SMART MOBILITY STRATEGIES BASED ON BUS SIGNAL PRIORITY FOR NOISE REDUCTION

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Abstract
Probably, the promotion of public transport has been one of the measures to urban noise in which local administrations have placed more expectations, but whose implementation hasn’t had the same success everywhere. Fortunately, today's technology can give us the opportunity to start providing integrated and innovative solutions that contribute to increasing public transport demand. This paper considers different prioritization systems of public transport (TSP or Transit Signal Priority) that adapt the changing traffic conditions. VISSIM microscopic traffic simulation is used to test different traffic solutions involving ITS (Intelligent Transport System) technologies and check their effectiveness in different simulated settings. Thus, the aim of this work is to develop strategies for prioritizing buses for each situation, taking into account the balance between the environmental noise and mobility.

Keywords: traffic noise, smart mobility, traffic microsimulation systems.

PACS no.: 43.50.Lj 43.50.Rq 89.40.Bb

1 Introduction

European cities face daily to old and new problems that play an important role in the development of any modern city. Mobility and environmental pollution under constant urban sprawl are two of them. The hope in their total resolution is based on future substantial changes affecting how the citizens perform their daily activities and the technological achievements. In the meanwhile, we put the focus on small advances that can improve the solutions to achieve more habitable and sustainable cities regarding how to reconcile transportation and environment. Not surprisingly, all of us could be considered responsible for the problem, since in transportation is sustained much of the economic activity and our way of life. This paper revolves around smart mobility or, in other words, how transport and information and communications technologies (ICT) can combine to enhance the quality of life of the urban inhabitants.
Promotion of public transport is repeated as a mantra in all manuals, reports, and best practice guidelines for policy makers to mitigate traffic noise and air pollution, (for example [1] [2] [3] [4]), and to improve mobility relieve traffic congestion in urban areas (for example [5] [6]). This interdepartmental synergy is an added attractive characteristic that any local government takes

seriously into consideration, being one of the favorite measures for urban noise action plans in Europe [7].
It is well known that the effectiveness of noise solutions by reducing the traffic volume depends on the proportion of traffic removed as long as the rest of characteristics of traffic flow remains the same (% of heavy vehicles, speed distribution and driving patterns, mainly) [8]. “Getting people out of cars” is the motto. To persuade the usual drivers to leave their cars at home a combination of carrot-and-stick measures should be applied. On the positive stimuli side, we can find noise measures like the renewal of public transport introducing low-noise buses [2], extending the bus transit network, enlarge the schedule of public transport, and decrease ticket prices [3]. On the other hand, in the part of negative stimuli, we can find measures based on restriction and totally ban to access with the private car to the city center, parking restriction, etc. This study has focused on those aspects of the promotion of public transport based on infrastructure measures designed to reduce the travel times of public transportation with:

- The redesign of road space by installing segregated lanes for buses [2] [3].
- Strategies for prioritization of buses in intersections through the optimization of traffic lights in a single intersection or in a corridor. ITS technologies applied to transit signal priority (TSP, also known as BSP when employed in bus lines) is found to be low cost and effective ways for enhancing public transit systems [9].

TSP can provide the right of way to buses in response to real-time traffic and transit conditions. TSP modifies the existing signal plan to provide priority to transit in lonely signalized intersections and big arterials. Traditional TSP strategies [10] supply early green (red truncation) and green extension to the normal traffic signal sequence. One of the concerns of traffic engineers is to find a compromise between transit priority and the capacity of the designed network [11]. A good TSP strategy can assure a better schedule adherence. If the transit vehicles are able to move smoothly and with the least possible number of stops along the corridor, then, this effectiveness will also benefit the rest of vehicles following the priority buses [12].
Finally, a microscopic traffic simulation model (VISSIM) was used for predicting transit and cars travel time along an intersection proximity. For a more realistic approach for vehicles crossing the different types of intersections and networks, the interactions of vehicles have to be taken into consideration. This is the reason that commonly it is used these traffic micro-simulation software, to generate all the traffic information needed for the time/space evolution of noise [9] [13] [14] [15] [16] [17] [18] [19] [20]. The performance of proposed TSP strategies was evaluated through application to a hypothetical road network through the comparison with other normal signal operation.
This paper explores how the use of intelligent infrastructure technology for smart mobility can contribute to creating sustainable cities, improving the attractiveness of public transport, without impairing the other road users and never at the expense of increasing the traffic noise.

