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INFLUENCE OF THE BUS ROUTES LAYOUT ON URBAN NOISE

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ABSTRACT

The promotion of green public transport will require significant investments to replace the conventional bus units that circulate in our cities. The introduction of electric buses could require a review of the routes. A macroscopic traffic simulation platform for transport planning is the key tool for comparing bus routes using sustainability as the basis for decision-making. In public transport, sustainability means a multidimensional commitment that considers the efficiency of the transport service, but also profitability, road safety, environmental impact, social function, etc. Many performance indicators measure the quality of service for each dimension as a direct result of the traffic simulation. This study focuses on the design of a future noise annoyance indicator that will be implemented in GIS and that will allow an analysis and optimization of the annoyance in the city. This elaboration will help to identify those routes where the shift to electric vehicles will be a priority for noise mitigation.

1. INTRODUCTION

Environmental noise continues to be a cause for concern in the EU [1] and its effects on health continue to be a source of scientific attention [2]. This has made it possible to align the objectives of environmental policies with the updating of this scientific knowledge on the impact of noise on health [2,3]. Research in this field has not only been aimed at improving noise dose-effect indicators but in line with the European Noise Directive [4], progress has also been made in finding better methods for calculating the noise dose and harmonizing them at a European level [5]. The Directive [4] also establishes that the results must be accompanied, where necessary, by specific noise mitigation measures included in the action plans. But these measures are decided at the level of the environmental policies of the member states. The noise action plan data presented by the Eionet [6] paints a very diverse picture of action plans in cities and agglomerations. The types of noise mitigation measures within the urban areas can be the most diverse nature, especially if it is examined country by country. If the focus is on the initiatives to improve public transport, the following distributions can be observed. The agglomerations of Belgium have adopted this measure in 38% of the cases (concerning the total number of measures) and Estonia in 29%. If the focus is on the initiatives to promote sustainable mobility in general, we have that in Latvia it is the only measure adopted (100%).

EEA publications [7] highlight that the public transport system remains the backbone of sustainable urban transport. Being an essential part of the mobility offered in urban areas, its efficiency is vital, although it is valued differently by users, operators, and administration. Therefore, the transit system requires precise design and planning. The generation of efficient route networks for public transport is a problem that has been addressed in the literature by a considerable number of studies. When the influence of buses on urban noise is analyzed, the studies come to adopt the positive perspective in the sense that, in general, the rate of noise in the city decreases as a consequence of the use of public transport to the detriment of private vehicles.

However, the position of this article is different. Here we intend to examine how the noise in the streets and avenues as a consequence of bus traffic can be quantified in terms of the possibility of annoyance. This is not new and it can be found in several studies, for example [8], which develop a methodological approach to assess traffic noise intervention and its connection with the perceived well-being of the population. In that case, the study is based on the results of the noise mapping process and proxy databases that determine noise-related well-being probability regarding certain L_{den} ranges. Another study [9] has identified a cause-effect connection between the presence of public transport (buses, trolleybus, and trams), and the level of noise annoyance. It was claimed that during the daytime, the number of public transport vehicles is a major influencing factor on noise annoyance. However, at night, it is the type of public transport being the combination of buses and trams the most annoying. In the work [10] it was shown that unexpected high annoyance can be detected when noise is low. Other variables considered under the scope are the sections of the streets, and the presence of public transport (tramway).

1.1. Objectives

This study focuses on the design and tests of a specific noise annoyance indicator that will be implemented in GIS and that will allow an analysis and optimization of the possibility of annoyance in the city, as a consequence of the design of bus routes.

1.2. Scope and limitations of the present paper

This paper is presented as a preliminary advance of the work that is being carried out. The methodology is presented in its entirety, although in a summarized manner. Only a part of the results of the work is anticipated. In this paper, only cars and buses, are included in the noise traffic model (for simplification purposes) and bus line 7 of the city of Cadiz is used as a Case Study. Pending the results of the surveys, the indicators used in the study will recreate only a linear categorization of 5 stages, between the maximum and minimum values. The advanced noise measurement campaign was dedicated to comparing the two configurations of bus stops located on one-way streets with one and two lanes.

