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Classification of Noise Sources for Port Area Noise Mapping

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Abstract: Maritime transportation is recognized to have advantages in terms of environmental impact compared to other forms of transportation. However, an increment in traffic volumes will also produce an increase in noise emissions in the surroundings for a greener source, as ports are frequently surrounded by urban areas. When more sources or higher noise emissions are introduced, the noise exposure of citizens increases, and the likelihood of official complaints rises. As a consequence, among the most demanding aspects of port management is effective noise management aimed at a reduction in the exposure of citizens while ensuring the growth of maritime traffic. At the same time, the topic has not been thoroughly studied by the scientific community, mostly because port areas are challenging from a noise management point of view; they are often characterized by a high degree of complexity, both in terms of the number of different noise sources and their interaction with the other main transportation infrastructure. Therefore, an effective methodology of noise modeling of the port area is currently missing. With regard to the INTERREG Maritime Program, the present paper reports a first attempt to define noise mapping guidelines. On the basis of the current state-of-the-art and the authors' experiences, noise sources inside port areas can be divided into several different categories: road sources, railway sources, ship sources, port sources, and industrial sources. A further subdivision can be achieved according to the working operation mode and position of the sources. This classification simplifies actions of identification of the responsible source from control bodies, in the case that noise limits are exceeded or citizen complaints arise. It also represents a necessary tool to identify the best placing of medium/long-term noise monitoring stations. The results also act as a base for a future definition of specific and targeted procedures for the acoustic characterization of port noise sources.

Keywords: port noise; harbor noise; noise mapping; noise sources; ship noise; noise emission; sustainable management; harbor noise; noise characterization; noise complaints; environmental pollution

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1. Introduction

Maritime traffic has constantly increased in recent years, and, despite the effects of the recent pandemic, it is expected to continue its growth [1]. This will inevitably lead to an increase in noise emitted in the environment, if no proper management is established. It is known [2–4] that ships in the open sea have a non-negligible effect even on marine mammals, which use long-range underwater acoustic signals. On the other hand, in ports, they represent moving sources placed at significant height and with broad noise spectra, with low frequency components that can propagate at considerable distances [5]. Considering all the activities connected to ports, which often act as industrial sites too, the port represents an area with high noise potential that, in many cases, is close to inhabited areas.

Around the world, the ports that represent critical issues for the surrounding communities could be manifold; however, there are very few assessments of citizens' exposure to port noise at the moment. Without proper management and with the expected growth in traffic, the impact of noise will only become worse in the years to come. Excessive noise emissions and consequent complaints from citizens could also compromise the natural growth of maritime traffic.

In fact, nowadays, it is finally clear that prolonged exposure to noise can affect human health in a direct or indirect way. Direct effects can even cause permanent hearing loss; they occur when the sound pressure levels exceed 75 dB(A), but the effects on subjects depend on the duration of exposure and the sensitivity of the individual. Prevention of direct effects is a success of previous decades, and exposure is far below the direct effect threshold, except for cases in work environments [6]. However, below this threshold is where indirect effects on health can occur, which are equally important in cases of prolonged exposure. Student learning disabilities due to reduction in speech intelligibility in the classroom [7], hypertension and cardiovascular disease [8], sleep disturbance [9], and annoyance [10] are the most important indirect (or nonauditory) health effects of noise pollution.

In order to prevent such effects, the scientific community has extensively studied the most impacting sources on land, which are the major transportation infrastructure and the industries. Road and railway traffic and airports have received a large amount of attention from the scientific community in all aspects, from their noise generation mechanisms [11–13] to their propagation; the mapping of their impact on land and the population [14,15]; and their mitigation with innovative solutions, such as low-noise pavements made of recycled materials [16,17], real time monitoring systems [18,19], and sustainable mitigation solutions [20–22].

The marginalization of port noise with respect to the major sources of infrastructure starts at the regulatory level, which is never properly treated and excluded from the strategic noise maps required by the European Noise Directive (END) [23] only for the main roads, railways, airports, and urban centers. As a consequence, ports have been poorly studied in the past, and only in recent years, some studies or projects concerning noise impact have been conducted [24–26]. Aiming at the acoustic characterization of a ship's sources, several authors studied noise emitted at berths [27–29], while our previous work dealt with small and large vessels in movement [30,31]. In addition to ships, many different sources (cranes, forklifts, reach stackers, etc.) have different functions in ports, and they should all be included in a proper acoustical description of the port area and noise exposure assessment, which are generally performed with a noise map of the studied area.

The acoustic mapping phase is not helped by this status of infancy in which the acoustics field of study in ports lies. In fact, in order to properly define outputs, a noise model needs precise inputs, i.e., the best acoustical characterization of the sources.

In order to improve this situation, the INTERREG Maritime programme [32] addresses the problem of port noise from different points of view through a set of projects. Precisely, because the present literature is poor and still in its early stages, the projects need to act quickly, outlining the guidelines for acoustic mapping in port environments. Such a result will allow all ports to be held to the same standard, and their results would also be comparable.

