EFFECTS UPON THE URBAN NOISE OF PRIORITIZING BICYCLE TRAFFIC AT INTERSECTIONS

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ABSTRACT

The term "Smart-Mobility" will probably be commonly used in traffic management in the cities in the twenty-first century. But this concept not only involves issues related to mobility, but also sustainability and efficient use of information technology. In this sense, urban experts have lately paid great attention to the promotion of cycling as a daily mode of transport. This paper aims to explore the possibilities of establishing the right of way to the flow of cyclists at signalized junctions and to describe the consequences it may have on environmental noise. However, this strategy of urban mobility would not have been feasible without the prior development of increasingly more reliable detection technologies of bikes as part of intelligent control systems at intersections. Considering that these intelligent systems have traditionally been used to avoid traffic jams as well as to give priority to public transport, this approach could involve new ways of thinking and imagining the modern city.

This work is developed in a simple arterial where upon it is studied under which conditions these traffic control systems are more or less efficient through the network. For this purpose, a VISSIM traffic micro-simulation model has been applied.

Keywords: Traffic Noise, Bicycle Traffic.

I-INCE Classification of Subjects Numbers: 38.4.1; 52.3

1. INTRODUCTION

One of the most repeated claims regarding sustainability of urban transportation systems stresses that the bicycles should progressively be introduced into the cities as a substitute for conventional transport. The city of Seville appears in the media as an example of successful example to follow of “Smart-Mobility” in Southern Europe. This is due to the promotion of urban cycling by the local and regional authorities. Some figures can help to understand the current situation [1,2]: The total network covers over 120 km of segregated cycle tracks throughout the entire city. On a typical business day, more than 70,000 trips are made along this network (20.000 of which are made using the public bicycle sharing system, and most of these are made by commuters [2]). This means that bicycles make up 9% of all trips (excluding pedestrians). The success is most striking if we consider the evolution of these figures during these last six years which shows they have increased tenfold.

The strategy of the Regional Government of Andalusia [3] regarding mobility consists of introducing this model throughout the region, so that the bicycle becomes a preferred means of transport in urban and metropolitan areas. Although cycling traffic figures for Seville are far from those presented by some northern cities, where certain paths are frequently used by close to 20,000 a day, the fact is that numbers continue to rise in Southern Spain. We wonder to what degree this model that has served to promote the use of bicycles, will be in turn, the reason why cycling is not imposed as the most preferred mode of transport for commuting. Therefore it is necessary to explore new ways of planning and implementing cycling infrastructure that takes into account future traffic demands, especially those during peak hours.

Regardless of the kind of improvements needed to be made in cycling infrastructure local authorities should focus on guaranteeing the improvement of at least three requirements:

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1. The safety of cycling trips [4,5].
2. The environmental health of cycling routes [4].
3. The cycling mobility [5].

Safety is the precondition for the promotion of cycling and also the prerequisite for any demand or proposed solution for mobility and environmental efficiency of urban traffic. Thus, segregated bicycle lanes are the safest and best option for mobility. Unfortunately, the problems arises at junctions [5,6,7,8]. But not all the conflicts are found solely in the physical interaction between different modes of transport. When bikes and the rest of the motorized traffic share the same signal control system, every measure applied into the system with the purpose of improving cycle traffic, has simultaneously, a knock-on impact on the rest of motorized vehicles and vice versa. In turn, these effects cover energy efficiency, environmental health variables and mobility of the entire transportation system. "Smart-Mobility" involves that policy makers should keep a holistic perspective to the transport policy that it is required to manage the balance between all these factors. This study basically focuses on understanding to what degree traffic noise and mobility of motorized traffic on urban roads, are compatible with some steps to improve the quality of bicycle commuting.

From the perspective of traffic engineering, the approach to maximize the cycling mobility at signalized intersections, concerns:

- Improving the average travel time (avoiding delays). This is achieved by minimizing, as far as possible, the time that cyclist must wait at intersections.
- Increasing ride comfort by maintaining continued cycling momentum. This is achieved by avoiding, wherever possible, the number of stops between starting point and destination (without the need for setting a foot on the ground).

