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Impact of traffic simulation parameters on the estimation of noise exposure in an urban environment

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ABSTRACT

Since road traffic is the most impactful noise source in the European cities, the evaluation of citizens' exposure is crucial. Although the noise map accuracy is affected by uncertainties in traffic volume, to perform extensive traffic monitoring is not practical and expensive, even in small cities. Traffic simulation software uses routing algorithms to suggest the fastest path to distribute vehicles from an origin through a network to a desired destination which interacts within the urban environment. Therefore, it could represent an important tool for noise mapping in the critical task to fill the data gaps in traffic volumes, also for implementing action plans using a suitable traffic management approach. However, there is a lack of evidence on how the choice of traffic simulation parameters influences noise estimation. In this work, we design a simulation framework to evaluate the impact of routing algorithms on the estimation of population noise exposure in an urban area. Using an open-source pipeline based on public databases and open-source software SUMO and NoiseModelling, we evaluated the implication on the traffic distribution and resulting noise exposure for a set of traffic model key parameters.

1. INTRODUCTION

Environmental noise exposure is linked to numerous health effects and it constitutes one of the main threats to the well-being of the European population. Road traffic is also well-known to be its predominant factor in the urban environment [1]. To estimate noise exposure at receivers, critical variables include the traffic volume, the type of vehicle, and its speed. One of the commonly neglected aspects regarding traffic is the presence of a Port in a city, as it adds a level of complexity, contributing not only as a noise source itself but also producing induced traffic. Despite many recent projects and studies focused on port noise, it is still challenging to properly model port-induced traffic. A significant contribution can be provided by micro-simulation software, which, even though has been available for many years, was validated mainly for small-scale traffic studies given the complexity of obtaining the required measurements and calibration clusters definition [2]. Recent research has suggested traffic simulations can also be applied to assess noise exposure in the urban environment by using multi-agent traffic models [3]. Thus, a near-to-real-time noise assessment was also achieved by

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implementing a calibration with sparse counting [4]. However, none of the related works in the literature investigates the impact of route diversification on noise exposure.

The present work, developed under the PNC SALPIAM Italian project, aims to evaluate the possibility of successfully calibrating a traffic model on a more complex environment, evaluating the impact of alternative routing as randomization of the fastest path on road traffic. The work has been accomplished by taking advantage of two open-source software, NoiseModelling [5] for noise estimation, and SUMO [6] for microscopic traffic simulation. Traffic parameters were modified in the traffic model and subsequently, noise calculations were performed powered by custom Python scripts.

2. SIMULATION FRAMEWORK

A virtual experiment was conducted by using an open-source pipeline for traffic simulation and noise modeling [7]. The objective was to evaluate how parameter variation in a random simulation could influence the vehicle network distribution and thus affect noise impact estimation in an urban context.

2.1. Piombino city model and road classification

The simulation scenario was created based on open-access local databases described in previous works [7]. To focus the analysis, the streets were classified according to their functionality [8]. Such classification stratifies from noisier to less noisy urban roads [8], it may also imply similar traffic behavior. For this study only four categories were defined. Figure 1 shows the classified streets and the 60 edges to be analyzed: 18 edges belong to C0, 29 edges are C1, 8 edges correspond to C2, and 5 edges to C3.

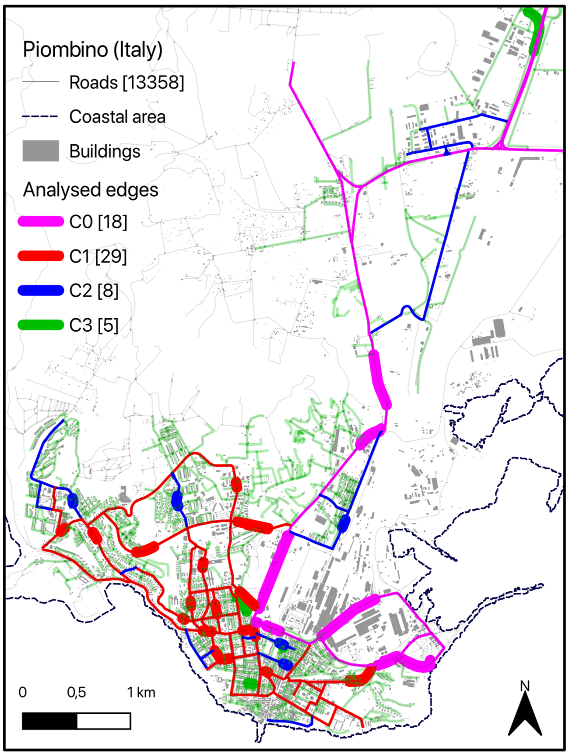

Figure 1: Piombino’s functional urban road classification and 60 edges to analyze.