2 Methodology

VISSIM [21] is a behavior-based microscopic traffic flow simulation environment that includes different modes of transport. VISSIM enable us to manage public transit operations in different scenarios and analyzes their impact on the traffic flow patterns and mobility. We use VISSIM for two main reasons:

1. Its capacity of generating traffic data like the type of the vehicles, speed, acceleration/deceleration, position in every second etc., shows the potential of VISSIM for an accurate estimation of noise emissions [22]. The quality of the results depends on the realism of the vehicle behavior (actions and interactions of every vehicle within the traffic flow).

2. VISSIM has proven to be a valuable tool to test traffic signal control schemes including bus actuated signal control strategies [23]. Actuated Signal Control is defined as “a type of signal control where the time for each phase is at least partially controlled by detector actuations” [24].

In order to perform the simulations, we have created a theoretical network to test various traffic scenarios (Figure 1).

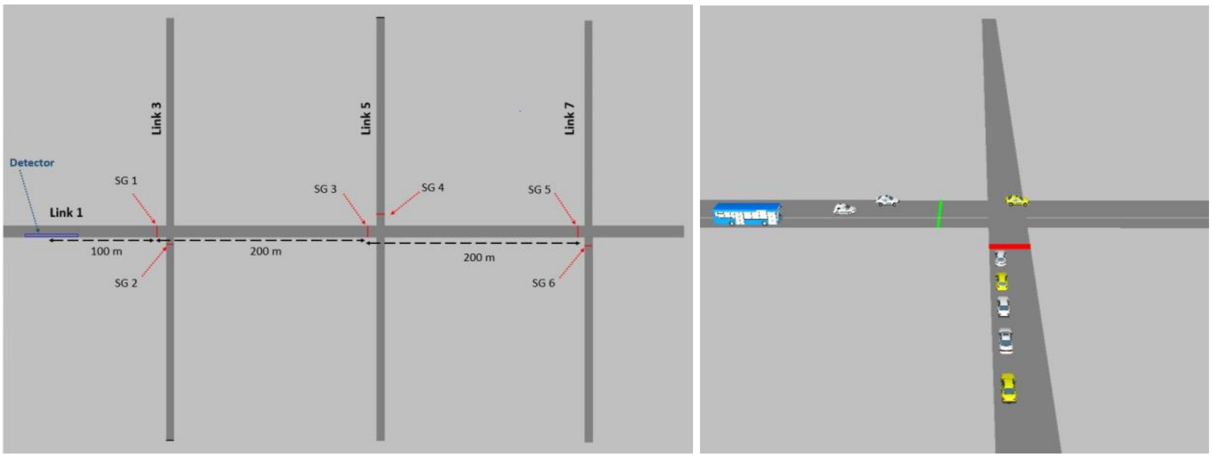


Figure 1 – VISSIM capture of the simulated network.

The layout of the network was created with the following requirements:

- The arterial (Link 1) is designed with three junctions. These three intersections are regulated by a traffic signal control system (SC) that consists of 6 signal groups (SG) two per junction [21]. In some traffic engineering literature, signal groups are usually referred to as signal phases.
- Link 1 is composed by 3 lanes with the vehicles driving in the E-W direction. The right lane of the road is a bus-lane, leaving the remaining two lanes, to the private cars (in one of the scenarios Link 1 has only two lanes with mixed traffic). The stretch of Link 1 under analysis is extended over 1000 meters length.
- Bus demand in link-1 remains the same in all cases: 60 buses per hour.
- The secondary roads, Link 3, Link 5 and Link 7 have 400 meters length by each and just two lanes and vehicles circulation in the N-S and S-N direction. Link 3 has a dedicated bus lane while Link 5 has a mixed traffic on both lanes (Link 7 is out of test).
- All lanes width is 3,50 m.
- The traffic composition includes only private vehicles and buses (shown in Table 1). The links 3 and 5 conserve the same figures during all simulations, that is to say: 475 vehicles per hour, of which 12 are buses.
- Driving behavior for the private cars is divided into three categories: calm 15%, normal 70% and aggressive 15% [9].
- The simulation time considered was 1 hour with a simulation step of 1 s.