From the perspective of noise engineering these signalized intersections are pretty interesting due to anomalies in the emission of noise, compared to that of uninterrupted traffic flow [10,11,12,13]. A non-optimized coordination of traffic light junctions can increase the number and the importance of noisy events in two ways: by number and intensity. All traffic management measures for noise mitigation in these areas has to take into account changes in certain parameters of traffic, specifically speed and driving patterns (accelerations/decelerations).

We have the hope that all requirements can be satisfied by Intelligent Transport Systems (ITS). So, this paper pays special attention to the ability of traffic signal controllers in reducing journey times for cyclists but not at the expense of increasing environmental emissions or excessively penalizing motorized traffic mobility.

2. OBJECTIVES

Firstly, to establish the environmental consequences of some traffic management measures that had proved their benefits in arterials by reducing the number of bikes stops at intersections.

Secondly, to design an actuated signal control that can be the core of signal coordination for arterial that would eliminate the trade-off between traffic noise and travel times for all vehicles through the arterial.

3. METHODOLOGY

The study was carried out with VISSIM 5.4. A micro simulation traffic model was employed, because it is well known that the noise signature at a receiver point of every categorized vehicle in the fleet is a function of the space/time evolution of sound power levels caused by this vehicle. To conduct a micro analysis of noise emissions, we need to properly characterize the uneven traffic flow through the use of the dynamic data (speed and acceleration) from each of the noise emitting vehicles in the fleet. But before this, we need to identify and classify every vehicle class that participates in traffic flow (modes contemplated for noise analysis: car, bus, and motorcycles). This includes a technical break down of every noise emitting vehicle class (engines, tyres, etc.). There is an extensive literature on the estimation of noise emitted by the different vehicle classes in urban traffic, and technical specifications of all these classes [14,15,16]. Nevertheless, others groups have conducted studies that assess the variability of the emissions due to distinctive characteristics of the fleet. This dispersion of results is more important when the Lmax is evaluated for noise action plans purposes [17,18].

On the other hand a realistic vehicle kinematic pattern depends on how VISSIM simulates a credible model of actions and interactions between vehicles and how it resolves conflicts between them. Each vehicle is modeled individually updating its position, acceleration and velocity using behavioral models based on statistical information: reaction times, safety distance between vehicles, gear choice and decision on lane changes. This is why micro-simulation traffic models should be used, which can generate the above-mentioned information in a discrete time steps, usually lasting 1 second. We use this data to estimate the noise power per meter using MATLAB.

VISSIM also includes a traffic control block that contains all elements required to control the traffic at a signalized junction. This control block encloses the rules to govern the traffic at junctions. In the case of static control, the logic can be defined easily, but users may design actuated control with the VAP (Vehicle Actuated Programming) module allowing arbitrary logic creation using information provided by detectors.

3.1 VISSIM layout, traffic data and parameters of simulations

The following methodology is consistent with previous studies [13,19]. The layout designed for that purpose consist in a simulated straight E-W arterial road with 1,400 meters in length. This main avenue has 4 lanes; 2 per carriageway for motorized traffic in both directions, with a fixed width of 3.5 meters and a segregated single bike lane with a fixed width of 3 meters. The bike lane width is large enough to allow for continuous free overtaking even in high occupancy situations. It has been incorporated into the simulation only the corridor W-E. Both bikes corridors W-E and E-W (not drawn) will be the most demanded as a function of the hour of day (for example, toward the city financial area or to the University Campus, the peak hour in this direction is most likely to be between 8.00 and 10.00 a.m.). There are 5 intersections regulated by traffic lights. These intersections are separated every 200 meters. In summary, the study focus on the stream of vehicles (motorized and bicycles) moving together in the main artery in W-E direction (forward traffic flow). A simplification is considered since all we expect to learn from these experiments is the relationship between traffic lights planning, traffic noise power and mobility issues.

