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Research Article

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# Influence of meteorological conditions on noise dispersion in the Port of Thessaloniki

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**Abstract:** Although noise dispersion models are widely used for the assessment of noise levels across different domains, the influence of meteorological conditions on environmental noise is usually neglected even though modelling requirements often list meteorological data as a key part for conducting successful modelling exercises. In order to evaluate the magnitude of influence of meteorological conditions on noise dispersion, different meteorological scenarios have been tested. The meteorological parameters that have been addressed include wind speed and direction, air temperature and atmospheric pressure. The simulations have been performed using data obtained from the Port of Thessaloniki, which include standard noise data (locations of noise sources and barriers, noise power levels of individual sources), as well as yearly averages and extremes for the meteorological parameters. Wind speed and direction have been shown to have a major influence on environmental noise levels. The modelled difference in levels due to changes in wind speed and direction reached 7 dB in several receivers indicating an effect that should not be neglected. Air temperature and atmospheric pressure had very little influence on noise levels. In conclusion, when addressing and modelling environmental noise levels, wind speed and direction must be properly accounted for and should not be neglected.

**Keywords:** meteorological conditions, noise modelling, noise mapping, maritime sector

## 1 Introduction

Noise dispersion models (noise maps) are an extremely useful tool for assessing environmental noise levels in various areas, regardless of their purpose and size. Noise mapping is defined, according to [1], as a "presentation of data on an existing or predicted noise situation in terms of a noise indicator…" The key part of the definition is that it can be used both for the assessment of the current levels and the prediction of noise levels in different situations, such as "the worst-case scenarios" or any other change from the current situation.

Use of the noise maps created with a noise modelling software, like the ones used in this article, can be dated back to the late 1990s and early 2000s, with the works such as [2] and [3]. However, noise mapping can be traced back several decades earlier. Among others, noise maps based on the noise measurements were created for several towns in Czechoslovakia and German Democratic Republic, as shown in [4]. While that method can be useful for the assessment of current noise levels, like in [5] and [6], it is not suitable for the prediction of noise levels for different scenarios, as well as the estimation of the influence that individual noise pollutants have on total noise levels.

There were several studies conducted with the main goal of creation of noise dispersion maps in order to estimate the influence that the ports have on their environment (*i.e.* only sources in the ports were taken into account). Those studies were done using a noise mapping software, instead of using on-site measurements to make the noise map.

Among the most important projects for the establishment of noise mapping conventions was the NoMEPorts project, where an example for future use was set [7]. One of the ports participating in the project was the Port of Livorno, where the main subject was the influence of the

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port noise emissions on the total noise levels in the city [8]. A very similar paper was written as a part of the MESP project, with the participating ports being the Port of Patras (Greece) and the Port of Tripoli (Lebanon) [9].

An example of the creation of the noise map for a larger area is the one presented in [10]. The emphasis was on the city area as a whole (Piraeus, Greece), instead of the city port area only. However, the port was seen as a major noise pollutant (in addition to roads, railways and the industrial zone) and a separate map was created for it. The maps were used only for the assessment of the current situation and for an estimation of the situation after the implementation of certain noise reduction measures. Meteorological conditions were not considered.

Noise maps can also be used for an estimation of the noise propagation of a single source. An example of such maps was presented in [11], where the main topic was the noise propagation of a single ship in the Port of Genoa. Such maps are especially useful when assessing the influence that complex noise sources, such as ships, have on their environment. Although the subject of the papers was not the creation of noise maps, the discussion and guidelines for the modelling of ship noise are presented in works such as [12], dealing with the noise prediction of moored ships, and [13], in which the main subject was the assessment of ship influence on noise dispersion, including both moored and moving vessels.

Although the listed examples do not represent the entire field of noise assessment studies, they are nevertheless representative of the current state of the subject. Study of meteorological influences is completely neglected in each one of them. Despite meteorological conditions being listed among the requirements in [7], they are still a subject for further research.