2. METHODOLOGY

The methodology is supported by the following five elements and processes:

(i) A macrosimulation traffic tool, PTV Visum [11] is a traffic planning software that provides the results of the best public transport routes.
(ii) The use of a dynamic traffic noise assessment tool based on CNOSSOS in combination with the traffic microsimulations model, VISSIM, [12] to find out the probability in which a noise event

due to bus traffic emerges from traffic noise. This combination is named the Dynamic Traffic Noise Assessment tool (or DTNA tool).
(iii) A noise measurement campaign that confirms the achievements of the micro traffic simulations, regarding noise events in all interesting situations.
(iv) A procedure to categorize the annoyance capacity due exclusively from public transport represented as a noise indicator. A survey questionnaire is currently being prepared following the standard questions carried out in [13] for example, with the distinctive aspect of evaluating noise annoyance from sound events due to bus traffic.
(v) A procedure based on GIS (Geographic Information System) to classify the streets stretched regarding the risk of noise annoying situation considering bus traffic during the peaky hour during the day. For this section, it is expected to use HSIP 3D-tool (Hot Spot Identification and Prioritization) [13] for the estimate of exposed inhabitants and their connection with the street stretches.

2.1. Step (i): PTV VISUM. Examining different bus routes layout using efficiency criteria

Thinking in public transport, VISUM can be defined also as a decision-making system that can be applied for optimization of public transport from different points of view (multicriteria analyses in which environment noise can be adopted as one of the variables used as a decision-criteria). The analysis and study of efficiency will be carried out by taking into account performance indicators, cost indicators, and efficiency indicators of the public transport system, distributed by each bus route of the network design. Included in the last set of indicators is included the environmental impact.

- Bus traffic density.
- Frequency
- Transfers.

The main data input is the Transit Bus Routes (GTFS-static), generated by the operator with the actual service (Figure 1). Therefore, commercial speed, frequency, distance traveled, service time, etc. are the real figures. This data is enough for VISUM to calculate the noise emission according to RLS 90 (and also includes another tool to estimate emissions of air pollutants according to HBEFA). As these calculations are macro estimations, the goal of this study is to include micro and more detailed noise estimations. Although the long-term idea is to explore the possibility of including a noise annoyance indicator within VISUM, for the moment, it will decide to work on GIS since it is the easiest way to handle the population and building shape data (since VISUM only takes into account the population of the macro-areas to create origin-destination matrices).

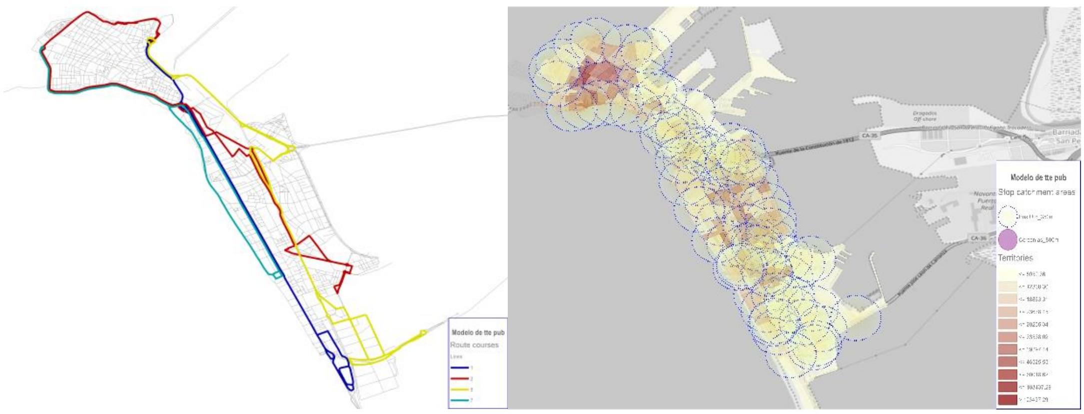

Figure 1. The image on the left shows an example that includes the streets that are part of the routes (highlighted in colors) in the city of Cádiz. The map on the right point out the bus stop situation and the isochrones circles of 5 minutes walking calculated from the bus stops around the city. This information is calculated and then extracted from PTV-VISUM.