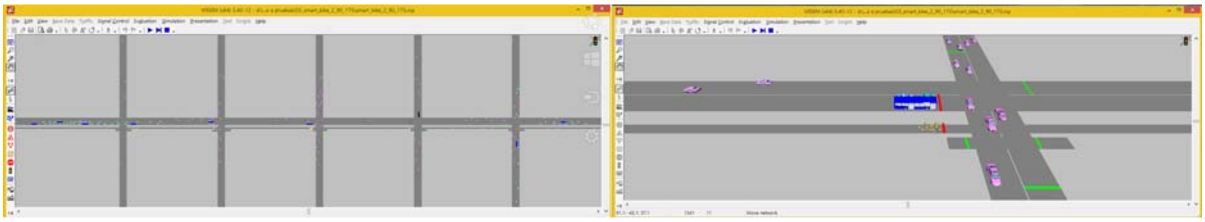

Figure 1 Overview of the computer-generated artery and its five intersection.

Whether isolated intersections or arterial roads, all that traffic engineering seeks is the highest efficiency in the movement of vehicles. Thus, the goal along the arterial axis is to set the appropriate length of each traffic light cycle, the best deal of cycle time for each of the phases and the correct synchronization of all traffic lights. Thus coordinated control allows a green wave (green platoon) to occur when the offset between traffic light are set to create them. The offset is defined as the delay in the start of cycles of each intersection in the arterial, respect to a reference intersection. We call this reference traffic light (the most westerly): "the feeder".

The performance of the arterial is usually evaluated using Level of Service (LOS) indicator. LOS can be defined as the measure or estimation of the quality of operational conditions within the road traffic stream. It is necessary to take into account that the LOS indicators have been estimated for the first traffic light in the arterial avenue for motorized traffic. If the green wave is well designed, the capacity of the rest of the arterial remains the same. That is the reason we plan to measure the variables included in this study only along the 1,000 meters behind the feeder. For our purposes we can consider LOS as the ratio between demand (D) and capacity (C) of the first junction. To determine this, the first parameter to be estimated is the capacity of the road, a value that can be calculated by following different ways [20,21,22], including the following:

$$C = N \bullet S \bullet V / T_{ciclo} \qquad (1)$$

Where C is the capacity (vehicles/lane/hour); S is the saturation intensity (vehicles/lane/hour); N is the number of lanes; V is the effective green (s) and Tciclo is the time cycle length (s). The traffic light cycle used in this study varies from 60 to 90 seconds. Effective green must remain constant, and is set for this work in 0.5 (neglecting the reaction time to red-green shift is usually set at 2 seconds). The key is to establish a pragmatic "S" factor [21] which depends on the number of lanes, lane width, heavy vehicle composition of the fleet, weaving, slopes, behavior of the drivers (cities with disciplined traffic patterns or undisciplined), the weather, etc.

A green wave is scheduled in this artificial avenue with the two LOS defined for motorized traffic. First one D/C = 0.40 (free flow) D = 375 v/l/h, and second case D/C = 0.80 (near saturation) D = 750 v/l/h [20]. Defining maximum demand for D = 1,500 v/h proved to be a pragmatic figure consistent with expectations for the VISSIM simulation.

The green waves are programmed using two plans. The first is designed for motorized traffic using the maximum legal speed limit of 50 Km/h. The second plan is designed for cycling. In this case we consider green waves designed for a range of velocities: from 15 Km/h to 25 Km/h. Eventually the speed of 22.5 Km/h is selected for several reasons. Lower speeds do not make sense for commuting. A platoon of bikes with an average speed of 22.5 Km/h is consistent with the specifications provided by builders of electric pedal assisted smart-wheels. Safety reasons recommend that measures incorporated can assist bike riders with up to 25 km/h. Once the rider goes over the 25 km/h the assistance stops. There are some experiences around the world for the coordination of cycling stream traffic though important arteries of urban areas through the use of traffic control systems. This means surfing green waves through a couple of kilometers giving access to the crowds of riders to the points of attraction at downtown during the rush hour. There are some examples of success in Copenhagen, Amsterdam, San Francisco, New York, etc [23,24,25,26]. Maintaining the correct bike speed can be achieved in different ways, the most innovative is the use of lights along cycle lanes and showing where the cyclist wishing to reach the next green have to be situated, which allows riders to adjust their pedaling pace to 22,5 Km/h.

