AN OPEN-SOURCE PIPELINE IN NOISE MODELLING AND NOISE EXPOSURE REDUCTION IN A PORT CITY

Alexandra L. Montenegro, Dulia Melluso, Gianmarco Stasi
Department of Earth Science, University of Pisa, Pisa, Italy
Andrea Panci, Matteo Bolognese, Diego Palazzuoli, Mauro Cerchiai, *and*
Gaetano Licitra
Environmental Protection Agency of Tuscany Region (ARPAT), Florence, Italy
email: g.licitra@arpat.toscana.it

Ports and their associated transportation infrastructures create a complex noise environment, necessitating comprehensive characterization and exposure mitigation in alignment with EU Directive 49/2002. Within transportation infrastructures, road traffic typically emerges as the predominant noise source, particularly in urban areas with commercial or tourist ports. SALPIAM project, under the PNC-PNRR Italian financial framework, is dedicated to implementing targeted measures to enhance the capacity for assessing the environmental impact and health implications of cities hosting port areas, with a specific focus on noise and air quality. One of the project's focal points is the Municipality of Piombino, where predictive open-source systems for real-time traffic management will be developed to mitigate urban noise exposure. The system will suggest real-time traffic flow modulation on various roads to and from the port, aiming to reduce noise impact in urban areas by minimising the exposure of the population. This study presents preliminary results from the implementation of a comprehensive open-source pipeline by using a microscopic traffic simulation tool through SUMO and NoiseModelling software.

Keywords: noise mapping, port noise, traffic management, urban environment, simulation.

1. Introduction

One of the major environmental issues in urban contexts is the transportation noise and measures to manage and reduce citizens' exposure to it. According to the European Environmental Agency [1] long term exposure to environmental noise is estimated to be responsible for 12000 premature deaths contributing to about 48000 new cases of ischaemic heart diseases per year in Europe. Moreover, chronic high annoyance affects 22 million people, and 6.5 million people suffer chronic high sleep disturbance [2]. On the other hand, noise mapping data according to the Directive 2002/49/EC (END) [3] could underestimate negative health effects as new WHO exposure limits stated [4].

END Directive stipulates the obligation for Member States to define noise maps according to common methods [5] describing noise exposure from "road traffic, rail traffic, air traffic, and industrial activity" with emphasis on noise from ports in agglomerations (Annex IV). Strategic noise maps in agglomerations also provide the basis for action plans. Noise mapping in port sites, especially in urban areas, are usually very challenging [6] and no standard, specific procedures or regulation are well defined or tested [7][8].

Among different noise sources in port areas and its urban environment, road noise is one of the most important for people exposure [9][10] and represents a priority to be addressed in action plans.

Real-time or near-real-time road noise estimation tools are useful instruments to adopt actions for reduce noise exposure in urban areas. Traffic simulations are a promising input for noise prediction due to the lack of sensitivity to anomalous noise events which instead can invalidate real time noise predictions in urban areas [11][12]. Traffic models mimic the dynamic behaviour of individual vehicles on a defined road network updating their position and speed at each time step [13]. Some approaches are presented in literature about traffic simulation and noise prediction [14][15].

The present work has been developed as part of the national project PNC - PREV-B-2022-12376988 "*Sostenibilità per l'ambiente e la salute dei cittadini nelle città portuali in Italia*" (SALPIAM), under the Italian PNC-PNRR financial framework, which aims to decrease environmental impact of Ports from different perspectives, developing innovative solution in five Italian harbours: Bari, Brindisi, Cagliari, Genova and Piombino. In the last one, the project is developing a real-time scalable noise prediction tool based on open-source software and existing traffic monitoring system installed under the Interreg Maritime L.I.S.T. PORT[1] project suitable for classifying traffic according to CNOSSOS-EU categories [5]. In the following sections, the feasibility of using SUMO software [13], calibrated with 4 traffic counters, coupled through Python with NoiseModelling software [16] to produce noise maps is shown.