The first one class labelled C0 represents the main access streets to the city and the Port. Categories type 1, 2 and 3 from the categorization method [8] were grouped together to clustering principal streets defined as C1. Urban roads type 4 which connect principal streets between them and to the neighborhoods, were defined as C2. Finally, C3 streets are the type 5 roads comprising the rest of the city's roads, excluding pedestrian-only streets.

2.2. General traffic and noise model settings

To begin with, general SUMO settings were defined. The traffic assignment definition follows the CNOSSOS-EU with SUMO default vehicle parameters [7] as shown in Table 1.

Table 1: CNOSSOS-EU vehicle categories by using SUMO and NoiseModelling.

CNOSSOS-EU category			**SUMO classification**					**NoiseModelling**
Description		ID	vClass	length (m)	minGap (m)	accel (m/s2)	maxSpeed (km/h)	ID roads type
Light vehicles		1	passenger	5	2.5	2.6	200	LV
Medium heavy vehicles		2	delivery	6.5	2.5	2.6	200	MV
Heavy duty vehicles		3	truck	7.1	2.5	1.3	130	HGV
Mopeds, tricycles or quads	< 50 cc	4a	moped	2.1	2.5	1.1	45	WAV*
	> 50 cc	4b	motorcycle	2.2	2.5	6	200	

*Mopeds, tricycles or quads < 50 cc (WAV) and > 50 cc (WBV) were grouped in one road type since the noise emission is considered the same in CNOSSOS-EU as well as in NoiseModelling.

The Krauß-model [9] with some modifications is the default Car-Following model used in SUMO considered in this study. Besides, teleport parameters were used to check the transport network for connection errors, among other issues. Traffic lights and their status were extracted from OSM. On the other hand, rails were not included in the traffic model, thus signals moving-block operation was not configured. Actuation detectors were also not incorporated into the simulation, hence we neglected all their parameters. Likewise, electric vehicles energy assessment has not been considered. Moreover, pedestrian models were not taken into account, consequently all these parameters were excluded.

The vehicle noise emission was determined principally from the 1-hour average traffic and speed results generated by the traffic model using the NoiseModelling script "road emission from traffic". The road geometry was adjusted by the city's digital elevation model and previously validated to detect the slope, each lane was defined as a bidirectional way. In addition, the default values were used for the road pavement (NL08) and road average temperature (20°C). Vehicles equipped with studded tires were not present. The distance to junctions and their type were not explicitly defined. The estimation of noise exposure at the receivers, it was calculated as described in previous studies [7].

2.3. Random trips generation

A number of random trips and corresponding routes were generated with the randomTrips.py, which first selects the start and end edge and then applies a routing algorithm to create a route to be followed by the vehicle. The SUMO documentation recommends varying the parameters described in Table 2 to customize the simulation [10].

Table 1: SUMO RandomTrips modifies values.

Parameter	**Description**	**Values**		
--fringe-factor	Probabilities of journeys ending and/or start at a boundary edge	0	1*	'max'
--min-distance	Minimum straight-line distance (m) between start and end edges for each trip	50	0*	1000
--speed-exponent	Edge speed weight probability by speed	0.5	0*	1
--random-routing-factor	Randomness of the edge weights disturbance	2	1*	8

*Default value.

The values for the experiment in Table 1 were chosen based on discussions between user and developer in SUMO forums [11].

3. RESULTS

3.1. Traffic simulation parameters

3.1.1. Period

The period describes how often new vehicles are generated. If traffic counts are available, the period can be calculated by dividing the simulation time by the total number of generated vehicles. An estimation of the correct period for each vehicle class was done based on the total traffic for each vehicle class measured by the installed traffic monitoring system during July 2021. Piombino is frequently affected by traffic congestion thus, to reproduce this scenario, the obtained periods were divided by the factor between day average traffic and night average traffic. The calculated periods (s) are: 0.33 for LV, 3.4 for MV, 3.6 for HGV, and 12 for WAV.