Regarding motorized flow in Southern Spain this can be gauged by taking into account three types of car's driver behavior [27] that can be included as 3 "ad hoc" categories of cars: "calm" (15%), "normal" (65%) and "aggressive" (15%), and also buses (5%). This distribution has a deep significance in how platoons are created and how they behave along the green waves. These categories deal generally with several interrelated issues to include in VISSIM simulations:

- Large accelerations, the use of low gears and sometimes associated with high-powered vehicles. Or on the other side, progressive acceleration in long, own eco-driving gears.
- Haste that relates to a higher or lower than the maximum desired speed of the track.
- Time of reaction to a green light, that impact on the effective green.
- Spacing (headway).
- Overtaking behavior.

These percentages are drawn from experiences in municipalities in the province of Cadiz and they need to be compared.

The last studied scenario came from solutions provided by ITS. The regulation of the flow of vehicles takes place within actuated traffic signal controls that use sensors to detect the downstream flow of bikes approaching the traffic lights. The detection introduces changes in (preprogrammed) existing fixed phases after the detection of a bike (or a predefined number of bikes). ITS incorporate a logic that ensure the overall efficiency of the junction (motorized traffic included). It could be applied only in critical situations, like high flow cycling, bad weather situations, etc. The potential disadvantages for the motorized traffic need to be stablished.

VISSIM includes a signal control model that can use detector values to decide on the current signal state. Signal control can be performed by the VAP (Vehicle Actuated Phasing) programmable signal control software [28]. The characteristics of the simulation include several aspects to consider. First, the arterial feeder is set at a fixed time control with a cycle of 60 seconds and with a ratio between red/green equal to 30/30. The control strategy is based on a similar design as cases 1 and 3 with the same offset and a cycle of 60 s. So the green wave is planned for motorized traffic, but with the particularity that the green (the minimum green time) is set to 20 s. The maximum green time for this major arterial is set to 40 s. Prioritizing bicycle traffic will launch between traffic signals number 2 to number 5, mainly by the use of green extensions and red truncations (early green). Vehicle Actuated (VA) signal control performs independently in each junction. Each VA signal control use cycling information obtained from detectors allocated in bike lane at the upstream the traffic signals. This information is related with the traffic profiles of bikes approaching the traffic signals. With these parameters there are some different manners to program the logic that manage the decision of extend and recall the green. In this paper is showed the most balanced between mobility and noise.

Table 1 – List of simulation study cases

Case nº	Demand Motorized	Demand Bikes	Arterial D/C	Cycle length (s)	Signal Control Type	Off-set Green Wave
1	1500 v/h	500 v/h	0.8	60 to 90	Fixed	50.0 Km/h
2	1500 v/h	500 v/h	0.8	60 to 90	Fixed	22.5 Km/h
3	750 v/h	500 v/h	0.4	60 to 90	Fixed	50.0 Km/h
4	750 v/h	500 v/h	0.4	60 to 90	Fixed	22.5 Km/h
5	750 v/h	500 v/h	0.3-0,4	60	VA	50,0 Km/h

3.2 Noise emission model

A code for the estimation of noise power per meter was written in MATLAB. The variables considered for the calculation of noise emissions that must be referred to the instant "t" of the simulation [10] are.

1. Class of vehicle concerned
2. The instantaneous vehicle speed
3. The acceleration or deceleration of the vehicle
4. The position of the vehicle.