In this paper, the main aim is to assess the influence of different meteorological parameters, such as wind speed and direction, air temperature and atmospheric pressure. Depending on those meteorological factors, noise level assessment will be made for several different scenarios. Based on the methodology and simulations described for the port of Thessaloniki, which is a part of the PIXEL (Port IoT for Environmental Leverage) project, the results shown below are obtained. The project focuses on the ecological aspects of port operations, including the use of resources and sustainable development, and noise pollution is among the aspects it is directly concerned with. Aside from the PIXEL project, other projects have also accentuated the importance of noise reduction in port areas, such as REPORT-Rumore E PORTi, with its multidisciplinary approach to the problem [14].

On the following pages, the methodology for the creation of the noise maps is presented, as well as the results obtained using the procedure. The results were also discussed at the very end of the article and the relevant conclusions were made.

# 2 Methodology

## 2.1 Data requirements

The first step in noise modelling is to obtain all the relevant data. The data required is very similar to the data presented in [7], where the general guidelines were given and noise maps were created for several European ports participating in the NoMEPorts project, and consists of geographical data and data about noise sources. Geographical data consists of information about buildings and other noise barriers (locations and height information), terrain heights and the surface characteristics of the ground. Location of noise sources can be sorted in both geographical data and data on noise sources.

The noise sources data should contain, besides the location of the sources, noise emissions (for industrial sources), number of vehicles and their speed (road and railway traffic), as well as “working hours” of each source, regardless of its type. All the relevant data was either provided directly by the port or taken from its yearly report [15]. Emissions of traffic noise sources are calculated from the available traffic data, while other sources (ships, cranes, area sources representing port operations) are defined with sound power levels in single octave bands.

Locations of buildings, receivers and noise sources can be seen in Figure 1. The sources are represented with red lines and symbols similar to “*”, while the buildings and other structures, such as tanks, are represented with grey areas. The black line represents the border between the port and the sea and does not have any influence on the calculation. The receivers are marked with black symbols and are also numbered, as their numbering is used in the latter part of the paper. As there are different noise sources, a distinction should be made between them. Point sources located on the black lines represent the immobile cranes and those located slightly outside them represent ships. Ships were represented as point sources in the port’s yearly report, but also in papers such as [13]. The single “line source” represents a moving crane. Area sources represent the areas where port operations, such as cargo handling, are performed.