After introducing the INTERREG Maritime programme, the present paper explores the issues in the acoustic characterization of a port area through the authors' in-field experience and from the analysis of the scientific literature. Generally, inhabited areas close to operational ones, many and different noise sources, connected road and rail traffic and the lack of specific regulations are the most frequent obstacles. This analysis shows that a proper acoustical characterization of the main sources acting in ports is still an unsolved task because of the many different sources and the issues arising when measuring in such a complex environment with non-negligible background noise.

The present work therefore analyzes all the noise sources present in a port environment that must be considered for developing acoustic map properly, with the aim of defining the inputs that reduce the uncertainties on the output of the model. At first, sources are divided into macro-categories based on their characteristics, and, then, are further subdivided following different criteria, such as their activity mode or location. This classification would be useful for competent authorities to properly assign responsibilities of noise exceedances and then find the most impacting activities, in order to develop appropriate noise mitigation actions. Further studies aimed at defining specific measurement protocols of noise produced by sources would benefit the division into categories.

2. INTERREG Maritime Programme

The INTERREG Maritime programme Italy-France 2014–2020 was conceived to fill the knowledge gap regarding port noise. Different projects are being simultaneously carried out in order to describe the current state-of-the-art and pinpoint the best practices in terms of long-term sustainability in the north Tyrrhenian area. The projects currently approved, aiming to assess different aspects of the port noise, are:

- RUMBLE: aims to realize noise reduction infrastructure in big ports.
- MON ACUMEN: has the objective of developing a common monitoring system on the North Tyrrhenian ports;
- REPORT: aimed to develop simulation models, noise evaluation, and noise control strategies producing guidelines;
- DECIBEL: aims at the realization of infrastructure for noise reduction in small ports;
- L.I.S.T. PORT: has the purpose of developing logistics and management models for lightweight and heavyweight vehicle traffic from and to the ports.

The partners involved in this acoustic cluster of projects are:

- Three Italian universities (the University of Cagliari, University of Genoa, University of Pisa),
- One French university (University of Corsica Pasquale Paoli),
- The Italian region of Liguria, two municipalities associations (ANCI Liguria, ANCI Toscana)
- The port authorities of the involved Italian ports (Cagliari, Genoa, La Spezia, Livorno, Portoferraio)
- The Environmental Protection Agency of Tuscany region (ARPAT), two municipalities (Nice Côte D'azur, Olbia),
- Two French Chambers of Commerce and Industries (Nice, Bastia),
- The French research center CSTB, the Corsica's Transports Office.

At the end of the research activities, the REPORT project will aggregate all the results reached in all the different projects to summarize and capitalize them.

The results presented in this paper are obtained by means of the efforts carried out during the three projects involving big ports, i.e., RUMBLE, MON ACUMEN, and REPORT.

RUMBLE is a French acronym that stands for "Noise reduction in large port cities in the cross-border maritime programme". The programme aims at reducing noise emission of ports and logistics infrastructure, developing noise reduction infrastructure in large ports. Analyzing the state of the art in port noise in terms of available technologies and citizens' perception of port noise represents the first step of this programme. In collaboration with MON ACUMEN and REPORT, a common questionnaire was then established, to collect all the available data on port noise in the area of interest, and to perform an investigation on local citizens' perception of port noise. Then, after ante-operam monitoring campaigns, the infrastructure was built, and post-operam noise monitoring campaigns are going to be conducted to evaluate the obtained benefits.

MON ACUMEN is an acronym for "MONitorage Actif Conjoint Urbain-MaritimE de la Nuisance" (Collective Active Monitoring of Urban and Maritime Noise). The aim of this project is tackling noise monitoring and noise management in the port area, in order to allow port authorities to manage port activities in a sustainable way. The project started with an in-depth analysis of the state-of-the-art concerning port noise, noise monitoring, noise measurement, and acoustic characterization of port-specific noise sources. Noise maps of the involved ports are needed to correctly design the monitoring infrastructure.

More specifically, a relation between the different port activities and noise levels at the receivers would allow the project to correctly pinpoint the monitoring position. The goal is to build an integrated monitoring system following common rules for all the ports in the area, which allows real-time simultaneous monitoring of noise in all the ports and, in the case noise exceeds the limits, assess the responsibilities.

Compared to the projects described above, REPORT approaches the issue of port noise from a more theoretical perspective, aiming to develop models that lead to a better understanding of the phenomenon. In particular, the project focuses on the following models:

- modelling ships as a noise source and development of an integrated tool capable of handling ship noise in a similar way as railways noise and road noise in MithraSIG;
- development of a neural network specialized in traffic flow analysis capable of performing real-time prediction of noise levels based on traffic flow and traffic composition data;
- analysis of the newest propulsion technologies (viz.: electric, hybrid, fuel cell and liquified natural gas) in terms of noise reduction when adopted by cargo handling units in port areas and estimation of global noise reduction based on the total adoption of those technologies;
- econometric evaluation of social costs generated by noise pollution in the port area which, excluding the last one, are all in the validation stage.

The validation of the noise model in port areas will be followed by a final document, which will present all the results produced during the INTERREG Maritime programme.

3. Noise Issues around Ports

The present section reports the criticalities in a port environment from an acoustical point of view by means of international published works or authors' direct experiences in some important ports in the Mediterranean Sea.