2. Methodology

2.1 Study case

This study was carried out in Piombino city, located in the central coastal area of Tuscany region in Italy. The population is 34419 inhabitants, with 98.3% of them in the urban area. The principal economic activity in Piombino is related to the Port activities. The city's main road (Figure 1) provide access to the historic centre and welcome tourists who travel to nearby islands, especially in the summer season.

Figure 1: Main roads connecting port areas of Piombino and the L.I.S.T. project traffic flow counters.

2.2 Dynamic noise model framework

First, a digital model representing the case study city is generated from OpenStreetMaps[2] (OSM) data by using QGIS, over this model the noise exposure at the defined receivers is mapped by using NoiseModelling [16]. Afterwards, historical traffic and speed measurements as defined in the CNOSSOS-EU [5] are provided by traffic flow counters installed along the main road as depicted in Figure 1.

[1] https://interreg-maritime.eu/web/listport
[2] https://www.openstreetmap.org/copyright/en

Furthermore, a traffic simulation scenario is generated in the SUMO software [13]. The results of the traffic simulation are used to calculate the noise emission of the vehicles and the respective immission at the receivers and at the measurement points by using NoiseModelling. The following figure shows the flow of the overall developed open-source pipeline.

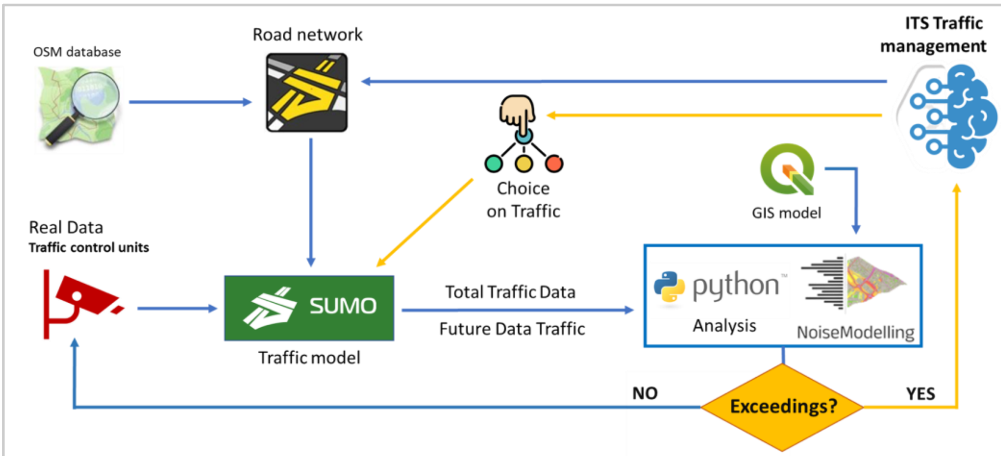

Figure 2: Open-source pipeline for dynamic noise modelling and real-time traffic management to mitigate urban noise exposure.

3. Results

3.1 Noise model

To build the digital model of Piombino, official digital elevation model (DEM), buildings and its residential population were downloaded from a local database[3], and land cover classification was extracted from a European database [17]. Subsequently, all the geographic information was organised and adapted by using QGIS, since NoiseModelling is very restrictive in terms of labelling, data type and geometry. The Table 1 mention the parameters configured to create the digital model of Piombino:

Table 1: Digital model description and parameters.

Object type	Nº	General description	Acoustic absorption	Ref.
Buildings	5485	170 Ha of total area	G = 0,4	[18]
Receivers	32828	1 m from the road geometry. 4 m above the floor (height). 5 m of distance between receivers (delta). Distance of 0,01 m from the building facade	—	[5]
Roads	13358	Pavement type NL08: Fine broomed concrete surface	—	
DEM	313117	Definition: 10 m. Elevation from 0 m to 249 m	—	—
Ground	6536	2240 Ha of forest, bughouse, and park area	G = 1	[19]
	637	783 Ha of residential land use	G = 0,5	
	34	12 Ha of water bodies	G = 0	

[3] https://www.regione.toscana.it/-/geoscopio

Typically, historic centres are urban areas where buildings are located very close to each other, and their geometrical representation overlap between them. To avoid NoiseModelling bugs, the validation of the buildings generates a minimum buffer between buildings around 0,05 m. Which later has an impact on some receiver points created with the script[4] falling inside the adjacent building.