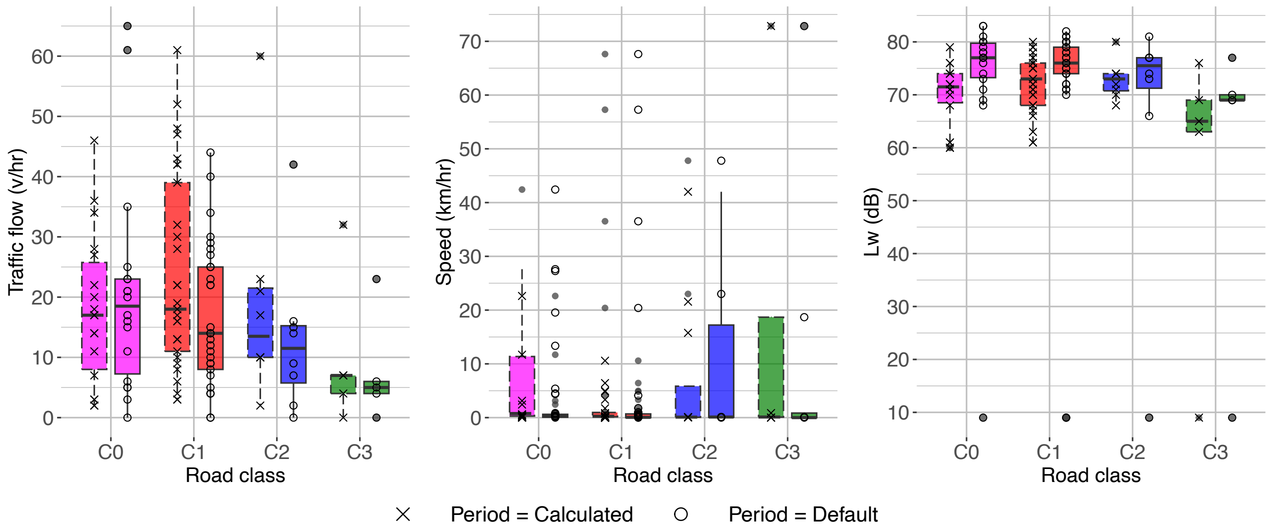

Figure 2: Trend analysis of traffic flow, speed and Lw, default & calculated period.

From Figure 2 the trend is clear, when the calculated period is selected, traffic decreases on C0 streets by diversifying the traffic assigning a different period to each vehicle category. Conversely, traffic increases on the rest of the classes. This can result from the fact that light vehicles were defined as the most frequent type of vehicles, exactly as in reality. Regarding the sound power level (Lw), it decreases for all street classes. However, it is not ordered from highest to lowest noise emission levels when using the calculated period, particularly in class C1 and C2 it shows greater levels than class C0. On the other hand, when using the default period, the expected noise stratification is achieved.

3.1.2. Fringe factor

Fringe-factor parameter increases the probability that trips will start/end at the fringe of the network. If the value 10 is given, edges that have no successor or no predecessor will have a 10 times higher probability of being chosen as the start- or endpoint of a trip. Setting a high value will generate more through-traffic which is plausible for small networks [10], where a high percentage of the vehicles come or go outside the simulated area.