Table 1 – Bus priority in link 1. Scenarios studied.

Case	Link 1 design	Car demand	Base cycle time	Green split	Traffic Control Logic along the corridor
1	2 lanes + 1 bus lane	950 v/h	60 s	Variable	TSP-1
2	2 lanes + 1 bus lane	1900 v/h	60 s	Variable	TSP-1
3	2 lanes for mixed traffic	950 v/h	60 s	Variable	TSP-1
4	2 lanes for mixed traffic	1900 v/h	60 s	Variable	TSP-1
5	2 lanes + 1 bus lane	950 v/h	60 s	40 s	Green Wave-1
6	2 lanes + 1 bus lane	1900 v/h	60 s	40 s	Green Wave-1
7	2 lanes + 1 bus lane	950 v/h	60 s	30 s	Green Wave-2
8	2 lanes + 1 bus lane	1900 v/h	60 s	30 s	Green Wave-2
9	2 lanes for mixed traffic	950 v/h	60 s	Variable	TSP-2
10	2 lanes for mixed traffic	1900 v/h	60 s	Variable	TSP-2

We also simulated a free flow scenario for each link just for comparison. In this case, the traffic circulates free, without any rule. Green Waves are quite used nowadays to improve the mobility in cities. In this case, not just the buses, but all the vehicles meet with the green light of the traffic signal, so they don´t have to stop at all traffic lights. This model implies calculating a specific time in which a car crosses a road section in order to meet with the green light. The time is calculated considering the speed, and the distance between the traffic signals on a boulevard. The only traffic light where the vehicles could stop is the first one. TSP1 and TSP2 are explained in the next section. Cases 3 and 4 have been included to see if TSP programmed regulation is enough to solve the problems removing the bus lane. In this way, the space saved could be used in bicycle lanes, parking, expanding sidewalks, etc.

2.1 Traffic signal controller's logic for bus priority developed in VAP

VAP (Vehicle Actuated Programming) is a signal controller language to build scripts that used to run custom signal operations in VISSIM [25] [26]. VAP executes the control logic commands for the VISSIM network during simulations and testing. The core of VAP programming is based mainly on three commands: the conditional loops "If-then-else-end", the "goto" jump command and the assignment of values to variables ":=". The TSP control logic depends on information provided by detectors. In VISSIM, there are three different kinds of detectors [21], such as actuation, headway, and occupancy. TSP developed in VAP under the following requirements:

- TSP1 is based on a sensor situated 100 m upstream the first group of traffic signals in the corridor.
- The SG1 and SG2 actuate under the information transmitted by the bus detector following the TSP logic rules programmed in VAP.

- SG3 and SG5 copy the actions of SG1 with and offset that permits a green wave. SG4 and SG6 copy the actions of SG2 with and offset that permits a green wave.
- In the absence of transit vehicles, the SGs on the corridor operates in a fixed-time mode with green time ratio of 0,5 and with an off-set that makes a green wave possible. As amber is not taken into consideration for the purpose of the analysis [9] the ratio of the effective green time to the cycle length is the half of the cycle length. As we can see in table 1 the selected cycle length for this paper is 60 seconds.
- The offsets do not vary depending on demand because only the transit needs to be accommodated to an optimal (smooth) progression on the corridor through coordinated signals, not the car traffic flow in rush hours. Only in those conditions where buses share space with the rest of the fleet the offset needs to be modified to favor transit.
- TSP strategies used in this work are designed with a combination of extended green and early green. Conventional prioritization schemes often use one or the other [27]. The former prioritization treatment consists of an extension of the current green stage if a bus is detected approaching the intersection. The last (also called red truncation) consists in reducing the green stage for SG2 in order to return to green as soon as possible for SG1 when the bus is coming. The parameters considered in TSP1 and TSP2 are shown in Table 2.