To make the use of the bus service attractive for users, profitable for the owner, and efficient for the administration, it must be a trustworthy service. This means limited delays, a good frequency of service, accessibility requirements, minimum and comfortable transfers, easy and integrated payment possibilities, etc., [7]. Figure 1, spatially attests to how the service covers the territory efficiently. For example, the bus stops are distributed in such a way that covers all the territory within a radius of fewer than 5 minutes on foot. It also shows that the most densely populated areas have more routes, guaranteeing a correct frequency of buses. To evaluate the efficiency of the service there are some limitations, i.e., the number of buses needed to fulfill the function, the number of drivers, the cost/benefit ratios, etc.

2.2. Steps (ii) and (iii): Dynamic traffic noise assessment tool (DTNA tool) and noise measurement campaign design

The output of the DTNA tool is two time series of noise (LA_{eq}, $T=1s$) generated during the VISSIM test. The first is the noise generated by buses during the time in which the simulation takes place and the other is the noise generated by the rest of the transport modes.

From now on it will call Noise Events caused by Bus Traffic (NEBT) to bus noise emergencies audible above the traffic noise. The design of the streets has a great influence on the probability of NEBT. There is a considerable number of studies that analyze the influence of roundabouts and intersections on the dynamics of vehicles and therefore on the noise emissions, they generate Traffic flow conditions must also be taken into account, not forgetting the type of bus and its age. Finally, we will mention both the traffic regulations and the procedures that bus drivers follow (or not) for ecological and safe driving.

Infrastructure:

- A straight artificial carriageway (only one direction is examined) is proved in two versions 1 and 2 lanes.

Traffic conditions during the simulations:

- The bus transit schedule is always the same (20 vehicles per hour in the tested direction)
- Speed limits. 30 Km/h speed is allowed in the one-lane street and 50 Km/h in the two lanes version.
- A traffic light whose regulation is fixed is installed with a cycle of 110 s, being the green of 85 s.
- One of the bus stop examined is the Pull-Out Stops, also known as bus-bay, this type allows other vehicles to pass during passenger boarding.
- The second bus stop analyzed is the In-Lane Stop. These stops allow transit vehicles to pick up passengers without leaving the lane, which reduces boarding and departure time but can create significant traffic queues if not employed in a dedicated bus lane or a two-lane street.
- Traffic demand fluctuates between 2 situations: fluid traffic and traffic near saturation. In practice, 500/1,000 v/h) were chosen for the single-lane street and 1,000/2,000 v/h for the two lanes streets.

Test sections:

- Four sections of 50 m in length were selected to test the influence of the probability of noise events around:
    - A section of free traffic without obstacles.
    - The two bus stops the different configurations.
    - A traffic light regulating pedestrian crossings.

Therefore 16 different scenarios were analyzed (table 1), i.e., 4 sections x 2 different roads wide (1 and 2 lanes) x 2 LoS (Level of Service: near saturation and free traffic). And, for each scenario, 10 independent tests of 1 hour each were carried out.

Noise campaign:

- The predicted noise is calculated in a virtual sound level meter situated in the middle of the road test section. To test if DTNA tool can predict the events and is worthy, the noise measurement campaigns were planned. The following ones were designed to check the influence of the bus stop for the following situations
  - 2-lane road (1 direction) with the bus stop on the side (Pull-Out Stop) vs a 1-lane road with an In-Lane bus stop.
  - LoS (Level of Service). Fluid traffic.