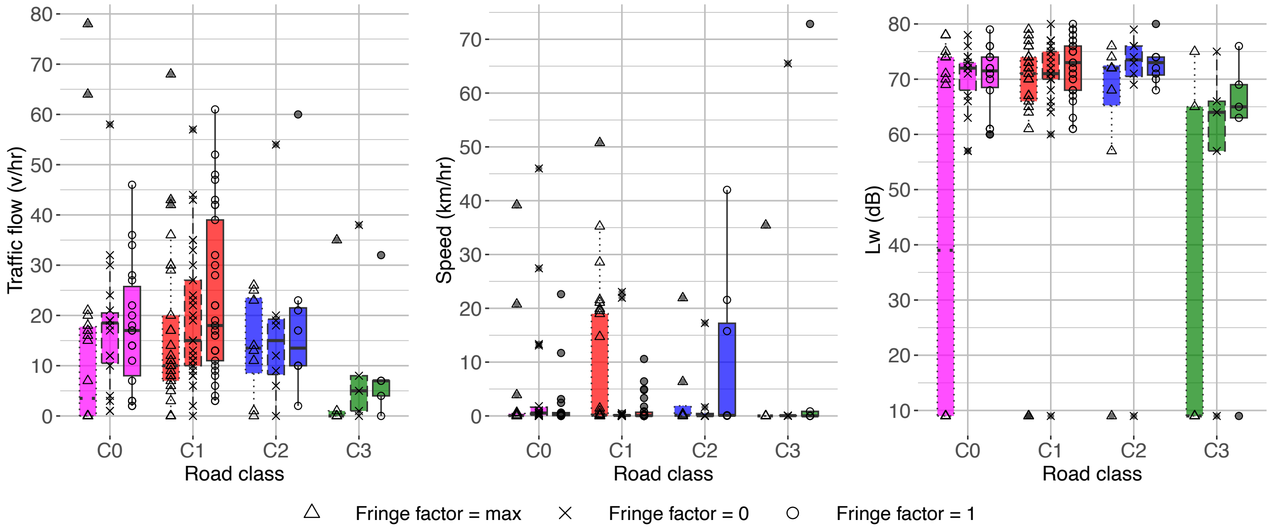

Figure 3: Trend analysis of traffic flow, speed and Lw, fringe factor = 0, 1* & max.

From Figure 3 shows that forcing more trips to start and or end at the external city edges leads to a decrease in traffic and noise for all vehicle classes, since there are reduced numbers of trips remaining on the road network. Interestingly, the noise emission for this case is also stratified as expected. On the contrary, for the minimum fringe factor, traffic and noise levels increases because more trips are within the city.

The reference simulation (marked with *) consider each default value with the calculated period, explained in the previous Section 3.1.1. Therefore, it follows the same trend in this and all following parameters, so it is not re-analyzed.

3.1.3. Minimum distance

This parameter represents the minimum straight-line distance between the start and end edges for each generated trip. Restricting short routes, increases the chance that routes passing multiple counting locations are generated [10]. By increasing the minimum length of a trip, it will also increase vehicle active time on the network. This could lead to higher traffic and congestion in the network, thus lower average speed.

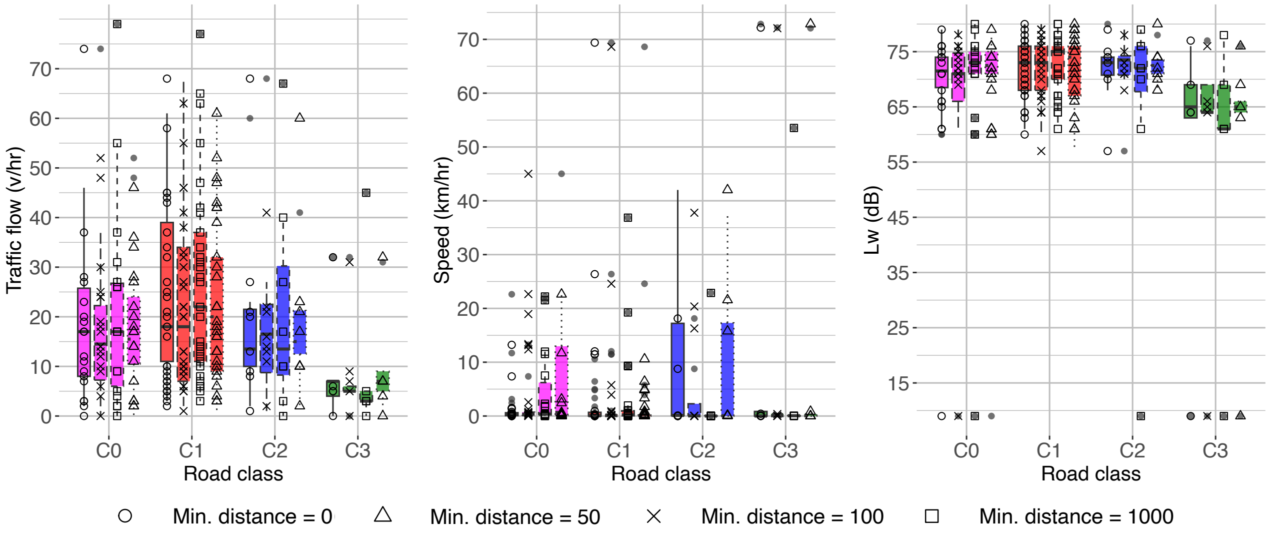

Figure 4: Trend analysis of traffic flow, speed and Lw, min distance = 0*, 50, 100 & 1000.