Table 2 – Limits to Bus priority programmed in VAP.

Base time cycle	Maximum Green SG1	Minimum Green SG1	Maximum Green SG2	Minimum Green SG2
60 s	40 s	30 s	30 s	20 s

- TSP2 is based on real-time detection of the buses along the road corridor. This allows the replacement of green wave by the application of TSP1 logic to all signal groups.

2.2 Noise emission calculation

The output generated by the simulations offers information about the type of the vehicle, acceleration (m/s^2), the speed of the vehicles (km/h), the position of each vehicle in the network in each second, and the time of the simulation. Using this data, the propulsion noise and the rolling noise can be calculated by introducing it in the following equations [23].
The propulsion noise:

$$L_{W\,P}(f) = A_P(f) + B_P(f) \bullet \left(\frac{v - v_{ref}}{v_{ref}} \right) + C_P(f) \bullet a \tag{1}$$

Where L_{WP} is the propulsion noise power, A_P B_P C_P: Coefficients that will change for each frequency band in octaves for each vehicle category; v: Speed of the vehicles; v_{ref}: Reference speed; and α: Acceleration of the vehicle.
The rolling noise:

$$L_{W\,R}(f) = A_R(f) + B_R(f) \bullet \log_{10}\left(\frac{v}{v_{ref}} \right) \tag{2}$$

Where L_{WR} is the rolling noise power; A_R, B_R: Coefficients that will change for each frequency band in octaves for each vehicle category; v: Speed of the vehicle; and v_{ref}: Reference speed.

In order to analyze the mobility, we used the Time Travel features of VISSIM, so we could see the time that needs a car to cross all the arterial (main and secondary). The noise (both from propulsion and rolling), and the mobility were analyzed on every arterial in the created network. We analyzed the sound emission from every type of vehicles employed in the study.

3 Results and discussions

In a previous work [9], the attention was focused on the effects of prioritization of buses at a single signalized intersection where it was claimed that this strategy has a positive effect on noise, and it is not causing any type of negative secondary effects on the mobility of the private traffic. In the current study the analysis was extended to a more complex network. The cases proposed in table 1 were simulated to obtain the output data to analyze the travel time for mobility and noise power emissions, as indicated in the following Table 3.

Table 3 –Scenarios 1 to 10 with the selected data to analyze.

Cases	Link	Vehicle	Travel times	Sound Power estimated
1 to 10	1	Buses	Recorded	---
		Cars	Recorded	---
		All	----	Rolling noise
				Engine noise
				Total noise
	3	Buses	Recorded	--
		Cars	Recorded	--
		All	----	Rolling noise
				Engine noise
				Total noise
	5	Buses	Recorded	--
		Cars	Recorded	--
		All	----	Rolling noise
				Engine noise
				Total noise

All the results are referred to one simulation of 60 minutes created in VISSIM with the same random seed. The distribution of vehicles is random at the entry in the network, 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. From these simulations, we chose to present the most relevant ones.

The first analysis shows that for the cases (1, 3, 5 and 7) where the vehicle demand is low in relation to the capacity of the link 1 (if we call this relationship “level of service” or LOS, these cases show a rating in-between 0,35 and 0,45) all signal programs present a similar noise behavior. The peak in the proximity of the SG1 (500 m) is explained, as traffic upstream link 1 is random, and downstream is formed by platoons. This LOS means a steady traffic, which allows the synchronization of traffic lights to permit the passage of the platoons. Travel times indicate that the best results for transit correspond to case 3 (TSP1 with bus-lane) that has a mean of 78 s and a standard deviation of 5,6 seconds. Compared to the figures for free flow for buses (mean = 75,4 s and standard deviation = 2,2 s) and cars (mean = 73,6 s and standard deviation = 4,9 s) case 1 and 3 also exhibit a good travel time for private traffic circulation.

When the demand of vehicles increases until 1900 v/h, (Figure 2) the LOS shows a rating in-between 0,70 (traffic reaches saturation) and 0,90 (in the case number 8, in which the traffic congestion appears). In the transition between case 7 and 8 when LOS increases, the noise emission grows in the surroundings of the 3 junctions (at LOS=0,9) until the traffic totally collapses.

