Noise Pollution – Introduction to the State of the Research and the Implementation in the Horizon 2020 Project Pixel

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Abstract

Noise pollution is a significant factor in the modern world. There are many researches dealing with the noise modelling, differing in their purpose, studied influence and the scope of the research, either in geographical terms or in the terms of studied noise sources. The objective of this paper is to give insight in the current state on the field of negative influence that noise has on the environment and/or human health. Special attention was given to the influence that ports' noise pollution has on the surroundings, both on the population and on the environment. Within the influence on the environment, underwater noise, which is often excluded when the main priority is the influence on general population, was also included. As it is one of the main tools for analysing the influence of noise, several examples of assessing the influence of the noise using noise maps are presented. Several objectives of the EU Horizon 2020 project (PIXEL), dealing with the reduction of ports' pollution, were covered. The segment of the project dealing with the noise is linked with the previous achievements, which forms the basis to give some guidelines for the further research of the noise influence on the environment.

Keywords: noise pollution, port pollution, environment, noise map

1. Introduction

Noise pollution has a highly significant influence on human life and nature. There are as many noise pollution sources as there are human activities. Among those activities, a special place is reserved for industry and traffic [1]. There are arguably no areas as affected by both industrial and traffic noise as the areas near the ports.

As stated in [2], the role of ports has changed significantly from its original purpose of handling the ships and the cargoes brought by them. The ports are now complex facilities whose environmental influence is very similar to other areas that are a site of substantial industrial and manufacturing processes. Some of the port activities include resource exploitation, coastal zone industry, inshore fisheries and mariculture [3]. Another issue is that the ports are usually located near urban areas and that any environmental issue that arises from port activities will have a direct consequence on those areas [2].

In the assessment of the influence that ports have on their neighbourhood (and larger areas), there are many things to consider. Port environmental aspects include air emissions (including odour), emissions to water, waste generation, spills, resource use and noise pollution [4]. Those aspects are monitored in a fashion very different from each other and, apart from the noise, won't be discussed in this article. However, it should give the reader a clear vision of the complexity of the port environmental management, as well as the importance of it.

On the following pages, an introduction to the noise pollution and a description of the influence that ports have on noise levels, including underwater noise, is given. A lot of researches are dealing with those two subjects and the objective of this article is to give an insight into some of them. In order to show the more practical side of noise assessment, an example of the procedure is provided, done for the Port of Thessaloniki in the scope of a European Horizon 2020 project PIXEL.

To conclude, the results of the noise assessment procedure are discussed and analysed. There is a comparison of legislated noise levels with the ones that are results of the port activities, as well as a general overview of the noise dispersion in the port area and the influence that individual noise sources and individual groups of noise sources, together with noise barriers, such as buildings, have on the final noise levels.

2. Literature overview

Before dealing with the practical application of the noise assessment, it is useful to provide the current state of the literature, both those dealing with the theoretical background and practical researches. The literature was divided into three groups. The first group includes works dealing with noise pollution in general and noise pollution in fields other than ports, but which are useful for better understanding. It also gives a small history of noise pollution research and methods for its reduction.

The second literature group covers the environmental noise, where the main dispersion medium is air. This group includes researches dealing with noise pollution in ports and is also more relevant for both PIXEL project and this article. The last group deals with a relatively less researched aspect of noise pollution – underwater noise. This group usually contains works dealing with noise pollution of various single sources (such as ships) and not about noise pollution in larger areas, such as ports, although several such examples were included.

2.1. Noise pollution in general and a historical perspective

Research on noise pollution is not a new subject. The importance of the noise impact was recognized in the late 1920s, with the first noise pollution survey being done in 1930 [5]. By the early 1970s, the research on noise pollution has grown significantly, enough to have researchers writing review papers on the available literature, such as [6]. In the paper, it is stated that pollution issues, despite noise being labelled as "New Pollutant" during the 1960's/70's, reach back to antique. However, most of the researches of the era cover the impact that noise has on human health, such as hearing and cardiovascular system, as well as mental health, and less the reduction and control of noise pollution. Despite that, some methods of dealing with noise reduction were also mentioned, such as building barriers and using proper construction techniques. It also mentioned early use of "zoning" - division of a city into several zones, based on their purpose, with different allowed maximum sound levels.