The main issues about port noise can be summarized in four bullets points:

- proximity of urban areas to noisy areas,
- countless sources that also differ in terms of emissions,
- traffic related to port operations,
- lack of specific regulations.

Paschalidou et al., in 2018, [24], described the port area of Piraeus (Greece) as a complex environment that made a complete representation of the noise environment all but impossible. The authors also underlined the simultaneous and conflictual presence of other big transportation infrastructure and industrial activities. This is an example of the underlying complexity of port noise mapping, which should include all the types of sources required by the END. The Greek work reported the presence of human settlements in the surroundings, without exploring the subject in depth; however, this clearly complicates the situation even further and may potentially lead to annoyance of the population. Still, Paschalidou et al. pointed out that the impact of port activities like container shipping and shipyards can propagate at long distances due to the heavy vehicle traffic flow.

A similar scenario has been described by Schenone, et al. in 2016 with the outcome of the MESP project [33], focusing on some important ports of the Mediterranean Sea like Patrasso (Greece) and Tripoli (Libya). Most of the studied ports present the same shortcomings:

> *"(. . .) if not well planned and managed, they (ports) can also represent a health threat for citizens living in the surrounding area. In fact, an improper and unsustainable management and development of ports usually mean difficult relationships with urban areas in terms of land use, pollution and citizens' quality of life".*

Moreover, Schenone, et al. [33] in a study carried out for reducing noise in the port of Tripoli, paid attention mainly to the noise produced by vehicles/machinery specifically used in a port environment, suggesting the maintenance of ports' equipment such as cranes, forklifts, but also trucks and vehicles. Only road traffic noise was assessed and mitigated with the application of sound absorbing asphalt, speed limit signs along the roads, ban on honking, speed bumps, and cross-roads.

However, besides road traffic, a wide multitude of noisy industrial activities is usually present in port areas, from shipbuilding to oil and gas industries, grain storage facilities, paper processing, and many others. The presence of industrial plants contributes in two different ways to the level of complexity: adding more traffic inside and outside the port boundaries and adding more noise sources in the area, which includes machinery and load/unload vehicles.

Major transport infrastructure near the port areas are usually built around the port, since the port itself often acts as a transport hub where all terrestrial lines converge on their way to seaways. In the last years, efforts have been made to promote intermodality [34], with the aim of reducing the environmental impact of international trade. In medium and long distances, the implementation of intermodality generally promotes the use of maritime transportation instead of rails and roads: as a result, even more terrestrial traffic will be directed towards the ports.

A recent measurement campaign performed by Alsina-Pagès et al. [35] acknowledged the need of an acoustic monitoring in the port of Barcelona, concluding in a consequent work [36] that:

> *"Ports and harbours are logistic nodes characterized by several types of noise, which can usually occur in a concurrent manner in the same harbour premises: ferries, cruises, fishing and trade ships coexist with other industrial and auxiliary services".*

As already stated, ports are also usually surrounded by urban settlements. Therefore, many inhabitants may be exposed to port noise, either directly or indirectly due to terrestrial traffic induced by the port. Moreover, port activities yield a significant impact on noise even at night [37], when human activities in the city usually decrease. The lower background noise means that noise from the port area is even more significant, and influences the soundscape at greater distances.

Murphy and King [38] studied noise exposure of citizens living in the vicinity of Dublin port. Their results showed that citizens were exposed to noise higher than the limits suggested for night-time exposure [39], with a significant low frequency content.

Finally, ships represent a distinctive noise source in the port area and are very variable in terms of size, sound power, and sound spectrum. Loading and unloading operations must be considered in order to properly assess noise emission by ships. The Eco.Port Project reports that the main difficulty found during the characterization of vessel noise emission was the correct evaluation of the background noise, which was heavily influenced by the noise emitted by the urban activities around the ports and the canals of Venice [40].

The study of noise produced by ships is very challenging and requires a specific characterization for each phase occurring during their stay in port environment: moving; maneuvering, mooring, and ground operations. Furthermore, each single ship category has a series of peculiar operations and can emit in different ways, making it impossible to generalize the results. Studies have been dedicated to moored ships, to noise from machinery propagating through hull vibrations, aerodynamic noise produced by funnels, heating and ventilation systems [28,29,41,42]. However, less attention has been paid to cranes or loading/unloading operations. Moreover, noise from moving ships has been studied [43–45], but a proper characterization of vessel noise emission divided into categories has been only reported during the last year [30,31].

As underlined by authors from different parts of the world, the lack of specific regulations regarding noise management in port areas appears to be a common denominator [46–51].

To sum up, the port area presents many critical aspects, such as the high number of sources operating in the port area that work continuously and in a random pattern, the traffic induced by port activities that produces noise far away from the port boundaries and mixes with regular traffic. All these issues have also emerged in the seven ports of the North Tyrrhenian Sea ports involved in the projects Rumble, Report, and Mon Acumen. Excluding the port of Portoferraio, the involved ports are some of the most important ports of Italy and France and, of course, of the entire Mediterranean Sea. Figure 1 shows the positions and affiliations of the ports on a map.