When acoustically classifying vehicles regarding Table 1, there are only two classes: buses (type 3 "Harmonoise") and car (type 1 "Harmonoise"). Once generated the emission model, the determination of the noise in a point or in a grid (noise map) is generated by a propagation model using a digital geometry model. The propulsion sound power is defined by the known equation for calculate the engine sound power (2) and the rolling noise power (3) in dB(A):

$$L_{W\,P}(f) = A_P(f) + B_P(f) \bullet \left(\frac{v - v_{ref}}{v_{ref}} \right) + C \bullet a \tag{2}$$

$$L_{W\,R}(f) = A_R(f) + B_R(f) \bullet \log_{10}\left(\frac{v}{v_{ref}} \right) \tag{3}$$

We will not expand on explaining the equations as there is extensive literature that makes, for example [10]. Saying "Ap", "Ar" and "Bp", "Br" are coefficients that change for each frequency band in octaves and vehicle category. The reference speed "vref" is 70 Km/h. There is also an acceleration correction is incorporated in the engine noise is (increase or decrease in dB) equals "C × a", where "C" correction coefficient associated with each class of vehicle acoustics and "a" is the acceleration in m/s2. Equations (2) (3) may be associated with a term + ΔLW, Pr (v) that accounts for the variability of noise in reference to the condition of the car in certain regions and the effects of the road [17,18].

4. ANALYSIS AND RESULTS

The following graphs show the comparison between cases 1 to 5. All the results are referred to the composition of 10 snapshots of 30 minutes created in VISSIM with different random seeds. The distribution of vehicles is random but the sequencing of vehicles entering the artificial road is always the same in the cases with the same demand and the same random seed. This allows for a more accurate comparison

4.1 Noise Power along the artery

The arterial is represented as a line source. The graphs thus represent the time averaged A-weighted sound power emission per meter along the ordinate and the abscissa axis quantifies the distance in meters along the arterial from the feeder (400 m.). Just remembering that the rest of the traffic signals on coordinated junctions are located at 600 m, 800 m, 1,000 m and 1,200 m. We focus on cases with the same traffic demands (cases 3 to 5); and the same cycle (60 s) for allowing the comparability.

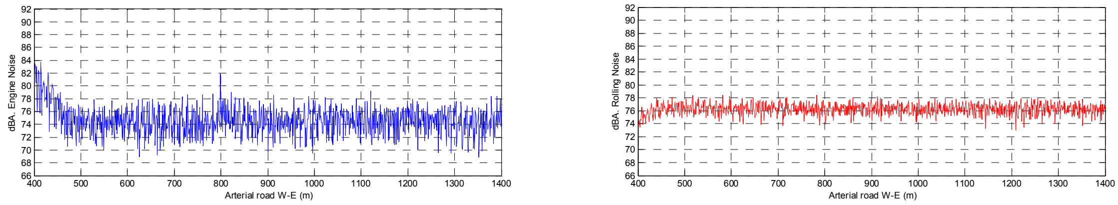

Figure 2 – Case 3. Spatial behavior of the propulsion noise power per meter (in blue) and rolling noise per meter (in red) along the coordinated group of traffic signals and averaged over the simulation time.

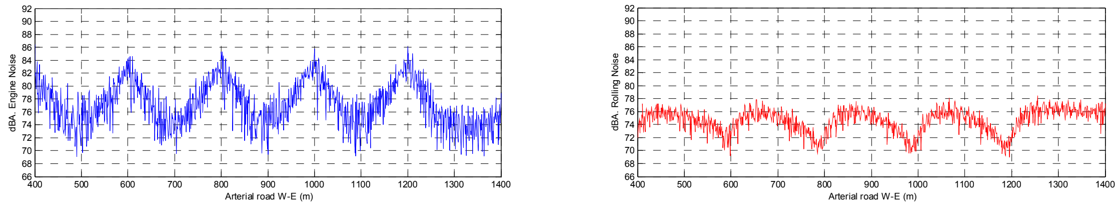

Figure 3 – Case 4. Spatial behavior of the propulsion noise power per meter (in blue) and rolling noise per meter (in red) along the coordinated group of traffic signals and averaged over the simulation time.