In that paper, several works dealing specifically with the traffic noise were mentioned, such as [7], [8]. Among the works dealing with noise pollution as an environmental issue was [1]. It deals mainly with traffic noise and recognizes it as the main source of noise pollution. Noise sources, monitoring of the noise and relevant predictions schemes are all covered in it.

Recently, in works such as [9], traffic noise is still recognized as the most important noise pollutant, with road noise being the most significant. The article is important for this paper, as it also deals with calculation methods used for road and railways noise, both of which are noise sources in ports.

Can and Aumond made a research about the influence that vehicle speed and acceleration have on noise emissions [10]. They compared various calculation methods based on its handling of speed and acceleration influence on the noise levels. Although acceleration data was not available in the case described later, there were significant differences in the maximal speed and the paper gives an important insight in visualising those differences.

2.2. Environmental noise pollution in ports

Noise pollution is widely recognized as a significant environmental aspect in ports. Most of the ports that have done environmental impact assessment reports mention noise among the most important aspects, such as A Coruña [11], Cartagena [12], Livorno [13], Roses [14] and Valencia [15]. Additionally, 60% of the Vietnamese ports surveyed in [16] stated noise pollution among their most significant environmental aspects. Table 1 shows the most important environmental priorities of European ports for several years. Apart from 1996, the noise was always in the Top-5 priorities [17].

Table 1: Top-5 environmental priorities of the European port sector [17]

	1996	2004	2009	2013
1	Port Development (water)	Garbage / Port waste	Noise	Air quality
2	Water quality	Dredging: operations	Air quality	Garbage / Port waste
3	Dredging disposal	Dredging disposal	Garbage / Port waste	Energy Consumption
4	Dredging: operations	Dust	Dredging: operations	Noise
5	Dust	Noise	Dredging disposal	Ship waste

Papers dealing specifically with the noise in ports are relatively new phenomena, despite noise pollution in airports being a subject from the 1970s onwards. For example, in [18], from 1990, noise in ports is given exactly one sentence.

Even nowadays, papers dealing with noise resulting from port activities are not common. Most of the works deal with single issues, such as [19], which covers the topic of using electric rubber-tired gantries. Ship noise emissions and their propagation are analysed in [20], where the issue of ship noise was accentuated as often overlooked, but important factor in noise mapping. The same authors have also covered the impact of ship noise both inside and outside of the vessels in [21].

Among the papers that cover noise in the ports on a larger scale is [22], which covers a subject of noise pollution in the city of Piraeus, in the form of noise mapping and developing action plans to fight noise pollution. Although the paper deals with most of the significant noise sources in the city, special attention was given to the port, as it has a significant contribution to the total noise levels. Similarly, a case study for two ports (Patras and Tripoli, Lebanon) was conducted as part of another project, outlines of which were presented in [23].

In [24], straightforward noise mapping was done for the port in Livorno. The goals of the research were similar to the goals of this paper – the influence of the noise levels of various sources on the total levels was tested, concluding that the road noise is the single most significant source, but that industrial sources (like cargo handling) have bigger influence when taken as a whole. Ships were also found out to be significant noise pollutants. Additionally, the number of people affected by high noise levels was also estimated.

Noise survey was also done for the port area of Napoli [25]. The research conducted together with the survey dealt primarily with the use of low-cost tools in order to measure noise levels in the port area. Consequently, the focus was on the monitoring of noise levels and not on the prediction of noise levels using relevant software. In [26], the authors have conducted a similar survey for Dublin Port. Despite interesting finds, such as noise levels being over the limit during the night, the focus was again on the assessment of the current state of noise levels, with no attempt to establish a methodology that would enable prediction of noise levels taking into account various influences (traffic flow, wind, etc.). Recently, something similar was done for the Port of Barcelona, with additional research on the type of noise sources, duration of the noise, etc [27].

Additionally, noise pollution is mentioned as one of several port environmental problems and steps for its reduction were provided in works such as [28], [29].