The modification of this parameter resulted in minimal variations on average traffic and noise for the defined street classes. Furthermore, the dispersion of the data is quite wide, thus, it is not feasible to remark any trend. A decrease of traffic and noise is expected because of a better distribution of trips spread over the whole network. However, it is necessary analyze different intermediate values to understand the actual role of this parameter in the model.

3.1.4. Speed exponent

Speed exponent parameter weight edge probability by speed raised by the provided value. Setting this option to a value higher than 0 will increase the probability of the routes passing by edges with higher speed limits, i.e. on model-important roads [10].

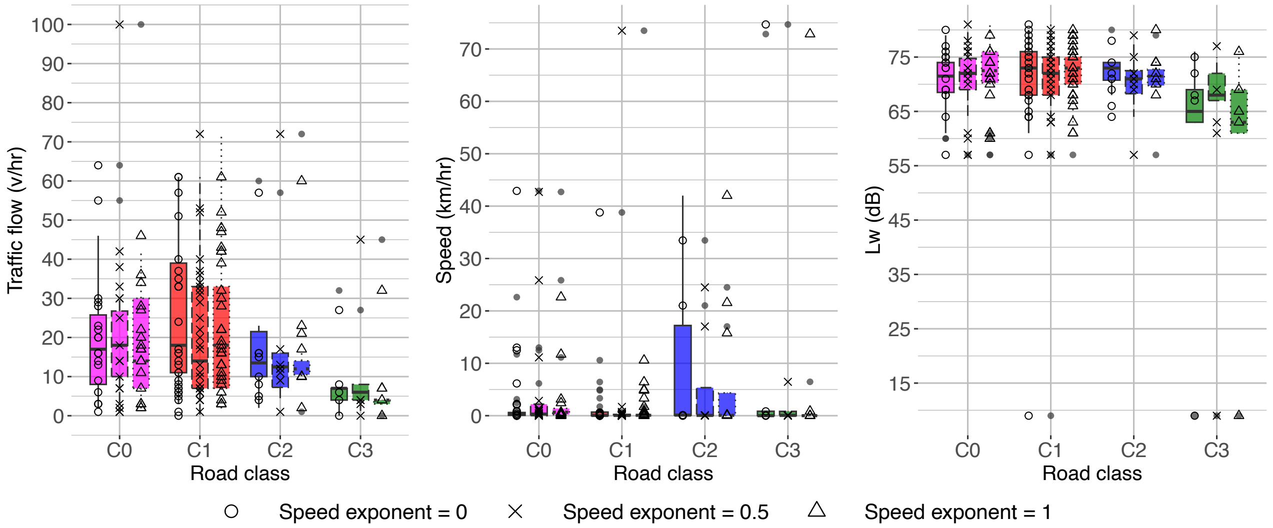

Figure 5: Trend analysis of traffic flow, speed and Lw, speed exponent = 0*, 0.5 & 1.

The simulation results after increasing the speed exponent reveal an increment in traffic flow and noise only on the main streets C0, without strong tendency for all the other classes. For a city like Piombino, there are few streets where the distance between intersections is long enough to allow for speed variations. As for the minimum distance, it is necessary to test with several values to be able to conclude any trend in the incidence of the speed exponent.

3.1.5. Random routing factor

The random routing factor parameter defines the randomness of the edge weights disturbance of the route choice, allowing trips with the same origin and destination to use different routes.