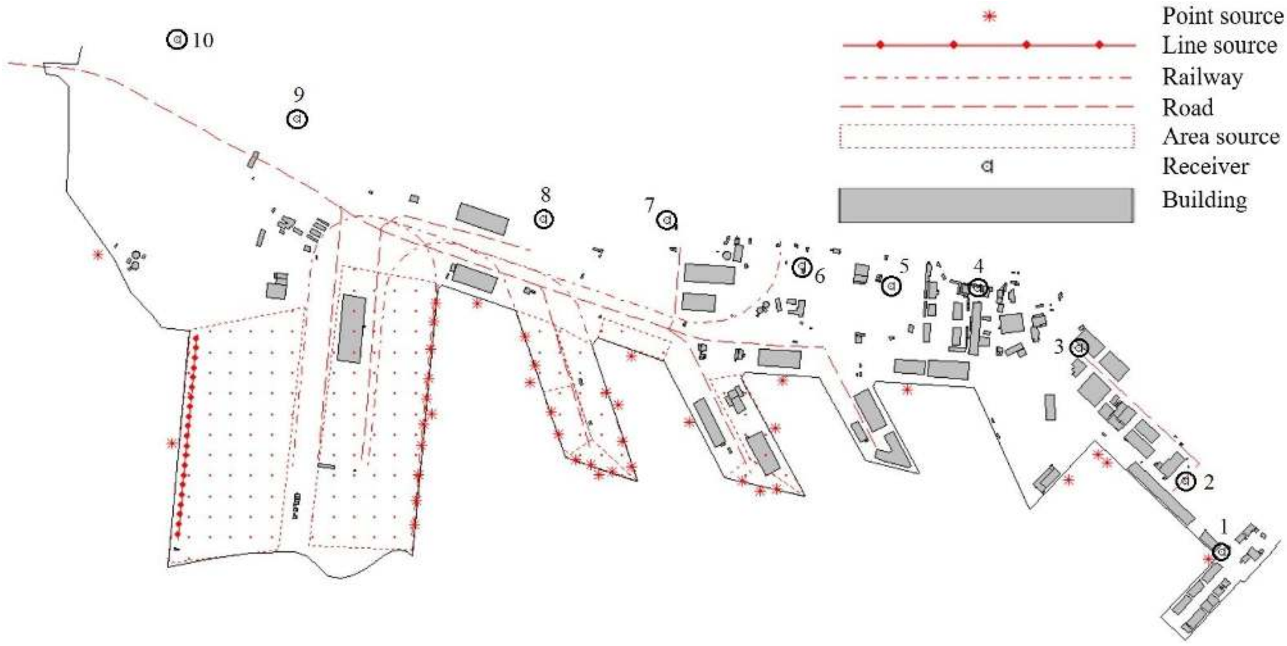

**Figure 1:** Locations of noise barriers (buildings and tanks) and noise sources in the Port of Thessaloniki [16]

In addition to the two data types described, there is a third set of data requirements that could be added – meteorological data. Despite sometimes being listed as a required data, as in [7], it is clear from the works mentioned in the introduction that it is almost always excluded. As the main goal of this article is to assess noise levels for several scenarios, based on different meteorological conditions, it is clear that meteorological data is, in this case, as essential as the geographical data and the data about noise sources.

## 2.2 Calculation methods

One of the main issues during the creation of a noise map is the choice of a calculation method. It mostly depends on two factors – software used for the simulation and the modelling requirements. The noise dispersion modelling was done using Predictor-LimA Software Suite, developed by Brüel & Kjær, specifically the version Predictor (v12.00, 64-bit). The software allows the calculation using 20 different calculation methods, differing in their purpose and calculating options.

In order to make possible the assessment of the influence of different meteorological conditions on the noise level distribution, a calculation method that has those options had to be used. In the Predictor-LimA software, methods are divided by their modelling purpose in four categories – road traffic noise, rail traffic noise, industrial noise and all of them. The most convenient way would be to use one of the methods that support the modelling of all the noise sources at once. However, two of such methods (Harmonoise and CNOSSOS-EU standards) have their limitations. The former is still in an experimental phase and not yet ready for scientific use, while the latter doesn't support the calculation with different wind speeds and directions.

The different approach had to be used and road and railway traffic noise sources were calculated using separate methods and their emission levels were imported into a method used for the general (industrial) noise calculation. Six methods were tested for railway noise modelling (the two previously mentioned plus NMPB-2008 (rail), XPS-Rail, RMR-1996 and RMR-2012 methods). The results were compared to the ones achieved by the simulation presented in the port's yearly report [15] and the closest results were obtained using the CNOSSOS-EU method. The method uses the following calculation formula for railway noise [17]:

$$L_{W',eq,line,i}(\psi,\varphi) = L_{W,0,dir,i}(\psi,\varphi) + 10\cdot\log\left(\frac{Q}{1000\cdot v}\right),$$

where:

$Q$ – the average number of vehicles per hour on the j-th track section per vehicle type, average train speed and running condition (vehicles/hour)

$v$ – the speed of those vehicles (km/h)

$L_{w,0,dir,i}$ – directional sound power level of the specific noise (rolling, impact, squeal, braking, traction, aerodynamic, other effects) of a single vehicle in the directions $\psi$ and $\varphi$ (dB(A)/m)

Indicator $L_{DEN}$ is calculated with the following expression [18]:

$$L_{DEN} = 10 \cdot \log \left[ \frac{12}{24} \cdot 10^{\frac{L_{day}}{10}} + \frac{4}{24} \cdot 10^{\frac{L_{evening}+5}{10}} + \frac{8}{24} \cdot 10^{\frac{L_{night}+10}{10}} \right],$$

where:
$L_{day}$ – A-weighted noise level during the day (dB (A))
$L_{evening}$ – A-weighted noise level during the evening (dB (A))
$L_{night}$ – A-weighted noise level during the night (dB (A))