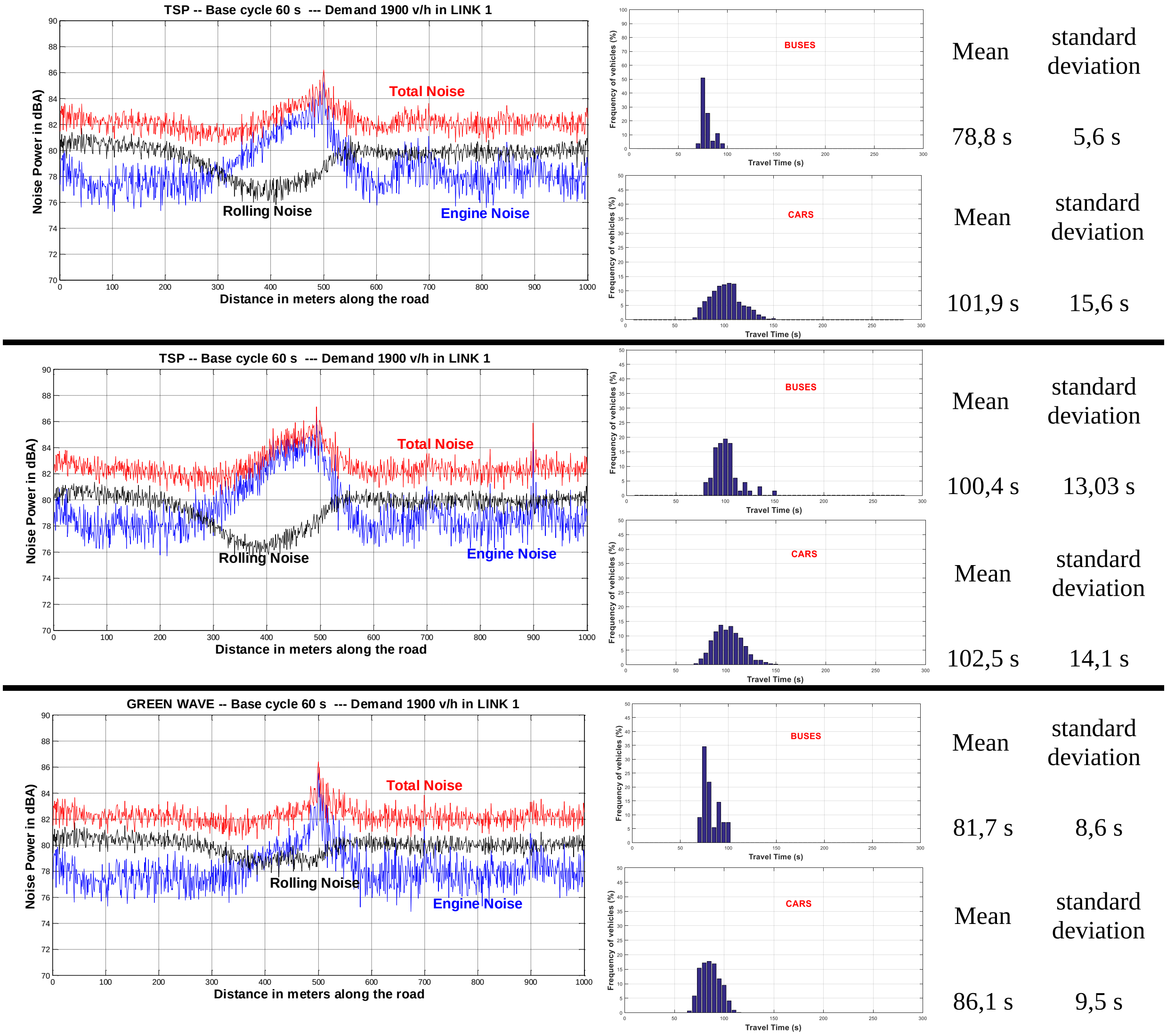


Figure 2 – From top to bottom, the graphical representations of the sound power emission and travel times for buses and cars for the link-1 for cases 2, 4 and 6. Case 8 is excluded for traffic congestion.