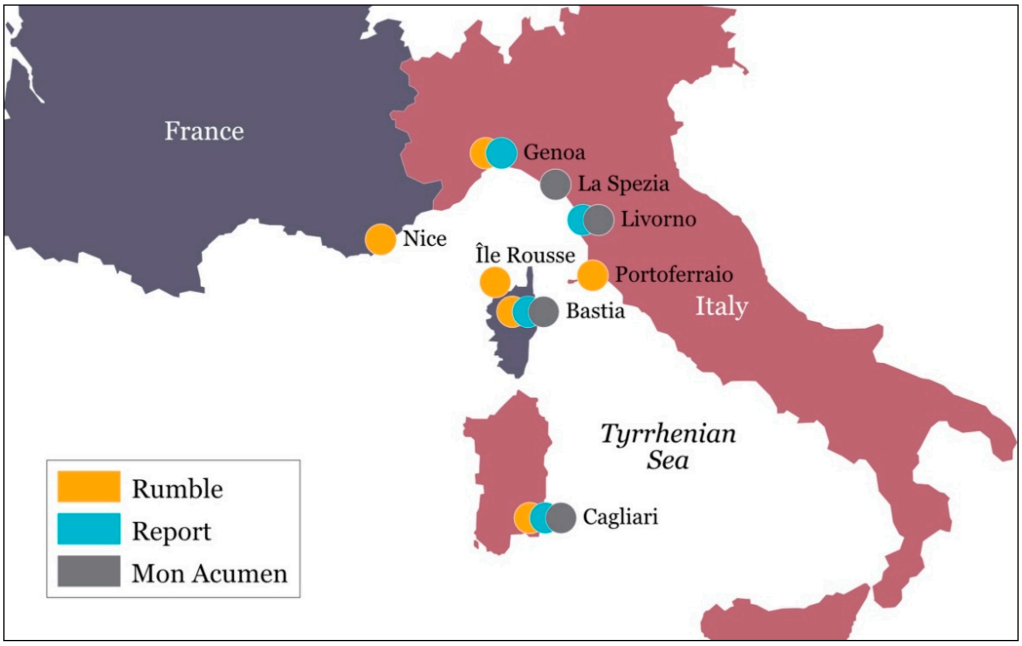

Figure 1. Involved ports in the three INTERREG Maritime programme projects Rumble, Report, and Mon Acumen.

Port noise in Bastia, La Spezia, Livorno, and Cagliari are going to be mapped as part of the MON ACUMEN project. These ports are surrounded by a dense urban environment and important urban road arteries are right between the port areas and the cities. Furthermore, three of them also have railways, mostly used for freight transportation. Other ports in the project show very similar characteristics, in particular the port of Genoa, in which all the criticalities are present in an even worse scenario. The port of Genoa, involved in REPORT and RUMBLE projects, is the most important port of the area in terms of passengers and freight flux and one of the most important ports of the Mediterranean Sea. Moreover, the entire city of Genoa is surrounded by the borders of the port and the slopes of the Ligurian Apennines mountains, a favorable condition for the propagation and reflection of sound rays. As a consequence, the population is even more exposed to port noise. National roads and railways infrastructure are also present between the port and the city.

Industrial plants are present in almost every port involved in the project. As examples of the critical issues of ports with many industrial and operational areas with different machinery (noise sources) and surrounded by inhabited areas, Figures 2 and 3 report Genova and Livorno maps with the area marked according to their use.

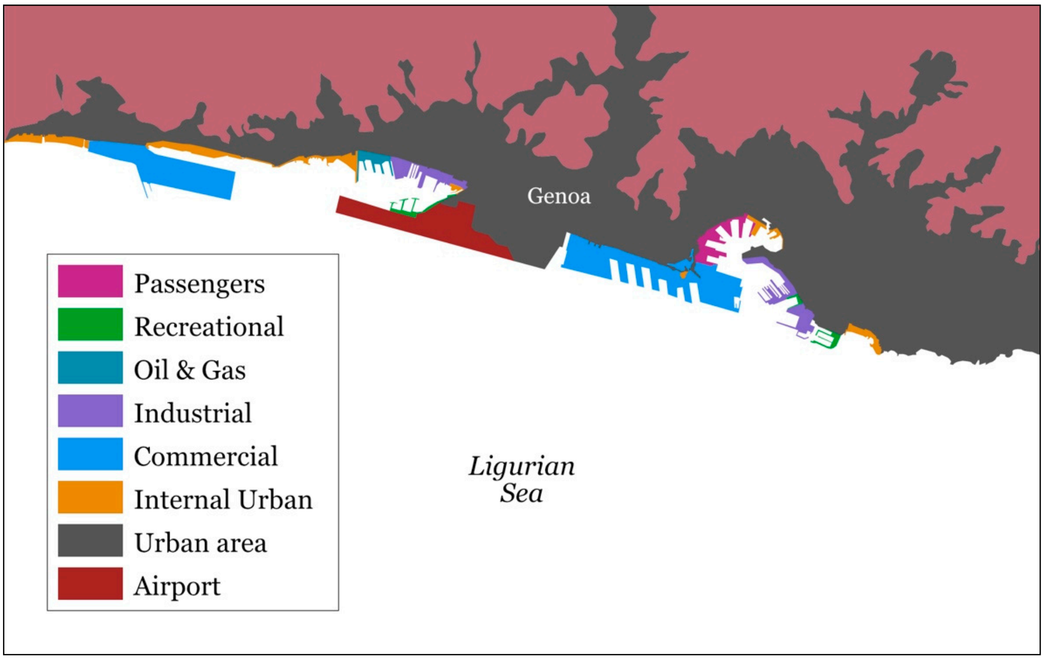

Figure 2. The complex scenario of the city of Genoa, where the port area is completely surrounded by the city.