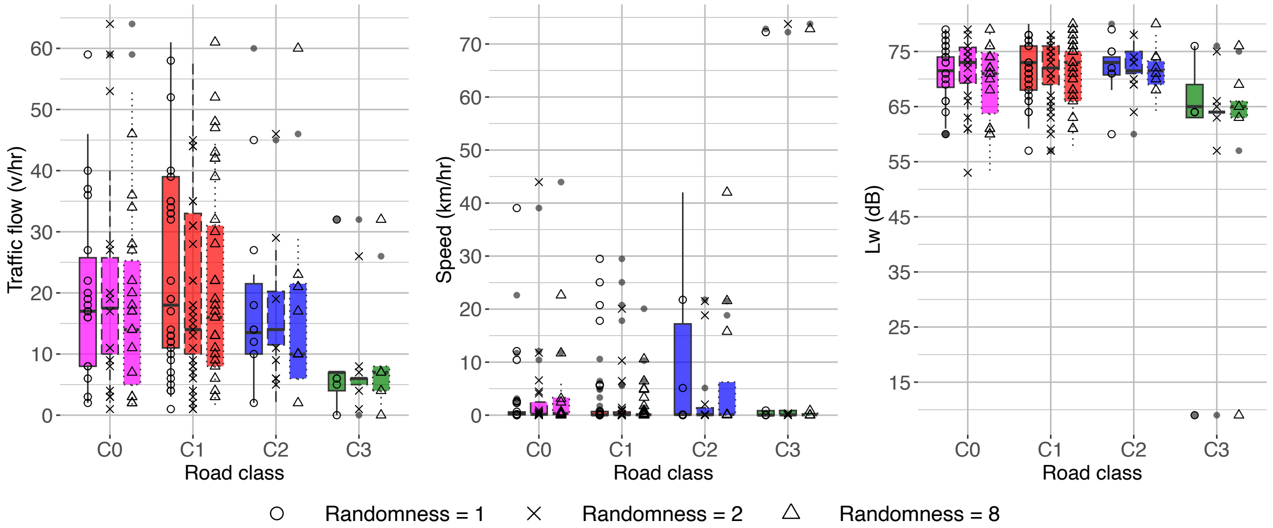

Figure 6: Trend analysis of traffic flow, speed and Lw, random routing factor = 1*, 2 & 8.

The value is randomized again for each vehicle, so there are no systematic biases [10]. Increasing this parameter will likely spread the traffic throughout the network, decreasing traffic flow on more "popular" roads and increasing it on the more neglected ones. The SUMO documentation explicitly mentions: "A value of 2 may change the apparent travel time on an edge by up to between 100% and 200% of its empty-network-travel-time. This ensures that the resulting routes take at most twice as long as the "fastest" route" [10]. Nevertheless, for this case, when the random routing factor is increased to 8, the expected impact is observed. As a result, traffic flow and noise are reduced on main streets and connecting streets because routes are generated to reach the same destination via alternative streets (C3). At the same time, traffic flow and noise are shifted to streets of less connectivity and importance for the network, allowing for longer trips. One consequence of this is a reduction in the intensity of the associated environmental impacts in certain zones spreading them over the whole area.

3.2. Noise exposure estimation

To show some implications of the traffic simulation parameters on the noise exposure in urban environments, three different factors and values were chosen to demonstrate their noise impact. The historic center with residents (Zone A) and the access Port area (Zone B), were analyzed given the different sensitivities of the receivers based on their land uses. The noise exposition is presented only where there are inhabitants [7]. Figure 7 shows the estimated noise exposure maps for Piombino Zone A and Zone B, by using the default period, the maximum fringe factor and a random routing factor of 8.