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2.3. Steps (iv) and (v): The metric used to build a reliable noise annoyance indicator (PNE) and GIS implementation

The future noise indicator (noise event dose-exposure) should show the capacity of buses in certain street configurations and traffic situations that create noise emissions that emerge and become audible relative to residual noise (traffic noise considering only the private transport modes). The "Probability of Noise Events" PNE can allow a comparison between different predicted situations without the necessity of carrying out noise measurements for each specific type of scenario. The PNE is established taking into account the number of times that the bus emerges in more than 6 dB during 2 or more consecutive seconds. The importance of the event is considered for its prevalence in the area measured by a virtual sound level meter. The other fundamental variable to assess the magnitude of the problem is to know how many people can really be affected by this probability. The questionnaire is currently being prepared and the in situ measurements should be extended to all the possible configurations that have been mentioned here.

It is convenient to keep in mind that this paper intends to systematize the categorization of bus lines' noise impact using certain noise annoyance indicators, in a research orientation that is very similar to previous studies on street categorization methods for urban noise prediction [14]. GIS will have the function of data repository (PNE and population per building) and final spatial processing of the data. The threshold is not a fixed value and takes into consideration the possibility of the emergence of transit noise.

2.4. Steps (vi): Case study specifications

Being a preliminary study, we will use the bus stop areas of maximum and minimum probability in bus route 7 of the city of Cadiz that we have adopted as a case study (Figure 1, route 7 is drawn in grey). This bus line has been marked by the different actions that the city council has incorporated to promote sustainable and non-motorized mobility. The most important of which was the construction of a bike lane that connects the city with the historic center through a corridor that never leaves the promenade. At the same time, actions have been taken to improve the route for pedestrian traffic, which in some sectors was even dangerous.

3. RESULTS AND DISCUSSION

3.1. VISSIM results

After 10 hours of simulations in VISSIM per scenario, the average data extracted are shown in table 1. Nothing is said in these results about the number of events, but only their average duration through the 10 hours of simulation is counted. The final number has been rounded.

Table 1 – Probability of noise events produced by buses passing byes during the 10 hours of simulation in different kinds of situations. The section of the road evaluated is 50 m in length.

PNE per bus pass bye				
	1 lane. Fluid traffic	1 lane saturated traffic	2 lane fluid traffic	2 lanes saturated traffic
Pull-Out Stops	13 s	11 s	8 s	4 s
In-lane Stop	17 s	17 s	9 s	5 s
Traffic light	4 s	4 s	2 s	1 s
Free flow	3 s	3 s	1 s	1 s

In the traffic simulation, a resolution of 1 second has been used, which has allowed, through a virtual sound level meter, to establish at what times the time series L_{Aeq}, $T=1s$, of the passage of the buses in the 50 m, is audible with respect to the synchronized time series of L_{Aeq}, $T=1s$, of the rest of the vehicles on the same section. For reference only, a vehicle traveling at 30 km/h takes 6 s to cross the section, but the bus enters the stop, the passengers get on/off board and it joins traffic with priority.

3.2. Measurements results

Before and after the rehabilitation of the promenade in which a bicycle lane and the sidewalk won the space dedicated to one of the 2 road lanes, a series of noise measurements were carried out, whose distribution is shown in figure 2 in the middle.

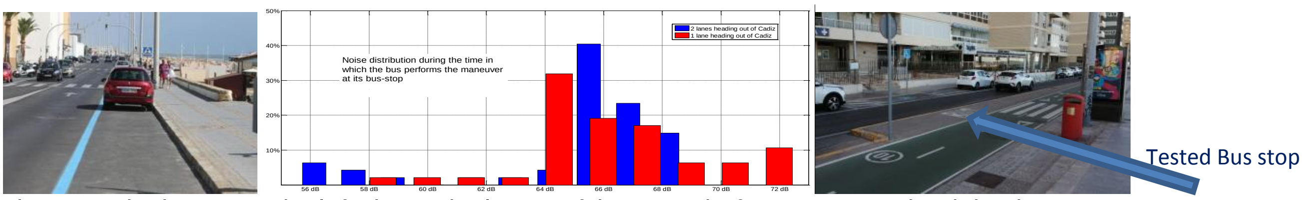

Figure 2. The image on the left shows the layout of the street before 2018. On the right, the current layout is shown in the picture. In the middle, the graph shows the results of a round of measurements on bus line number 7 bus stop, as it passes through the promenade in the two configurations tested, 1 and 2 lanes, with the same traffic and the same position in front of Isecotel bus-stop.