Consequently, a spatial analysis methodology was implemented in which the internal points were removed, and the total population of each building was appropriately assigned for only those receiver points exposed to the streets by using QGIS script. Although this methodology is not completely error-free, it is far more accurate than keeping the internal points as valid receivers (Fig. 3).

Figure 3: Spatial correction to generated receivers. Red points were discarded as their associated building has 0 population. Black dots are those internal points of adjacent building. Green dots represent the total receivers.

3.2 Traffic and speed measurements

A test run was performed using peak traffic data recorded by the traffic monitoring network. According to measurements in European cities [20], Tuesdays, Wednesdays and Thursdays are similar in terms of road traffic noise on the same street, therefore these days are considered equivalent.

Traffic data are collected from the road traffic detection cameras in the municipality of Piombino, which are set up to detect traffic by direction. The measurement takes a sample of data from August 14th, 2021, from 10:00 to 11:40, which is a period of heavy traffic due to the port's tourist activity: more than 1200 vehicles/h in each direction in STM 3 (Figure 4).

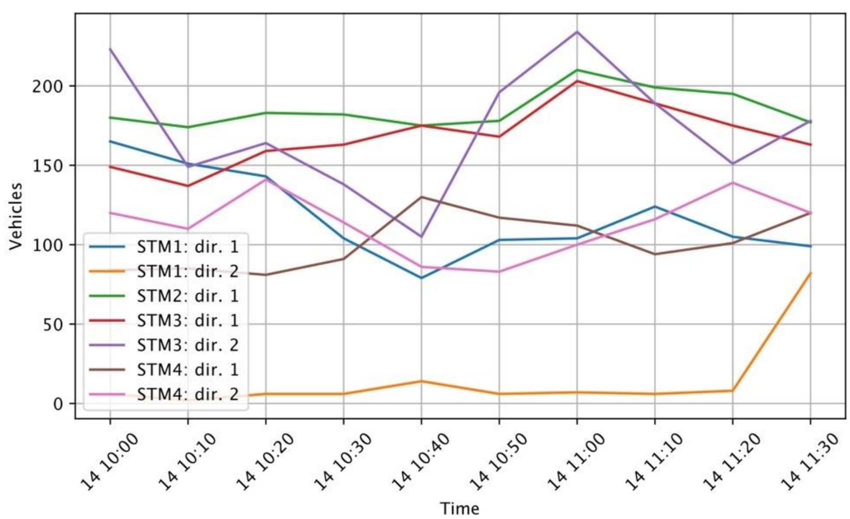

Figure 4: Total traffic flow per direction measured during the simulation period by each station.

[4] Receivers/Building_Grid.groovy

3.3 CNOSSOS-EU traffic categorization (SUMO)

3.3.1 Traffic assignment

SUMO allows the definition of several vehicle properties to each vehicle class in the road network. An early scenario model has considered a SUMO classification of vehicles (vClass)[5] based on the CNOSSOS-EU categories. A comparison with the main detailed parameters is given in Table 2.

Table 2: CNOSSOS EU categories by using some default vehicle type parameter from SUMO.

CNOSSOS category		SUMO classification				
ID	Description	vClass	length	minGap	accel (a_{max})	maxSpeed (V_{max})
1	Light vehicles	passenger	5 m	2.5 m	2.6 m/s^2	200 km/h
2	Medium heavy vehicles	delivery	6.5 m	2.5 m	2.6 m/s^2	200 km/h
3	Heavy duty vehicles	truck	7.1 m	2.5 m	1.3 m/s^2	130 km/h
4a	Mopeds, tricycle, or quads < 50 cc	moped	2.1 m	2.5 m	1.1 m/s^2	45 km/h
4b	Motorcycles, tricycle, or quads > 50 cc	motorcycle	2.2 m	2.5 m	6 m/s^2	200 km/h

3.3.2 Road network

A transport network was prepared by importing an OSM database as a basis by using netconvert[6] script. The case study city was visited several times to verify the allowed movements at intersections among others. The road geometry and traffic design was checked by using Netedit[7] software.