2.3. Underwater noise

Although underwater noise is often overlooked by ports, it is nevertheless represented in the scientific literature. In works like [30], it is considered as one of the main aspects of environmental pollution. A possible reason might be that it affects almost exclusively the animal population and is insignificant when considering negative noise influence on people. Most of the papers can be divided into two categories – those dealing with the influence of the underwater noise on marine species and those dealing with the sources of underwater noise and noise mapping.

One of the researches, [31], was conducted for the northern Adriatic Sea in Croatia and covers a topic of noise influence on the relocation of the bottlenose dolphins. The results have shown a significant influence on the dolphin population, especially during summer months, when sea traffic is increased because of tourism.

Species and areas affected by the underwater noise are hearing and communication of *Chromis chromis*, *Sciaena umbra,* and *Gobius cruentatus* in Miramare, Italy [32], the decline of the time spent caring for nests (*Chromis chromis*) and inside shelters (*Gobius cruentatus*) in the same area [33] and general negative influence on marine biology in Norway [34].

A study of the noise influence on marine mammals (bottleneck dolphins) in Moray Firth hadn’t detected any effect on their behaviour or living. A possible reason is given in the adaptation of the dolphins to higher noise levels [35].

Studies dealing with the underwater noise sources include sources such as drillships [36] and marine propellers [37], as well as whole ports [38], where ferry boats were shown to be a prevalent noise source in Civitavecchia. Study of underwater noise in south-eastern Brazil showed significantly higher underwater noise levels in areas affected by marine traffic [39] and a study of underwater noise in the Dutch North Sea showed a significant influence of ships and explosions [40]. Submarine noise pollution was studied in [41], with the emphasis being on the development of a boundary/finite element model. Among the studies dealing both with sources of underwater noise and its abatement is [42]. The relationship between the noise created under the water and outside of the water was discussed in [43].

3. Noise assessment in the PIXEL project

3.1. Background and theoretical framework

A practical example of the noise assessment in a port area would be shown in this section. Before continuing with the assessment, the PIXEL project needs to be described in short. It is seen as a “smart, flexible and scalable solution for reducing environmental impacts” of the ports [44]. One of the main goals is the optimization of the port operations to have a minimal negative impact on the environment.

The project is not limited to one type of pollution, but instead covers various environmental aspects, such as air and water pollution, waste generation and noise. The problem of the optimization of noise emissions is to be solved using noise maps and adequately placed noise sensors. The positioning of the sensors is partly predetermined by regulations about the permitted noise levels. However, noise maps can be of great help when choosing exact locations of measurement points, as they should be placed where the noise levels are critical.

For the noise mapping process described here, Predictor-LimA Software Suite, developed by Brüel & Kjær, was used, more specifically Predictor (v12.00, 64-bit). Required data is very similar to [2] and consists of geographical data and data about noise sources. Meteorological data is often cited among the required, but not all calculation standards support some of the important meteorological aspects, such as wind speed and direction.

The process was carried out for the Port of Thessaloniki and was based on the data provided in their yearly reports, such as [45]. The data is based on the values from the first year when the report was published and didn’t change in subsequent years. The main goal was to establish a valid model that would allow testing various scenarios, such as different meteorological conditions (primarily wind speed and direction) and various levels of traffic intensities (“traffic flows”) in the port.

The first step was to import building data and the data on noise sources, as well as the location of the receivers (see figure 1). Areas inside dotted lines represent area sources, which consist of various port machinery that would be too complicated for modelling separately. Receivers are marked with circles and are numbered, as their order is important in the latter part of the article.

Figure 1: Locations of noise sources and buildings in the Port of Thessaloniki

Another data that could be used are terrain elevations. However, they slow down the calculation and are also impractical for graphical representation. As the port has a terrain elevation difference of only a couple of meters between the lowest and the highest points, this data was decided to be omitted. Before omission, calculations were run both with and without terrain elevations and the results can be seen in table 2. It is noticeable that height points, which contain data on terrain elevation, have little influence on the results.