Similarly, different methods were tested for road traffic noise (Harmonoise, CNOSSOS-EU, ISO 9613.1/2 Road, CRTN, CRTN (NZ), CRTN (TRL), HJ2.4-2009, NMPB-2008 (road), TNM and XPS – road) and the closest results to the port's report were obtained using ISO 9613.1/2 Road method. Likewise, ISO 9613.1/2 method was chosen for the creation of the final model. The main reasons were its foundation on the ISO-9613-1/2 and the ISO 17534-3 quality requirements, as well as the support of calculation with different wind directions and speeds. The ISO method calculated the results using the following formula [19]:

$$L_{lt,per} = L_{dw} - C_{m.per} - C_{t,per}$$

where:
$L_{dw}$ – Equivalent continuous downwind octave SPL (dB)
$C_{m,per}$ – Meteorological correction during the evaluation period (dB)
$C_{t,per}$ – Correction for the active time of the source during the evaluation period (dB)

## 2.3 Assumptions and simplifications

Once all the data is obtained and the calculation method is chosen, the simulation can be started. However, significant slowdown (about four times) of the simulation was noticed when using the height points ("H.P."). In order to speed up the simulations, the results were compared for the simulation with and without height points. They can be seen in Table 1 and Figure 2 (the height points are represented by red dots).

It can be seen from Table 1 that the use of height points does not affect the final results by much. Similar observations were made in [16], also done as part of the PIXEL project. The reason for it is the small difference in elevation between different parts of the port (most of the port has an elevation in the range of 1 m, according to the data provided by the port). Having in mind the small difference between the results and the significant slowdown of the simulation caused by it, it was decided to omit them.

## 2.4 Meteorological conditions

The last issue to address is the choice of meteorological conditions for which the simulation would be done. It was decided to choose the situation with no wind at all, the most probable situation and the worst possible situations for the eight main directions. Also, the influence of atmospheric pressure, air temperature and humidity were tested for the situation without wind and one of the worst-case scenarios (to see if the influence is different when there is wind and when there is no wind).

The average wind speed throughout the year is 4 m/s, with the most common direction (in degrees) being 292° [20]. According to [21], the highest wind speed for the period from November 2018 until October 2019 was 19.2 m/s. That wind speed was used for all eight main directions and represents the worst-case scenario since it would lead to extreme values in the receivers.

# 3 Results

As stated in the previous section, there are four meteorological parameters considered for the noise modelling simulations. As most of the paper deals with wind modelling, and as the parameter that was proven to have the most significant influence on final results, it will be described first. Rest of the conditions for the following simulations are described below (all values are year averages for the period 1985-2015, according to [22]):

- Air temperature: 16°C
- Humidity: 67%
- Atmospheric pressure: 101.7 kPa

Stability class was chosen as D (neutral class), based on the wind speeds [23]. In all cases, wind speeds and stability classes were the same for different periods of the day.

The results can be seen in Table 2 ($L_{DEN}$) and Table 3 ($L_{night}$). From Figure 1, it is clear that the first three receivers are located in a place relatively well-surrounded by buildings, hence the lower influence of the wind, as shown in Table 2. The differences are higher for $L_{night}$ values, due to the smaller number of active noise sources during the period. The only nearby noise sources active near them during the period are ships moored to the south, hence