The public works involved transforming the old layout of two lanes in both directions (Figure 2 on the left) to a one-way layout (Figure 2 on the right), heading south (out of the historic center). This direction was marked mainly by higher demand. To maintain this last layout, it was decided that bus line number 7 (which is the one used by students to reach the different points of the Cádiz University Campus located in the historic center) would travel the city to the north along the main avenue (Figure 3 describe the situation of current bus stops). The noise measurements were performed just before the works that took place in this area at the beginning of 2019, at the "Isecotel bus stop" in the direction outbound of the city of Cádiz. Between the current configuration and the pre-2019, there was a period in which the two lanes were used in the same direction out of the city (noise measurements results in blue). The second round of measurements (in red) takes place during the current configuration, with only one lane in the direction leaving the city.

Both campaigns include only the situations in which the buses entered and left this bus stop. Although light vehicle traffic remained constant in the tests, both configurations generated different noise distributions (Figure 2 in the middle). Therefore the difference between both situations is found in the number of lanes and the type of bus stop.

3.3. GIS results

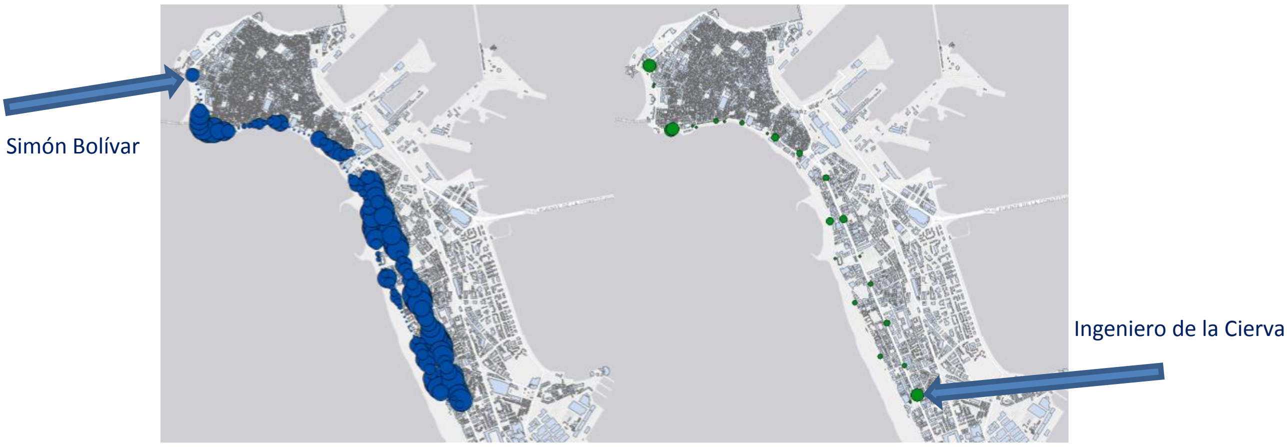

Figure 3. The image on the left shows the layout of bus line number 7, today and the number of people living under the influence of the vehicle passing through the streets (in blue points). On the right, it is represented only the number of people leaving under the influence of bus stops (in red points).

In both scenarios (Figure 3) what is shown is the number of people living in a buffer of 50 m with the center at a point (a bus stop on the right) or a line (the street on the left), and codified in ten steps symbol sizes. The maximum value is 1400 people. The classification method is equal intervals.