Table 2: Comparison of the results with and without height points

Receiver	L_{night} (dB(A))			L_{DEN} (dB(A))		
	With H.P.	Without H.P.	Difference	With H.P.	Without H.P.	Difference
1	50.9	50.3	-0.6	57.3	56.7	-0.6
2	39.0	38.7	-0.3	56.5	56.5	0
3	35.5	36.6	1.1	50.6	51.1	0.5
4	33.0	32.2	-0.8	47.3	46.4	-0.9
5	41.1	40.9	-0.2	56.3	56.2	-0.1
6	42.8	42.0	-0.8	54.4	54.0	-0.4
7	46.4	46.6	0.2	58.8	59.4	0.6
8	47.3	47.5	0.2	61.9	61.0	-0.9
9	45.9	46.4	0.5	56.3	57.1	0.8
10	43.6	46.0	2.4	53.1	54.9	1.8

Firstly, a relevant calculation method should be chosen. The software used supports 20 methods, divided into four categories (industrial noise, road traffic, rail traffic and all of them). As all of the sources are present in the ports, one of the methods that support calculation with all of them had to be chosen. There are two such methods - CNOSSOS-EU and Harmonoise standards.

The first one tested was CNOSSOS-EU standard, because it is the most frequently used of the two. However, it doesn't support changing some of the important meteorological conditions (such as wind speed and direction). For that reason, the choice was on the newly implemented Harmonoise method. It is a calculation method developed during the NoMEPorts project, initially only for the internal use, but was implemented into newer releases of Predictor-LimA [46]. Although it is in the development, it showed accurate results, at least for the calculation settings used in this example. The method uses the following calculation formula to assess the noise levels of a source segment (n represents a source segment) [46]:

$$L_{eq1h,i,n} = L_{W,i} - A_{div} - A_{atm,j} - A_{excess,ij} - A_{refl,i} - A_{scat,i}\,, \quad (1)$$

where:

$L_{W,i}$ – sound power level of a unit length source segment (dB)

A_{div} – attenuation due to geometrical spreading (dB)

$A_{atm,j}$ – attenuation due to atmospheric absorption (dB)

$A_{excess,i}$ – excess attenuation due to ground reflections and diffraction effects (dB)

$A_{refl,i}$ – attenuation due to energy loss during reflection (dB)

$A_{scat,i}$ – attenuation due to scattering zones (dB)

3.2. Results and discussion

Once the calculation is set-up, the model needs to be validated. The first choice was to do it by comparing it to on-site measurements provided by the port, which were taken on different days and in significantly different meteorological conditions. However, the measurements are affected by external influences, like roads, social events, etc. As the data on some of those sources is not available (especially social events), the choice was to compare the results of the simulation with the results of the calculation done by the port, described in [45].

Before comparing the results, several issues should be noted. The first is that there are no meteorological data provided in the port's report, so the calculation was performed with unknown boundary conditions and input data. The second issue refers to buildings that are included in the performed simulation whilst omitted from the report.

Although it won't have a huge influence on the receivers located in the open space, it can be the reason for a significant difference in the receivers located near those buildings. The comparison of the results is provided in table 3.

The meteorological conditions used in this calculation were:
- Wind: 1-3 m/s, south
- Temperature: 25 °C
- Humidity: 70%
- Pressure: 101.33 kPa

Table 3: Comparison of the results of the simulations conducted by the Thessaloniki Port Authority (ThPA) [45] and PIXEL

Receiver	L_{night} (dB(A))			L_{DEN} (dB(A))		
	ThPA	PIXEL	Difference	ThPA	PIXEL	Difference
1	51.2	50.3	-0.9	57.6	56.7	-0.9
2	39.1	38.7	-0.4	57.2	56.5	0.7
3	40.2	36.6	-3.6	55.9	51.1	-4.8
4	40.3	32.2	-8.1	50.2	46.4	-3.8
5	42.6	40.9	-1.7	52.9	56.2	3.3
6	44.1	42.0	-2.1	54.6	54.0	-0.6
7	45.3	46.6	1.3	56.9	59.4	2.5
8	46.7	47.5	0.8	58.3	61.0	2.7
9	43.7	46.4	2.7	59.4	57.1	-2.3
10	41.2	46.0	4.8	58.2	54.9	-3.3

As seen in table 3, most of the results differ within the range of 3 dB, which is very satisfactory, especially as meteorological conditions of the original simulation were unknown. The differences between the results obtained at receivers 3, 4 and 10 have valid explanations. The difference at receiver 3, although not large, can be attributed to the influence of the reflection factors of the nearby buildings. By increasing the intensity of the reflections, obtained results tend to result achieved in the original report, but also extend calculation time.