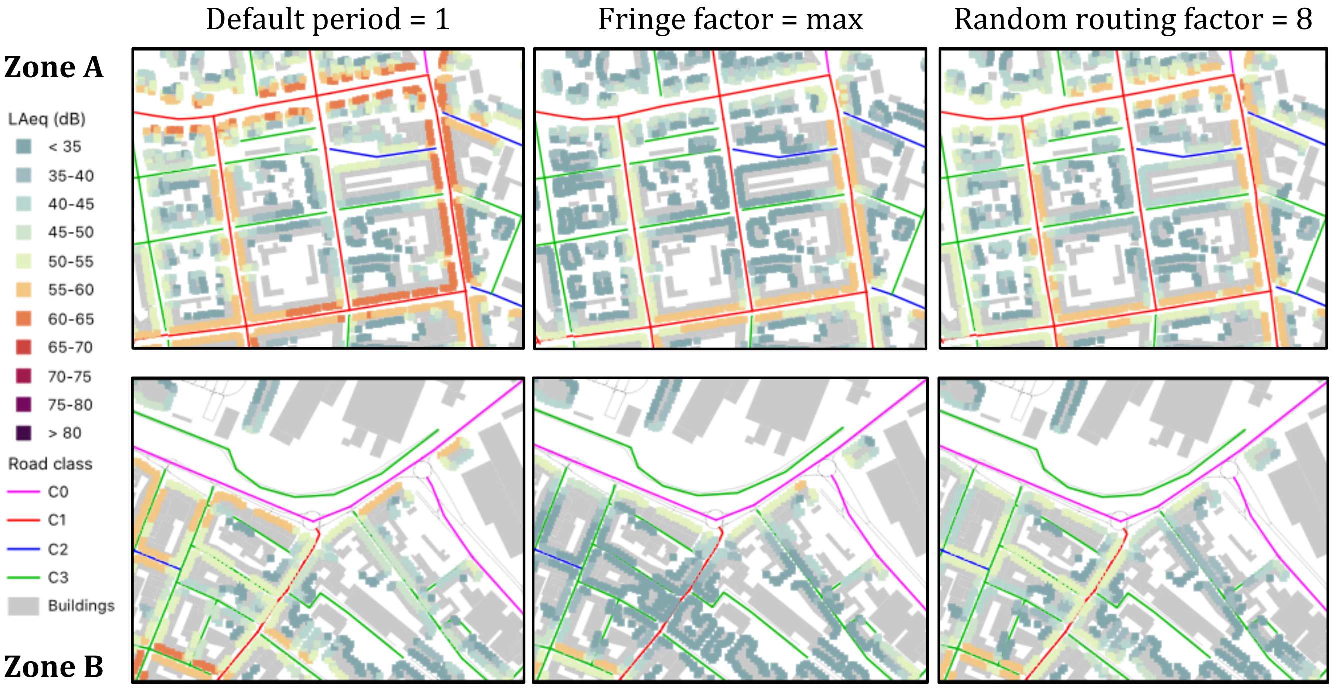

Figure 7: Zone A (residents) and Zone B (industrial and commercial) noise exposure map.

In Zone A for the default period, it is noticeable a stratification of noise exposure of the residents in relation to the street categories. Using a maximum fringe factor generally decreases the noise exposure at the receivers since there are fewer vehicles starting or ending a trip inside the city. On the other hand, when a large random routing factor is used, the noise exposure at the receivers on C3 streets rises by forcing traffic to take alternative routes to the main roads. However, this action decreases the overall noise exposure of the area.

Although Zone B shows the same tendencies, noise has a minor impact on residents because the area is mainly industrial and commercial. Forcing trips to not remain in the city (fringe factor max) does not show a significant increase in noise exposure around the main access road (C0) to the Port. This could indicate a lack of information in the traffic model indicating Port is another important way to enter and exit the city which must be implemented. The increment of the random routing factor uniformly increases the noise exposure on the receivers near streets C3 to similar levels seen in the default scenario.

4. DISCUSSION AND CONCLUSIONS

Looking at the default values simulation results, it can be observed that the analyzed edges present low traffic volume and low vehicles' travel speed. These results can be explained by the presence of congestions in the network, which prevent a regular flow. This hypothesis is supported by the fact that marginal roads (C3) show higher speed and higher flow, while having lower speed limits and lower capacity. Using calculated period, the traffic flow increases except in C0 roads while the average speed decreases for all categories, reproducing a scenario of an even stronger congestion. Thus the obtained results have limited relevance for situations where smoother traffic flow is present.

The exposure results highlight how the use of tools like SUMO to produce traffic estimation for noise mapping purposes cannot be carried out without an appropriate acoustic calibration. In addition to the period which is intuitively a relevant parameter, other less intuitive parameters, such as the randomization of the routes, can be decisive for an accurate representation of the real exposition. Indeed, routing parameters have been shown to slightly affect average traffic flow and speeds, but they affect traffic distribution and local exposure values, as shown in Figure 7.

The present work is a contribution towards the definition of calibration criteria for traffic simulations to produce accurate noise maps capable of describing urban situations of special interest. This study opens a debate about the choice of parameters for traffic models to complement field traffic measurements. It underlines the importance of defining calibration cases, as it is difficult to create a single scenario as a representative of all the situations in the dynamic contexts in an urban environment.

Future works aim to determine how to properly cross-validate this tool considering the estimated noise as the key factor in order to produce accurate noise maps. Consequently, it is important to develop and test effective solutions to implement action plans through an appropriate traffic management approach to reduce the noise exposure of the population and tourists in cities.

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