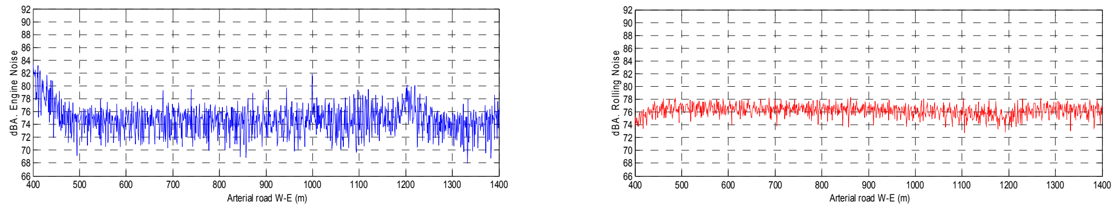

Figure 4 – Case 5. Spatial behavior of the propulsion noise power per meter (in blue) and rolling noise per meter (in red) along the coordinated group of traffic signals and averaged over the simulation time.

Table 2 – List of simulation results

Case nº	Distribution of data of sound power level per source line meter of the road emission for motorized vehicles				Cycle (s)
	Arithmetic mean for the 1000 m of arterial		Maximum values		
	traction component	rolling component	traction component	rolling component	
Free run	74.2	76.6	79,2	79	Open
3	74.6	76.2	85.8	78.5	60
4	77.2	74.6	87.4	78.4	60
5	74,8	76	83.3	78.9	60

4.2 Mobility figures along the arterial

The abscissas axis of the following graphs represent the travel times along the arterial counted from the feeder (400 m.). The ordinates show the percentage of vehicles (or bikes) per time class.

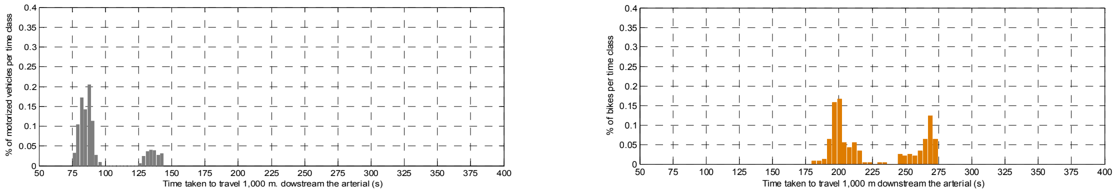

Figure 5 – Case 1 Motorized traffic travel times on the left and bikes travel times on the right. Cycle 90 s.

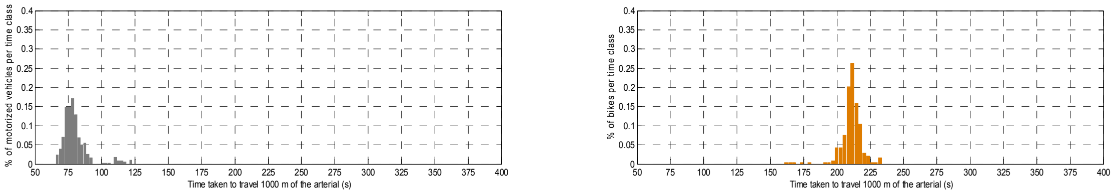

Figure 6 – Case 3 Motorized traffic travel times on the left and bikes travel times on the right. Cycle 60 s.