The receiver 4 is located near the buildings omitted in the original report and, as buildings act as noise barriers, it has lower values in this calculation. The last receiver is in the open space, with significant influence of the wind. If the wind direction is changed from south to north, L_{night} would lower down to 42.7 dB. Similarly, some of the receivers located near to the buildings show slightly higher values of L_{DEN}. A comparison of the noise maps is given in figures 2 (Thessaloniki Port Authority) and 3 (PIXEL). All values in those two figures are in dB.

Figure 2: Noise map from the Thessaloniki Port Authority yearly report [45]

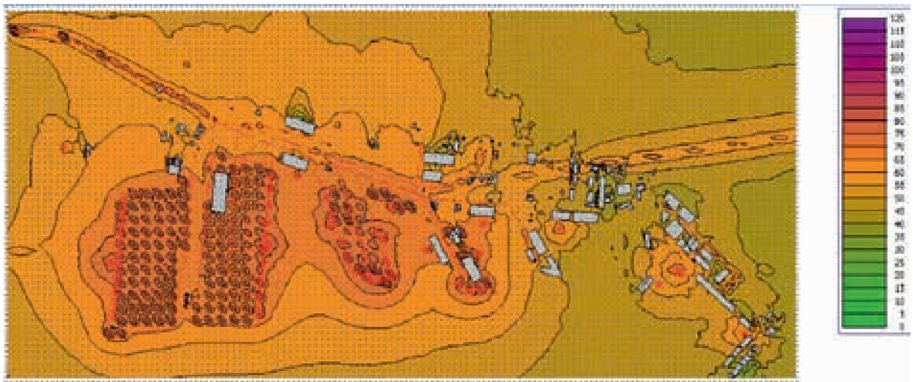

Figure 3: Noise map as done by PIXEL

As the results of the simulation conducted by the PIXEL project and the port contractors were similar, it can be concluded that the model is validated and suitable for future use. However, several things need to be discussed before bringing any conclusions. Harmonoise method was introduced only in the most recent versions of software and some parts of the implemented code are still not optimized, so it takes a significant amount of time to create a noise map (about a dozen hours on the average PC, compared to 30-90 minutes using other methods), although this is not an issue when calculating only values in the receivers. On the other hand, this can turn into a significant problem when using lower-capacity computers.

The second issue are the alterative calculation methods in case they need to be performed in less time than required by using the Harmonoise method. There is a way to overcome this by calculating the noise emissions of railways and roads using specialized calculation methods and importing them in an industrial noise calculation method as a line source. Some of the precision is likely to be lost, but it is a subject for further research.

Another subject for further research is to perform simulations for different meteorological conditions, especially to test the influence of the unstable atmosphere and strong winds, which might represent a significant problem for areas near the port in unfavourable conditions.

In the end, simulation results should be compared to the regulated values provided in [45]. The values stand at 70 dB(A) for L_{DEN} and 60 dB(A) for L_{night} and it is clear the simulation results are well under the limits.

The last thing to note is the influence of various sources on the total noise levels. From figure 3, it can be concluded that industrial noise sources have the largest influence on total noise levels and that traffic noise has a smaller impact. Buildings, as noise barriers, have a significant influence in areas near them, but lower influence in areas farther away.

4. Conclusions

The two main goals of the article were to provide a wider theoretical background on noise pollution and to give a practical example of the noise assessment as part of the work on the PIXEL project, which should result in a model usable for the future researches. Theoretical background was provided by dividing it into three parts – general researches, environmental noise pollution in ports and underwater pollution. The background provided should give the reader both introduction to the problems of noise pollution and a starting position for further theoretical research.

The practical work consisted of making a noise dispersion model for the Port of Thessaloniki. The model was successfully created and tested by comparing it to the results obtained in the port's yearly reports. The results were similar, which serves as proof that the model is validated and can be used in the future. Also, like the results in the report, the noise levels were under the regulated limits.

Some guidelines and goals for further research are also given. The main point of interest are various meteorological conditions, such as different wind speeds and directions. They are to be tested and the results obtained under those conditions should be compared with the results obtained here and with the regulated noise levels.

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