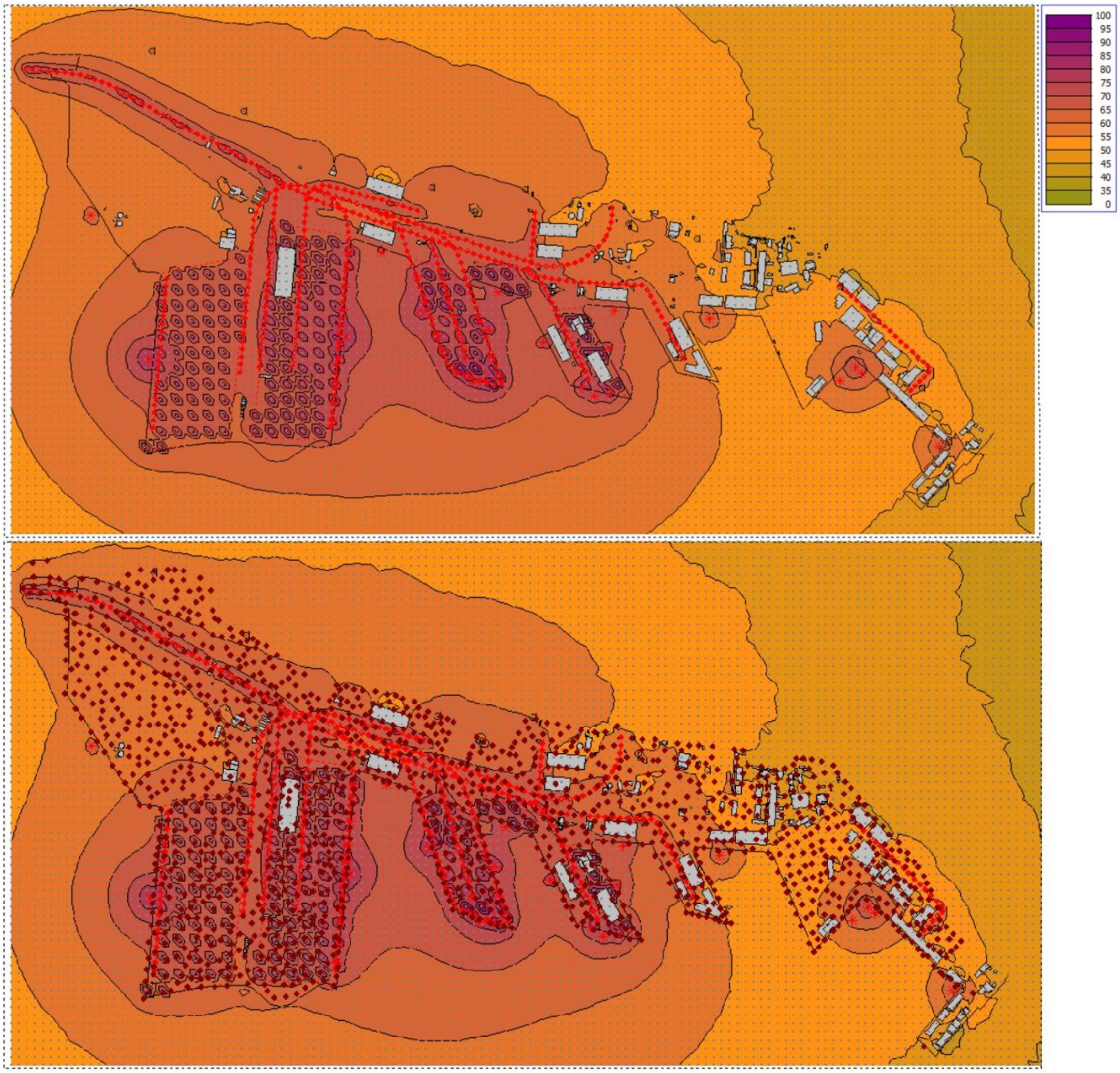

**Figure 2:** Comparison of results without (above) and with (below) height points

**Table 1:** Comparison of the simulated noise levels with and without height points

| Receiver | $L_{night}$ (dB(A)) | | | $L_{DEN}$ (dB(A)) | | |
|---|---|---|---|---|---|---|
| | With HP | Without HP | Difference | With HP | Without HP | Difference |
| 1 | 53.1 | 53.1 | 0 | 59.5 | 59.5 | 0 |
| 2 | 42.3 | 42.3 | 0 | 55.6 | 55.7 | 0.1 |
| 3 | 42.3 | 41.9 | −0.4 | 56.8 | 56.7 | −0.1 |
| 4 | 40.6 | 39.8 | −0.8 | 49.9 | 50.1 | 0.2 |
| 5 | 43.9 | 43.9 | 0 | 53.9 | 54.2 | 0.3 |
| 6 | 45.2 | 45.1 | −0.1 | 55.6 | 55.8 | 0.2 |
| 7 | 47.5 | 47.5 | 0 | 59.7 | 59.8 | 0.1 |
| 8 | 49.3 | 49.3 | 0 | 61.7 | 61.9 | 0.2 |
| 9 | 44.1 | 44.1 | 0 | 59.2 | 59.4 | 0.2 |
| 10 | 41.5 | 41.6 | 0.1 | 55.9 | 57.4 | 1.5 |

