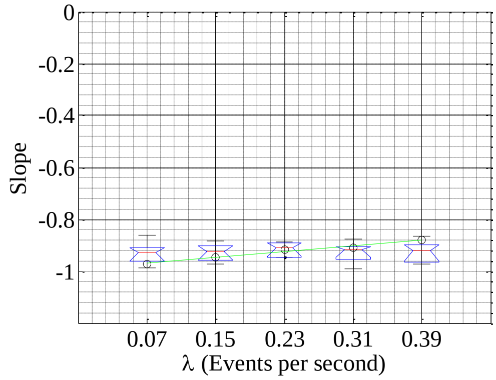

Figure 12: Response I_4 to λ variations

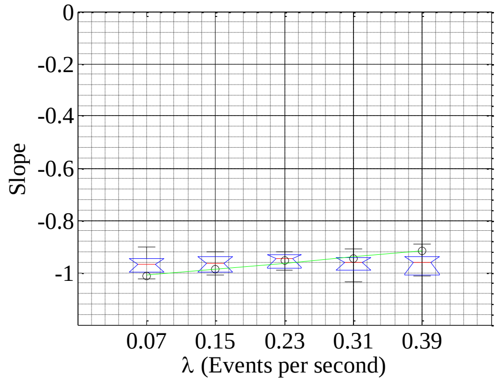

Figure 13: Response I_5 to λ variations

4.3 Minimum interval

Finally, Figures 14-18 show the results for the Slope at I_1 to I_5 ranges, respectively. In this case the varying parameter was the minimum time interval.

In this case the differences in the Slope descriptor are littler than when varying the other parameters. Similar results were found for the deviation of the linear fit in equation (1).

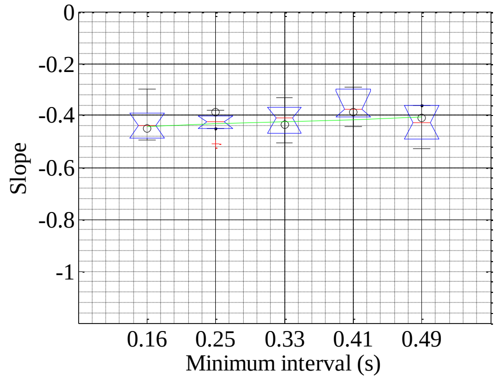

Figure 14: Response I_1 to t_s variations

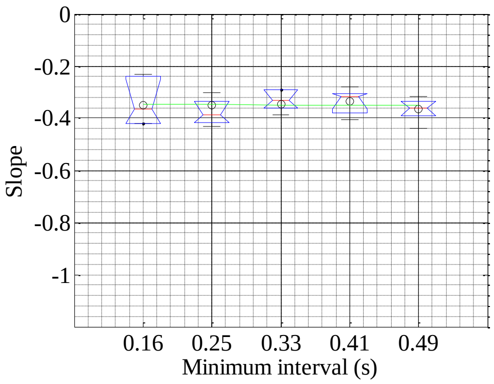

Figure 15: Response I_2 to t_s variations

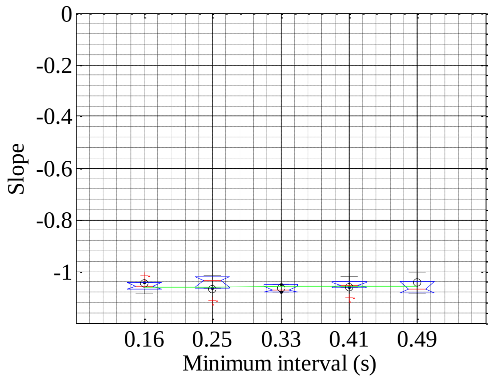

Figure 16: Response I_3 to t_s variations

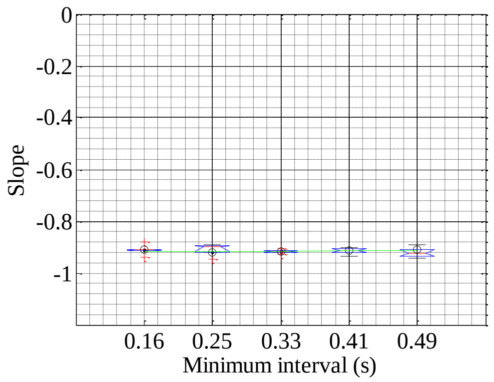

Figure 17: Response I_4 to t_s variations

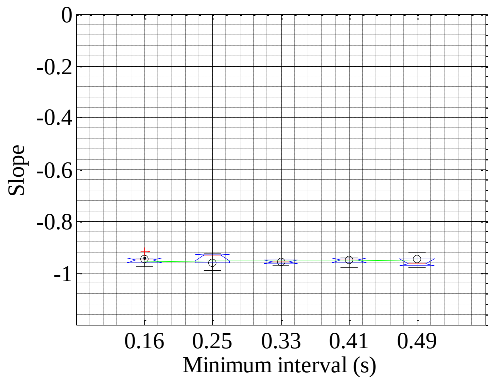

Figure 18: Response I_5 to t_s variations

5. DISCUSSION

Even though not effect was found for the studied variables, it is well known that in real cases some relation exists. This relation does not mean causality as can be drawn from the results presented here and probably from the theory of self-organized criticality. However the flow rate and also the percentage of heavy vehicles can possibly be indirectly related to the Slope jointly with other variables such as the road width, velocity restrictions, the possibility for drivers to change the lane in order to pass other vehicles and others. These variables can be related to clusters or vehicle jams formations that can probably be characterized by some ad hoc variables which can show a direct causality in the Slope descriptor.

The interest in causality is connected to the generalization of the theory in order to develop models that can take into account variables such as road width or velocity restrictions that in turn can be handled by city planning tasks. The results presented in this paper shows that the effort to control the Slope descriptor should be put on variables that characterize jam formations and dissolutions. It should be mentioned that the variables studied here are related to the equivalent level L_{eq} [5-7] that describes a large part of the human responses to noise [14] and should be toke into account in city planning.

The Slope as an environmental descriptor must be studied in relation to other streams. Further work is also needed to characterize the other streams, such as natural sounds, and how they interact with the traffic stream.

6. CONCLUSIONS

Although no direct relation of the Slope descriptor with the studied variables (flow rate, percentage of heavy vehicles and minimum time interval) was found, an indirect relation by mean of congested models has been suggested.

Even though a Poisson process is expected to have a SOC behavior, the studied frequency ranges shows that I_1 and I_2 do not show a 1/f noise behavior for Poisson process simulations of road traffic. Thus the ranges I_3-I_5 are proposed as the required frequency ranges for Slope evaluations. These I_3, I_4 and I_5 ranges are taking into account the time patterns occurring at intervals from 0.25 s, until 5 s, 500 s and 50 s, respectively. It is suggested here that time patterns exceeding 50 s are not important for human perception but exceeding 5 s possibly affects it. Then the range I5 = [0.02 Hz to 5 Hz] is proposed here as the better range (among the studied in this article) for Slope evaluations.

The used tools can be updated for further work in order to take into account empirical probability density functions or process such as traffic jams formation (and dissolution).

ACKNOWLEDGMENTS

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