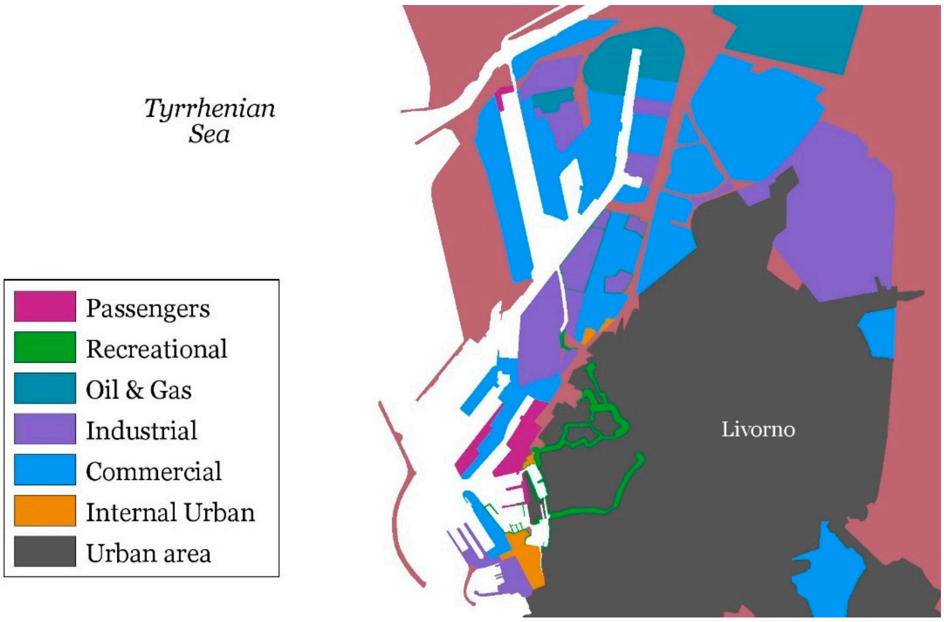

Figure 3. The complex scenario of the city of Livorno, where the port area is completely surrounded by the city.

4. Classification of Noise Sources in Ports

This section summarizes the fundamental elements for producing an accurate noise map, which is an accurate 3D model of the study area, a database including all the involved noise sources and, of course, an acoustical classification of the main noise sources in the area. The first subsection describes the basic requirements shared by all kinds of noise map, while the second one reports the division of port noise sources into categories.

4.1. Base Information for the 3D Model

A comprehensive 3D model of the area is the basic ingredient for accurate noise mapping. The information needed should be well known to the Port authorities and they are usually able to provide it, although it may not be up to date.

A simple clustering of the geographical data could be performed as follows:

- morphological data;
- topographical data;
- buildings.

Elevation points and isohypses are key points for building the Digital Terrain Model (DTM). A correct DTM is useful for a precise calculation of noise propagation, as well as for a proper positioning of buildings and sources. For example, roads and railways sometimes are only provided on a two-dimensional map, which then must be perched on the DTM. Instead, infrastructure maps can be directly included in the DTM when they also have elevations.

Thus, three-dimensional elements that could interfere with sound propagation must be included in the noise map project and they should be carefully perched on the DTM. The following data must be gathered and carefully reviewed:

- residentials and industrials buildings including their height;
- sensitive receivers (school, hospitals);
- obstacles such as acoustical barriers, stacks of containers and similar.

The number of inhabitants in each residential building, as well as the number of students in schools and patients in hospitals, should be retrieved in this phase, for the purpose of drafting an action plan. In fact, eventual noise exceeding limitations, together with the direct comparison with noise maps results and local noise limits would be used with inhabitant's data in order to get the priority index for the action plan activities. Traffic flow data and other data must be acquired for transport infrastructure.

A summary of the elements needed is reported in Table 1.

Table 1. Input data for the 3D model.

Geographical Element	Needed for DTM	Sound Sources	Receivers	Propagation
Elevation points and isohypses	Yes			X
Residential and industrial buildings	No		X	X
Obstacles	No			X
Roads	If provided with elevations	X		
Railways	If provided with elevations	X		
Industries		X		X
Land usage (Corine land cover)				X

4.2. Macro-Categories Subdivision of Noise Sources

The very first division of noise sources in the port area belongs to the NoMEPorts project [52], where the possible sources were divided into "industrial" or "traffic-related" categories. On the basis of the experience acquired with the analysis of the state of the art of port noise [47], a refined classification is here proposed.

The authors found that including in one big group all the sources different than roads and railways is not adequate since noise produced by very different activities or sources, would fall in one category such as:

- ships noise: moving or moored;
- noise produced by the plethora of industrial plants that usually are present in a port area;
- noise produced by the port activities: loading and unloading operations, container handling, boat service operations, etc.