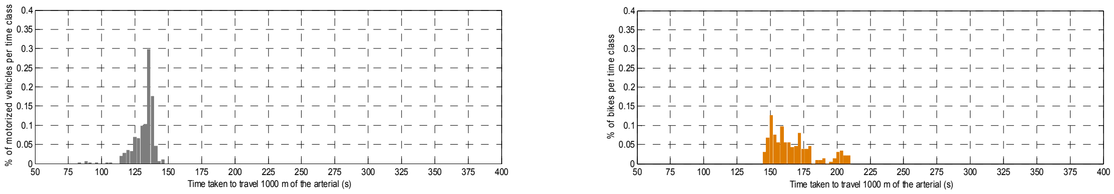

Figure 7 – Case 4 Motorized traffic travel times on the left and bikes travel times on the right. Cycle 60 s

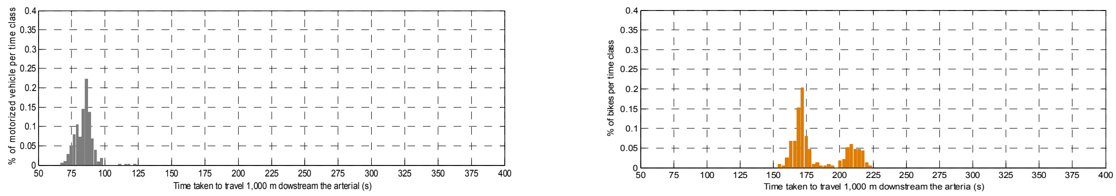

Figure 8 – Case 5. Motorized traffic travel times on the left and bikes travel times on the right. VAP.

Table 3 – List of simulation results

Case nº	Bicycle travel times (s)		Motorized modes travel times (s)		Cycle (s)
	Mean time to complete 1000 m of arterial	Standard deviation	Mean time to complete 1000 m of arterial	Standard deviation	
Free run	160,1	7,4	74,7	5,3	Open
3	210.6	8.7	80.1	9.9	60
4	166.8	17.2	131.7	8.3	60
5	182.6	19.3	85.1	6.6	60

4.3 Discussion

Most of the work on detection of traffic variables and actuated traffic signal control is performed at intersections where conflict occurs between the demands of traffic flows coming from the legs of such intersection. Obviously the conflict caused by incompatible movements through the intersection needs to be regulated. However, in this given case, there is no physical interaction between vehicles, and the conflict show up between vehicles that share the same direction and phases of the signal control system (any safety signal for cyclist was not considered.). The problem is that the two bandwidths (bandwidth is defined here as “the amount of green time used by a continuous moving platoon of vehicles through a series of intersections” [21]) diverge more and more which causes that cannot match simultaneously with any fixed time signal control schema. How to coordinate the traffic flow when slower vehicles should be prioritized, it is solved here with an actuated signal control planning that activate green extensions (and red truncations) when more than 4 cyclists are detected (per unit of time) approaching the intersection.

The research is still underway and this line of work will continue ahead, because the results, while not spectacular in terms of noise reduction figures, are promising; and the improvements in travel times are tangible. The ongoing study is ready to further explore the following working areas: the incorporation of more sophisticated signal control systems, the estimation of other environmental variables and the construction of increasingly complex networks. All these things will allow to understand the problems related to priority of bicycle traffic on a more realistic scale and thus provide holistic solutions.

5. CONCLUSIONS

A vehicle actuated traffic signal control system has been programmed to manage a traffic coordination along an arterial road composed by five signalized intersections, using VISSIM + VAP traffic micro-simulation software. The program is designed to use the information of density of cyclist approaching intersections within bike lane. Thus ensuring a commitment to control traffic noise and improve travel times of bikes, but not at the cost of penalizing the figures related to mobility of motorized traffic. Reference figures to compare the quality of solutions are those associated with the respective green waves designed for continuous traffic of bicycles and motorized modes (cases 3 and 4).

ACKNOWLEDGEMENTS

The authors wish to thank the European Regional Development Fund (ERDF), the financial support for the project: "*Eco-Bici*" received through the "*Programa Operativo FEDER de Andalucía 2007-2013*". We also would like to thank the staff and researchers of the Agency of Public Works and the Ministry of Development and Housing of the Regional Government of Andalusia, for their dedication and professionalism.

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