The calculations of the traffic simulation software do not use the geometry of the road network itself, instead it simplifies it by only capturing the nodes and the distances between them through edges and lanes to calculate the travel time. Consequently, it is not possible to directly export the generated traffic associated with the georeferenced transport network. Hence, a geometric network extraction methodology has been developed by using Python script and validated in QGIS beforehand for use as a valid zero emission road[8] and a dynamic traffic noise source in NoiseModelling. Figure 5 provides a capture of the entire 172.33 km^2 network area, it was georeferenced and exported. The total edges were 4824 (one lane: 4630; two lanes: 157; three lanes: 26; 4 or more lanes: 11). Each of them were associated with an ID, traffic flow and speed for each vehicle category. Total edge length was 1191.53 km, with 2249 nodes.

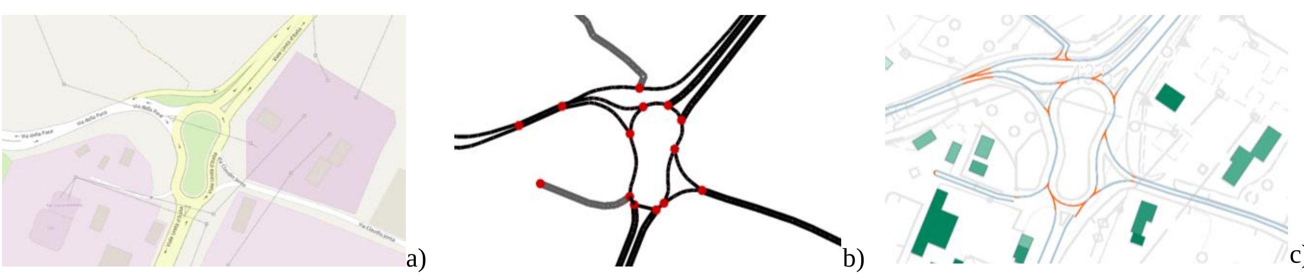

Figure 5: Geo-referenced network exported from SUMO. OSM view (a). Netedit view (b). QGIS view (c).

[5] https://sumo.dlr.de/docs/Vehicle_Type_Parameter_Defaults.html
[6] https://sumo.dlr.de/docs/netconvert.html
[7] https://sumo.dlr.de/docs/Netedit/index.html
[8] Geometric_Tools/ZerodB_Source_From_Roads.groovy

3.4 Dynamic noise model

3.4.1 Attenuation matrix

The attenuation matrix is pre-computed once and describes the noise propagation path between the sources and the receivers for different environmental scenarios setting as emission a null road sound power level (Lw), considering the receivers position, buildings geometry, DEM and land cover of the model by using NoiseModelling[9]. The order of reflections was 0, with horizontal diffraction, and a maximum reflection distance of 50 metres from the source. A maximum distance between source and receiver of 150 metres was specified. Air temperature of 15ºC and relative humidity of 70 % were set.

3.4.2 Sound power level

The sound power level (Lw) of each road segment is calculated from the traffic and speed results generated by the traffic simulation. CNOSSOS-EU road traffic noise emission model is already implemented in NoiseModelling[10]. Thus, the 15 minutes average traffic count and speed simulated in SUMO for each vehicle category were the principal inputs. The road slope (%) was adjusted by the DEM and a Python script was used to prepare the input file for the dynamic noise map script.

3.4.3 Noise exposure

To calculate the noise exposure every 15 minutes, the Lw of the road network was upgraded with each quarter hour traffic simulation. A NoiseModelling script[11] was modified and the whole road network, buildings and receivers were the same for every new calculation. The result is the sound exposure level at each receiver point, in terms of overall L_{Aeq} and L_{eqZ}, as well as its octave band spectrum.

3.5 Calculation performance

A standard computer was used to test the calculation performance of the developed pipeline. Our setup utilizes a 12th Gen Intel(R) Core(TM) i3-1215U, on 1.20 GHz clock speed, 6 cores and 8 total threads, RAM Capacity 8192 MB at 3200 MHz, with an SSD of 256 GB capacity, and a GPU Model Intel(R) UHD Graphics of 4066 MB, serves as the computational workhorse. The version of SUMO was 1.18.0, powered by Python 3.11.2 and NoiseModelling 4.0.5. The test was performed over 10 simulation intervals, each of them corresponding to 10 min of traffic monitoring. Random Trips generation, database initialization and matrix calculation were performed only once as preliminary calculations. Results are reported in seconds in Table 3.