Most importantly, when excessive noise occurs, the right responsible should act to mitigate it. Thus, having all the three classes of sources included in different groups makes the task of assigning the responsibility easier. Even in this regard, a finer resolution of the class can help in correctly identifying the responsibilities.

The relevant macro-categories are defined as:

- road sources;
- railways sources;
- ship sources;
- port sources;
- industrial sources.

In order to perform a finer attribution of responsibilities, a further geographical differentiation has been set starting from the fact that a port area is, by its nature, surrounded and penetrated by other transport infrastructure. While road or railway traffic inside the port boundaries is obviously related to the port activities, outside the boundaries, the port related traffic mixes with the regular one. Thus, even if it can be difficult, the following differentiation is required for both road and railways traffics:

- internal traffic;
- port related external traffic;
- external traffic not generated by port.

At first, for both roads and railways traffic, a single map including all the three components can be produced, but if criticalities arise, the proposed differentiation should be performed and will allow the evaluation of possible port responsibilities.

A deeper description of the proposed groups is presented in the following subsections.

4.2.1. Roads Sources

As discussed before, the traffic flow is divided into three components. The internal traffic could be estimated through flow monitoring at the gate, but the external traffic related to the port could be more difficult to evaluate properly. A traffic monitoring campaign is therefore suggested, but if it is not possible for economical or practical reasons, a traffic model could be applied starting from the gate flow data to estimate the flow distribution on the road network. In any case, the starting point could be a map including all the subclasses is required and specific maps should only be produced after the eventual emergence of noise criticalities. Figure 4 reports examples of road traffic complexity in port areas, where heavy freight flows merge with passengers from ferries and normal traffic.

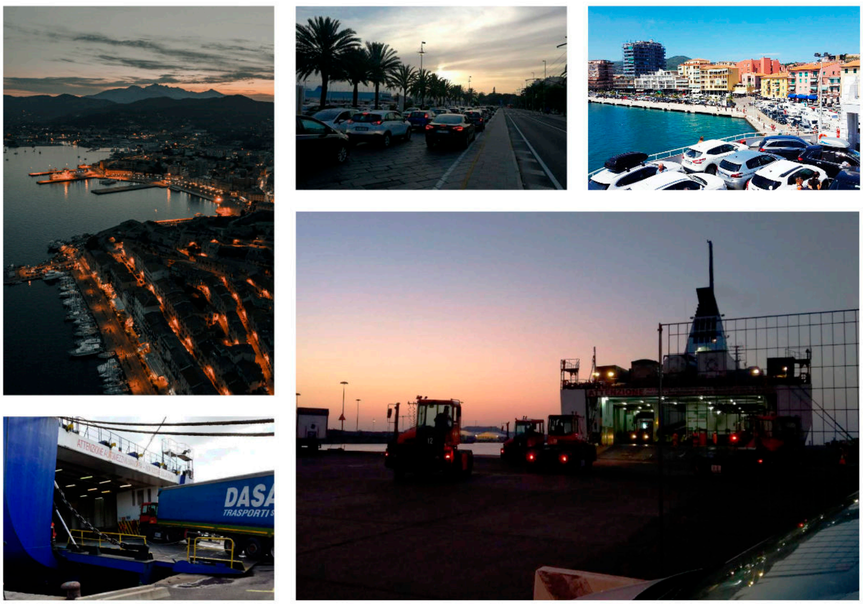

Figure 4. Examples of road traffic complexity in port areas.

4.2.2. Railways Sources

A similar approach to the one used for road sources is used for railways. The main difference is that trains can have a more precise differentiation between port-related and non-port-related traffic. For example, if a port does not present a passenger train station inside its premises, the entire passenger traffic could be considered not related to the port. Moreover, the railway network is likely simpler compared to the road one. For this kind of source, literature is rich and the requirements are the same for a railway noise map. However, differences from standard cases are possible due to the high percentage of freight trains in industrial ports, as reported in the examples of Figure 5.

Figure 5. Examples of railway traffic complexity, including freight trains operations.

4.2.3. Ship Sources

All the activities related to movement and stationing of ships fall in this category.

In the MON ACUMEN protocol, it is then asked to provide sound powers of the ship sources in the two different operational phases for the following categories:

- Ferries;
- Roll-on/roll-off;
- Container ships;
- Cruises;
- Chemical tankers;
- Tankers;
- Pilot boats;
- Tugboats.

The reason behind this choice is simply due to the technical differences between the different classes of ships. Moreover, the difference in the transported material will differentiate the loading and unloading procedures and, therefore, the noise emission. E.g., cruises interest mainly passenger traffic, which will lead to higher levels of induced terrestrial road traffic due to the passengers approaching the port area but will generate low levels of noise in the embarkation phase. On the contrary RoRo load and onload phases are characterized by high levels of trucks and cars right into the ships while ferries stay in between the two with a mix of passengers and trucks rolling on and off the ships. Container ships are completely different because only their loading and unloading phases involve containers only, thus they are characterized by containers impact noises, crane and vehicle warning alarm noises, and container deployment vehicles noise. However, all the loading and unloading operations are included in port sources categories. Different kinds of ships and operations are reported in Figure 6 as examples.