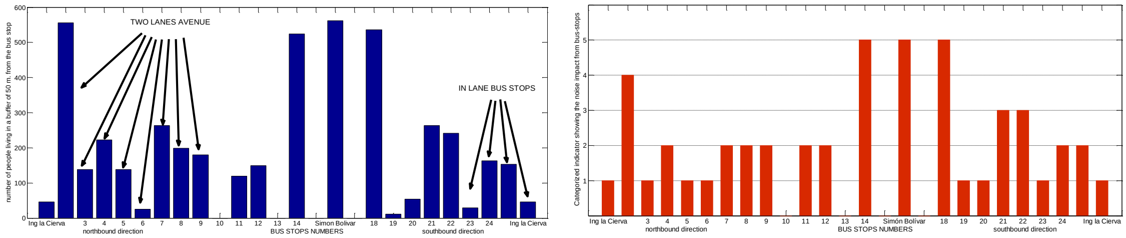

Figure 4. The graphic on the left shows the real number of people living near the bus stops of bus line 7. The graphic on the right shows the noise indicator built with the information of the buses belonging to bus line 7.

The population data (Figure 4 on the left) is categorized then into five steps of the equal interval as seen in the graph in red (Figure 4 on the right) taking into account the data provided in Table 1. Finally what it has is a precursor of the found indicator. But in these points, the necessary information is incorporated to separately evaluate the acoustic impact of the line. That information is the AADT per hour, the frequency of buses passing per hour, the typology of bus stops, and the presence of traffic lights. Therefore, the maximum probability that on bus line 7 there are people affected by the noise events produced by the bus traffic as they pass through the stops is precisely at stops 14, 16, and 18, even though there is more population living near stop 2.

3.4. Discussion

In the case of the gradual renovation of the bus fleet through the incorporation of e-buses, one of the priority criteria could be precisely to first renew those lines in which the probability of high noise annoyance is expected. This work opens the possibility of using new efficiency indicators to assess noise annoyance related to sound events generated by bus traffic and audible above the background noise associated with light vehicles. This approach proposes a future procedure to evaluate the probability of annoyance with metrics of social-urban acoustic impact easy to predict. This indicator can be a form of decision-making when local authorities need support.

Therefore, establishing the population that lives in the surroundings of the streets through which the bus routes to be analyzed pass is fundamental. However, in this paper, a precursor to the future indicator is applied only to the population living near bus stops. The round of noise measurements confirms the noise differences generated by modifying the two variables: type of bus stop and number of lanes. The sensitivity of the population at night has not been taken into account, but the difference in light vehicle traffic density has. Regarding the chosen study area, it is interesting to note that it allows the bus route to be isolated since the way back to the Glorieta Ingeniero de la Cierva station is not shared with other bus lines on the section of the seafront promenade. This is very important when interpreting the surveys and relating them both to noise measurements and estimates of sound events. Other variables remain constant throughout this section: traffic speed is 30 km/h, and one lane and bus stops are of the same type. Speed humps, cushions flat-top humps, lane narrowing, zebra crossing, etc., are left out of the scope.

The objective of the questionnaire should be to find out if the passing of the bus can be heard with the windows of the house open, regardless of the type of room, and if there are times when it is particularly annoying. There will be specific questions in the survey associated with the section of the street where the bus passes, which is subject to a classification that corroborates the generic simulations in VISSIM. The typology of the cross-section of the street is always with the shape of "L" with a space open to the sea, so there will be no need to worry about complex propagation and reflection phenomena.

4. CONCLUSION

This preliminary work presents an approach to a new environmental noise indicator for the evaluation of urban residential areas affected by bus routes. The first and most important conclusion, which still needs confirmation, is that in-lane bus stops located on single-lane streets present at least four times more probability of annoyance noise events than the passage of the bus in free traffic in the same street. The method is very promising although the proposal still needs to be confirmed by surveys that determine and compare the dose-response relationships in both situations.

ACKNOWLEDGMENT

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