Table 3: Calculation performance of the developed open-source pipeline to calculate dynamic noise maps [s].

	Preliminary calculations			Dynamic noise map				
	Attenuation matrix	Random trips	Database initialization	Route sampler	SUMO	Sound power level	Noise exposure	Total
Result	43 min	1.7	5.4	4.0	2.7	15.3	49.8	72.0
Dev. St.	-	-	-	0.4	0.2	1.8	1.6	3.1

9 NoiseModelling/Noise_level_from_source.groovy
10 NoiseModelling/Road_Emission_from_Traffic.groovy
11 Experimental_Matsim/Noise_From_Attenuation_Matrix.groovy

4. Discussion

The presented results shown how an integrated traffic and noise simulation pipeline for dynamic noise mapping can be implemented using open-source software preserving CNOSSOS-EU classification throughout the entire process. Calculation times prove that, after the initial calculation of the attenuation matrix, near to real-time dynamic noise mapping can be achieved for the test case with a common PC. In any case, minor critical aspect can be spotted and there is room for improvements to be implemented.

Since each receiver point represents a portion of the potentially exposed building population, it could be used to calculate several descriptors. However, the population described is static, as it corresponds to the inhabitants of each building. Future work may consider using the developed pipeline with a dynamic population which could be associated with their daily activities.

The SUMO vehicle classes, and its parameters are completely customizable allowing it to enrich the network vehicle fleets much more detailed than CNOSSOS-EU categorization. The definition of heavy-duty vehicles distinguishing between transit bus and trucks for Port freight activities will be implemented in future works to explore traffic management options. Enhancing the vehicle classification may increase the traffic model computational time, but it could be less resource intensive than the road network representation. This feature could also allow better vehicle recognition with traffic counters or monitoring cameras with AI [21] to improve the traffic simulation accuracy.

Considering that not every city road has cameras, complementary information is needed. Exploratory studies have shown that on uncongested roads with two lanes in each direction it is possible to estimate vehicle flow by extracting travel times from Google APIs and Big Data processing [22]. Hence, travel times and information on congested areas could be used to improve the traffic model estimation of main secondary and tertiary roads. The developed tool could support the definition of traffic routes by dynamic alerts on roadside panels or with dedicated messaging to drivers. Such systems could be useful as dynamic action plans to be implemented during the static five-years END one as complementary actions.

5. Conclusions

An open-source pipeline has been presented, enlightening principal nodes to provide real-time information on road traffic noise levels at the receivers, allowing consequent action to redistribute traffic flow on the network to minimise noise exposure. The developed system will be implemented in the SALPIAM project with the aim of providing time-dependent noise maps useful for the END requirements, while reducing the need for expensive software.

The implementation of the developed system represents a useful tool for monitoring the exposure of the population to road traffic noise and a planning tool for municipalities. Once up and running, it will be possible to evaluate indicators complementary to the END descriptors. The low cost of the system integrated with traffic monitoring systems makes it a feasible solution for small municipalities and smart cities which are not only surrounded by port activities, but also generally impacted by traffic from industrial activities.

Acknowledgements

The present work has been developed as part of the national project PNC - PREV-B-2022-12376988 *“Sostenibilità per l'ambiente e la salute dei cittadini nelle città portuali in Italia”* (SALPIAM), under the Italian PNC-PNRR financial framework.

REFERENCES

1 European Environment Agency. Report No 22/2019, Environmental noise in Europe, (2020).

2 Houthuijs, D., Swart, W., and van Kempen, E. Eionet Report - ETC/ACM 2018/10, Implications of environmental noise on health and wellbeing in Europe, (2019).

3 Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise. Consolidated text published 29 07 2021, (2021).