At the same time, the secondary roads exhibit a LOS from 0,25 (link 5, cases 7 and 8) to 0,7 (Link 3, cases 5 and 6). Apparently, these figures indicate an uninterrupted traffic flow conditions regardless of demand in the link 1, but actually, when saturated traffic occurs in the link 1, a conflict is created at every junction (case 8). Again, figures 3 and 4 show that the TSP manage the best figures for mobility, compared to the figures for free flow for buses (mean = 34 s and standard deviation = 1,3 s) and cars (mean = 29,7 s and standard deviation = 2,3 s). In figure 5 it is shown some figures for the promising TSP2 strategy which exhibit a good compromise performance.

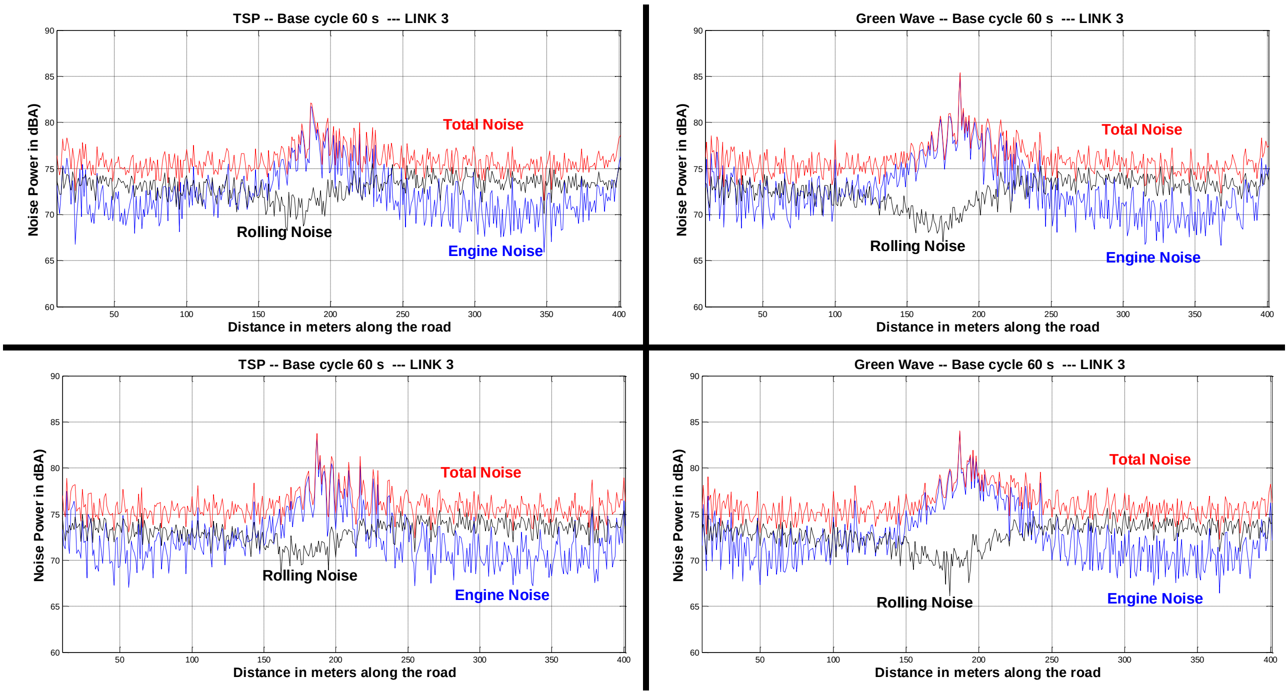
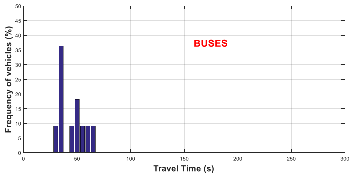
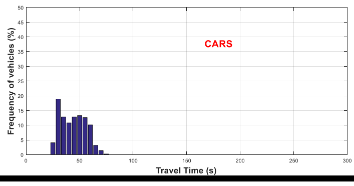


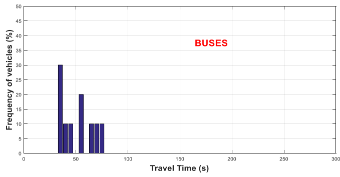
Figure 3– From top to bottom and from left to right, the graphical representations of the sound power emission of link-3 for cases 2, 4, 6 and 8.