Figure 6. Examples of types of ship, including containers, RoRo, pilot boats, and a canal city view.

Noise emission from moored ships mainly refers to engines, funnel, and ventilation, as well as transits in port regimes. The categorization is mainly based on the type of the ships. Moreover, the tonnage is linked to the tugboats used for the ship maneuvering. Container racks are generally bigger than ferries and Ro-Ros, so they generally need to be maneuvered with the help of one or more tugboats, while smaller boats may be moored without the support of tugboats. Ignoring the presence of the tugboats can lead to an underestimation of the total emission of the ship sources group.

For those reasons, a noise emission characterization during the different phases of operation is needed for all kinds of ships.

Only the ships that yield a significant contribution to noise, i.e., the noisiest or most frequent, should be considered. This would include all the commercial and passenger ships like RoRo, cruises, container ships, tankers, and so on. Smaller vessels like recreational crafts, law enforcement vessels, and fishing boats should be considered only if explicitly required or when a particular disturbance emerges locally. In fact, while their low number currently does not represent an issue for cities like Livorno [30], water transport system could represent an issue for coastal or riverfront cities, such as Hamburg, Bordeaux, Amsterdam, and Venice in the form of water taxi, water bus or private boats noise pollution. In these cities, water transport can be considered as a stand-alone category for a proper assignment of responsibilities in case of noise exceedance.

Considering the population of the ports under study, small vessels are excluded in order to avoid scattering efforts into secondary aspects that would poorly contribute to the total noise emissions [43]. As an example, taking into account the recreational crafts will require long-term noise measurement that are not compatible with the requirements of the projects and, moreover, their noise emission will likely be negligible compared to commercial and passenger ships.

Noise produced by moving and/or stationary sources should be properly divided according to its type. In order to properly implement a single type of ship, different noise sources must be created on the digital model of the port. However, its noise emission can widely vary, based on the chimney elevation, the positioning of the cooling systems' vents, and obviously, it can vary from type to type.

4.2.4. Port Sources

This category includes all the sources directly employed in port-related activities, such as:

- loading and unloading of freight trains;
- loading and unloading of ships;
- service operations.

Examples of these activities are container loading/unloading from container ships, refueling, boarding and landing of vehicles due to RoRo vessels, and containers loading/unloading on freight trains.

Examples of port sources are reported in Figure 7.

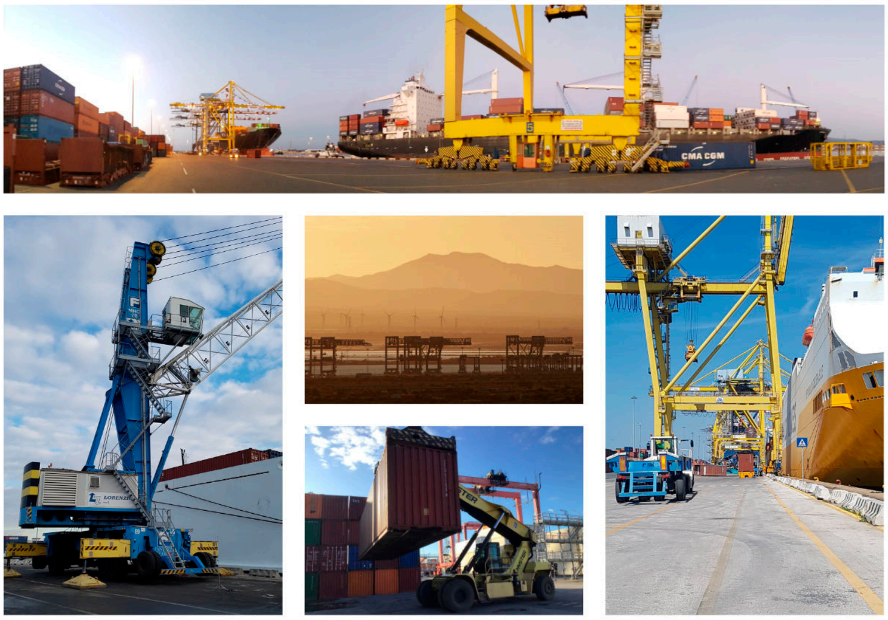

Figure 7. Examples of port sources. On top, a wide-angle view of a quay in the port of Livorno where can be seen containers, a containership and multiple cranes; on the center a view of a containers quay. On the bottom, three images from the Livorno port, from left to right: a portal-crane near a containership, a reach stacker carry a container and a mobile crane.

A further subdivision is necessary to properly describe the sources in such a big classification from an acoustic point of view. The criteria can be whatever it is moving or is fixed. While fixed sources are mainly represented by cranes, even if of different types, movable noise sources working in port areas include a huge variety of vehicles or machinery. The most important of which are straddle carriers, front lifts, contstacker, fork lifts, transtainers, moving cranes, dock tractors, and other cargo handling units.

Moreover, the sources included in this category perform different activities that correspond to different sound emissions. Hence, a unique definition is not sufficient for these sources, which can be characterized by different operational phases that can be grouped into three categories, each of them having different noise emission characteristics:

- transit;
- handling;
- loading/unloading operations.

For each category and phase, a proper measurement campaign aimed at their assessment is needed.