**Table 2:** Noise levels (LDEN) for different scenarios based on wind speed and direction

| Receiver | No wind | Most common | Worst-case situations | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | N | NE | E | SE | S | SW | W | NW |
| 1 | 59.5 | 59.6 | 59.6 | 59.5 | 59.5 | 59.5 | 59.5 | 59.6 | 59.6 | 59.6 |
| 2 | 55.7 | 56.0 | 55.9 | 55.1 | 55.5 | 55.5 | 55.6 | 56.2 | 55.9 | 55.9 |
| 3 | 56.7 | 57.5 | 56.1 | 55.9 | 56.2 | 56.2 | 57.5 | 57.7 | 57.5 | 57.4 |
| 4 | 50.1 | 52.7 | 46.2 | 45.7 | 46.5 | 47.1 | 52.8 | 52.9 | 52.7 | 52.5 |
| 5 | 54.2 | 56.6 | 50.3 | 50.1 | 50.7 | 52.8 | 56.7 | 56.8 | 56.6 | 55.9 |
| 6 | 55.8 | 57.9 | 52.0 | 51.9 | 52.2 | 54.9 | 58.3 | 58.3 | 58.2 | 57.3 |
| 7 | 59.8 | 60.7 | 55.9 | 55.8 | 56.8 | 61.2 | 62.1 | 62.2 | 61.9 | 58.7 |
| 8 | 61.9 | 60.8 | 58.4 | 58.7 | 62.5 | 63.8 | 64.0 | 64.0 | 61.8 | 59.1 |
| 9 | 59.4 | 58.5 | 56.9 | 56.9 | 60.1 | 60.8 | 61.2 | 61.2 | 58.9 | 57.8 |
| 10 | 57.4 | 56.5 | 54.0 | 55.1 | 58.0 | 58.9 | 59.4 | 59.0 | 56.9 | 55.7 |
| Average | 57.05 | 57.68 | 54.53 | 54.47 | 55.80 | 57.07 | 58.71 | 58.79 | 58.00 | 56.99 |

**Table 3:** Noise levels (Lnight) for different scenarios based on wind speed and direction

| Receiver | No wind | Most common | Worst-case situations | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | N | NE | E | SE | S | SW | W | NW |
| 1 | 53.1 | 53.1 | 53.1 | 53.1 | 53.1 | 53.1 | 53.1 | 53.1 | 53.1 | 53.1 |
| 2 | 42.3 | 42.9 | 42.4 | 38.9 | 41.7 | 41.7 | 41.8 | 44.0 | 42.5 | 42.5 |
| 3 | 41.9 | 43.2 | 38.3 | 37.8 | 41.2 | 41.3 | 44.3 | 44.4 | 43.0 | 43.0 |
| 4 | 39.8 | 42.1 | 35.4 | 35.4 | 37.1 | 37.9 | 42.5 | 42.5 | 42.1 | 41.8 |
| 5 | 43.9 | 46.0 | 39.7 | 40.1 | 41.4 | 43.0 | 46.4 | 46.3 | 45.9 | 45.3 |
| 6 | 45.1 | 46.7 | 40.9 | 41.3 | 41.8 | 45.0 | 47.6 | 47.6 | 47.4 | 46.0 |
| 7 | 47.5 | 48.2 | 43.2 | 43.3 | 44.4 | 49.3 | 50.1 | 50.1 | 49.8 | 46.2 |
| 8 | 49.3 | 49.0 | 45.1 | 45.3 | 49.0 | 51.7 | 51.8 | 51.8 | 50.3 | 45.8 |
| 9 | 44.1 | 42.1 | 39.7 | 41.2 | 45.3 | 46.9 | 47.0 | 46.6 | 43.9 | 39.9 |
| 10 | 41.6 | 37.7 | 37.2 | 39.7 | 43.2 | 44.5 | 44.5 | 43.7 | 40.1 | 37.2 |
| Average | 44.86 | 45.10 | 41.50 | 41.61 | 43.82 | 45.44 | 46.91 | 47.01 | 45.81 | 44.08 |

the lower values in the scenarios when the wind blows from the north. For all the other receivers, it is clear that the values are much higher when the wind blows from the south during all periods, with the difference in values exceeding 5 dB for receivers 4 to 9. The highest value (64 dB) was reached in the receiver 8, for situations when the wind blows from south and southwest, although the average values are slightly higher for the case when the wind blows from the southwest, both for $L_{DEN}$ and $L_{night}$.