4 World Health Organization. Environmental Noise Guidelines for the European Region, (2018).

5 Directive 2015/996/EU of 19 May 2015 establishing common noise assessment methods according to Directive 2002/49/EC of the European Parliament and of the Council, (2015).

6 Fredianelli, L., Gaggero, T., Bolognese, M., Borelli, D., Fidecaro, F., Schenone, C., and Licitra, G. Source characterization guidelines for noise mapping of port areas. *Heliyon*, **8**, (3), e09021. (2022).

7 Weber, M. Urban development in the port area of Rotterdam: challenging noise constraints, *Proceedings of the 8th European Conference on Noise Control*, Edinburgh, Scotland, 26–28 October, (2009).

8 Huenerberg, J. and Knauss, D. Noise control of harbors, *Proceedings of the 8th European Conference on Noise Control*, Edinburgh, Scotland, 26–28 October, (2009).

9 Murphy, E. and King E.A. Residential exposure to port noise: a case study of Dublin, Ireland. *Proceedings of 41th INTER-NOISE and NOISE-CON*, USA, New York City, 19–22 August, (2012).

10 Alsina-Pages, R.M., Socoro, J.C. and Bergad P. The impact of man-made noise on the passenger transport stations of port of Barcelona. *Proceedings of 48th INTER-NOISE and NOISE-CON*, USA, San Diego, 26–28 August 2019, (2019).

11 Wei W., Van Renterghem T., De Coensel B., and Botteldooren D. Dynamic noise mapping: A map-based interpolation between noise measurements with high temporal resolution, *Appl. Acoust.*, **101**, 127–140, (2016).

12 Sevillano X., Socoró J.C., Alías F., Bellucci P., Peruzzi L., Radaelli S., Coppi P., Nencini L., Cerniglia A., Bisceglie A., Benocci R., and Zambon, G. DYNAMAP – Development of low cost sensors networks for real time noise mapping, *Noise Mapp.*, **3** (1),172–189, (2016).

13 Alvarez Lopez, P., Behrisch, M., Bieker-Walz, L., Erdmann, J., Flötteröd, Y., Hilbrich, R., Lücken, L., Rummel, J., Wagner, P., and Wießner, E. Microscopic Traffic Simulation using SUMO. *Proceedings of the 21st IEEE International Conference on Intelligent Transportation Systems*, USA, Maui, 4–7 Nov., (2018).

14 Le Bescond, V., Can, A., Aumond, P., and Gastineau, P. Open-source modeling chain for the dynamic assessment of road traffic noise exposure, *Transp. Res. D: Transp. Environ.*, **94**, 102793, (2021).

15 Baclet, S., Khoshkhah, K., Pourmoradnasseri, M., Rumpler, R., and Hadachi, A. Near-real-time dynamic noise mapping and exposure assessment using calibrated microscopic traffic simulations, *Transp. Res. D: Transp. Environ.* **124**, 103922, (2023).

16 Bocher, E., Guillaume, G., Picaut, J., Petit, G. and Fortin, N. NoiseModelling: An Open Source GIS Based Tool to Produce Environmental Noise Maps, *ISPRS International Journal of Geo-Information*, **8** (3), 130, (2019).

17 European Environment Agency (2023): https://doi.org/10.2909/71c95a07-e296-44fc-b22b-415f42acfdf0

18 European Commission Working Group Assessment of Exposure to Noise. Good Practice Guide for Strategic Noise Mapping and the Production of Associated Data on Noise Exposure V2, (2007).

19 UNI/TS 11387:2010. Acoustics - Guidelines to support noise mapping and strategic noise mapping - Noise mapping procedures, (2010).

20 Brambilla, G., Benocci, R., Potenza, A. and Zambon, G. Stabilization Time of Running Equivalent Level LAeq for Urban Road Traffic Noise, *Applied Sciences*, **13** (1), 207, (2023).

21 Fredianelli, L., Carpita, S., Bernardini, M., del Pizzo, L.G., Brocchi, F., Bianco, F., and Licitra G. Traffic Flow Detection Using Camera Images and Machine Learning Methods in ITS for Noise Map and Action Plan Optimization. *Sensors*, **22**, 1929, (2022).