4.2.5. Industrial Sources

All the remaining industrial sources are included in this category, which can be easily described. However, gathering all the information and completing the task with sufficient detail can be very complex. In fact, many industrial sites or activities are close to the port area and they can perform every kind of activity. Thus, many different kinds of noisy machinery can be present. As a first approximation, it is recommended to place utmost care to external sources such as vehicles and industrial machines employed in industrial activities, and to loading and unloading activities related to industries. Sources inside buildings can be included if looking at finer details, as it is not expected that their impact to the receiver would be significant in a port environment.

5. Discussion and Conclusions

The assessment of noise produced by ports has become increasingly necessary because of increase in both passengers and freight maritime traffic. Furthermore, lack of control policies and specific regulations have allowed, over the years, the growth of noisy structures around the ports, such as power plants, logistic centers and industries. The first part of the present paper dealt with the analysis of the literature, combined with the experience gained by the authors in the INTERREG Maritime programme Italy-France 2014–2020. The results highlighted that the increased activities and/or territorial expansion of some ports has led to urban areas too close to noisy environments. To date, only some complaints arose from citizens living near ports, but an increase is expected in the future if the right attention will not be immediately paid to port noise.

The INTERREG Maritime programme aims at improving the knowledge on port noise through a set of different projects. Among all, RUMBLE aims to realize noise reduction infrastructure in big ports, MON ACUMEN has the objective of developing a common monitoring system on the North Tyrrhenian ports, and REPORT aims at developing simulation models, noise evaluation, and noise control strategies. The acoustic mapping phase is the first fundamental step for the assessment of citizens' exposure to noise and its eventual mitigation. MON ACUMEN is also conceived to produce the noise maps of all the ports involved in the project.

In the analysis of noise issues around port areas, the present work focused on showing the lack of studies concerning noise mapping of port areas within the current scientific literature. Very few studies have been dedicated to port noise, mainly because it is difficult and challenging from a characterization and measurements points of view. In fact, this work has shown that there are problems of technical nature, in addition to the lack of specific regulations and the proximity of inhabited areas to noisy areas. The very definition of a port area is a difficult task, given that many activities add to the quays and the loading/unloading areas. Examples are intermodal hubs and all transportation infrastructure, which can also be located at considerable distances from the coast.

The main difficulty lies in the size of ports and in the large number and variety of sound sources they host. The possible sources of noise that can be found in a port range from ships in transit, to stationary ships, generators, maneuvering equipment, cranes, machinery and ventilation systems, but also moving vehicles and trains. Some of these sources have been the object of specific studies, but many others have been overlooked and their different mechanisms of sound generation require specific attention. Moreover, it is often difficult to carry out the census of noisy industrial machinery, given that companies with different internal policies on environmental pollution can be within the territory managed by the port authorities. In addition, both road and rail traffic relating to the port area mix with local traffic, and therefore particular attention is needed when separating the contributions.

After these observations, it is now clear how insufficient previous methods present in the literature, which defined a port noise model based on only two categories of sources: industrial and traffic.

In the present work, after summarizing the basic information requested for the 3D model, the classification of noise sources has been extended to five macro categories, each of different nature or use: road, railways, ship, port, and industrial sources. Each of them has further subdivisions according to their working operation mode or position. Road and railway traffic are divided into internal, port-related external and external not generated by port traffic. Ship noise is divided into movement and moored phases for all the different categories of ships, among which the most impacting are recognized in ferries, RoRo, container ships, cruises, chemical tankers, tankers, pilot boats, and tugboats. Port and industrial categories include the majority of sources and, generally, they can contain the same types of sources. For example, straddle carriers, front lifts, contstacker, forklifts, transtainers, moving cranes, dock tractors, and other cargo handling units can be used for industrial purposes as well as port activities. However, port sources include all those acting during loading and unloading of freight trains and ships or during ship's service operations. Further subdivisions classify the sources into fixed or movable and according to their operational phases, e.g., transit, handling or loading/unloading operations.

A more detailed classification would help the competent authorities to correctly identify responsibilities of noise emission and noise exposure of citizens, a task that is not obvious in such a complex environment.

Moreover, the proposed source classification suggests an analytical approach in the identification of the most suitable position for the sound level meters in the MON ACUMEN project. In fact, a critical aspect that emerged from this study is the definition of the positions of a noise monitoring system aimed at identifying the source responsible for citizens' complaints and at correlating the port activities to noise. If performed correctly, this monitoring could lead to the definition of the relationships between non-acoustic parameters, such as the tonnage of bulk goods exchanged or the total number of passengers, with the average annual noise emission of the infrastructure.

Finally, the main use of this classification is to favor the definition of specific measurement procedures for the sound characterization of the sources. In fact, while the road and railways are well-known noise emitters, nautical sources still require attention from the scientific community. Towards the final goal of defining guidelines for the acoustic mapping in port environments, a detailed classification of the source, i.e., a better definition of the model's inputs, will lead to better outputs and a more precise evaluation of noise exposure. At the end, developing a common strategy will allow all ports to be aligned to the same standard and the noise maps produced will be comparable. The characterization of the noise emission of all the sources during their different phases of operation is underway and future work will also address it.

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