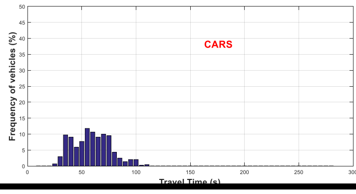
Mean	standard deviation
44,6 s	11,1 s



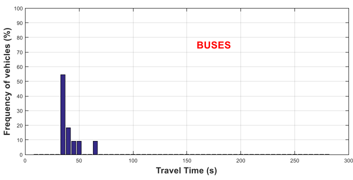
Mean	standard deviation
44,1 s	11,4 s



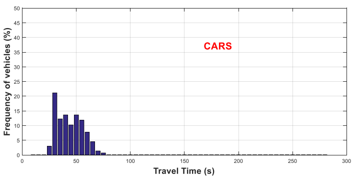
Mean	standard deviation
51,4 s	15,6 s



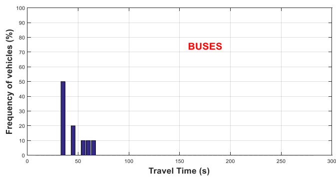
Mean	standard deviation
59 s	15,7 s



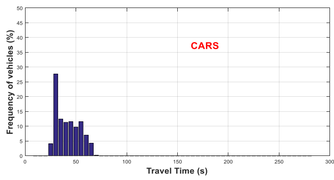
Mean	standard deviation
38,2 s	6,7 s



Mean	standard deviation
42,8 s	11 s



Mean	standard deviation
47,7 s	13,4 s



Mean	standard deviation
48,2 s	13,2 s

Figure 4 – Completing the figure 3. From top to bottom and from left to right, the graphical representations of the bus (and cars) travel time of the secondary road, link-3 for cases 2, 4, 6 and 8.

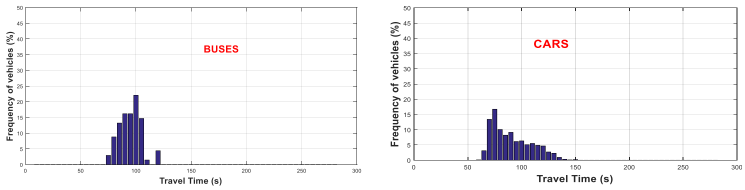


Figure 5 – Travel time for TSP2 case 10. Bus (on the left with a mean of 91,6 s), and car (on the right with a mean of 89,5 s) along link 1.

The most promising line of work is under development (TSP2 proposed in cases 9 and 10). The prioritization system will offer better results concerning mobility for private traffic modes, but without segregated bus lane. For the moment, we are obtaining car travel time decrements (Figure 5) in link-1 in more than 10 seconds respect to case 2 and 4 (TSP1 tested with a traffic demand of 1900 v/h with and without bus lane). All of this with the same or slightly better results for noise (links 1 and 3) and secondary road travel times (buses and cars). Respect to the prioritized bus travel times at link 1, the results are better than in case 4 but worse than in case 2. In future works, we have the hope of improving the figures obtained with TSP2, especially those related to bus travel times.

4 Conclusions

- Using a simple logic TSP1 based on one detector (SG1 and SG2) and synchronization of the rest of SGs in the artery (green wave for buses) is a good choice that exhibits the best travel time for buses in the artery showing the same or better levels of noise emissions in all the arms of the intersections.
- Bus priority TSP1 can substitute the need for segregation of guideway for improving public transport operation [12] only in situations in which LOS represent steady traffic.
- TSP2 behaves more efficiently than TSP1 in such situations when the bus stops are positioned between the intersections, or when the LOS is near the capacity in shared lanes.

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