On the following three figures, three noise maps are represented, one for the situation without wind (Figure 3), one for the most common meteorological condition (Figure 4) and the last one for one of the worst-case scenarios described before (Figure 5). The case when the wind blows from south-west was chosen, as the noise levels measured in the receivers are, on average, the highest for that situation.

For comparison, the noise maps showing the noise dispersion during the night ($L_{night}$), are shown on Figure 6 (no wind), Figure 7 (the most common situation) and Figure 8 (the worst-case scenario).

In addition to the influence of the wind speed and direction, the influences of other meteorological parameters (humidity, atmospheric pressure and air temperature) were also tested. However, none of those three parameters had any significant influence on the final results, mostly having either no influence at all or influence in the range of less than 0.3 dB, so they are left out of any further discussions.

In the end, it should be noted that the regulated noise levels in the port (70 dB (A) for $L_{DEN}$ and 60 dB (A) for $L_{night}$ [15]) were not exceeded in any of the scenarios.

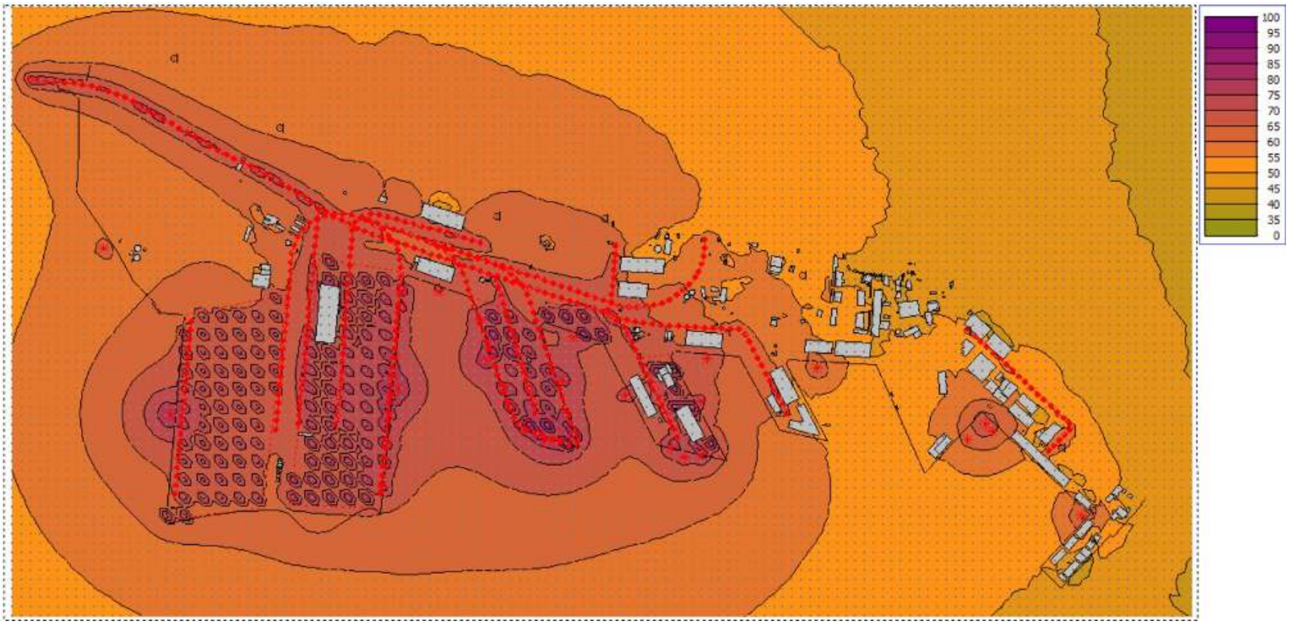

**Figure 3:** Noise map of the Port of Thessaloniki for the scenario without wind influence (LDEN)

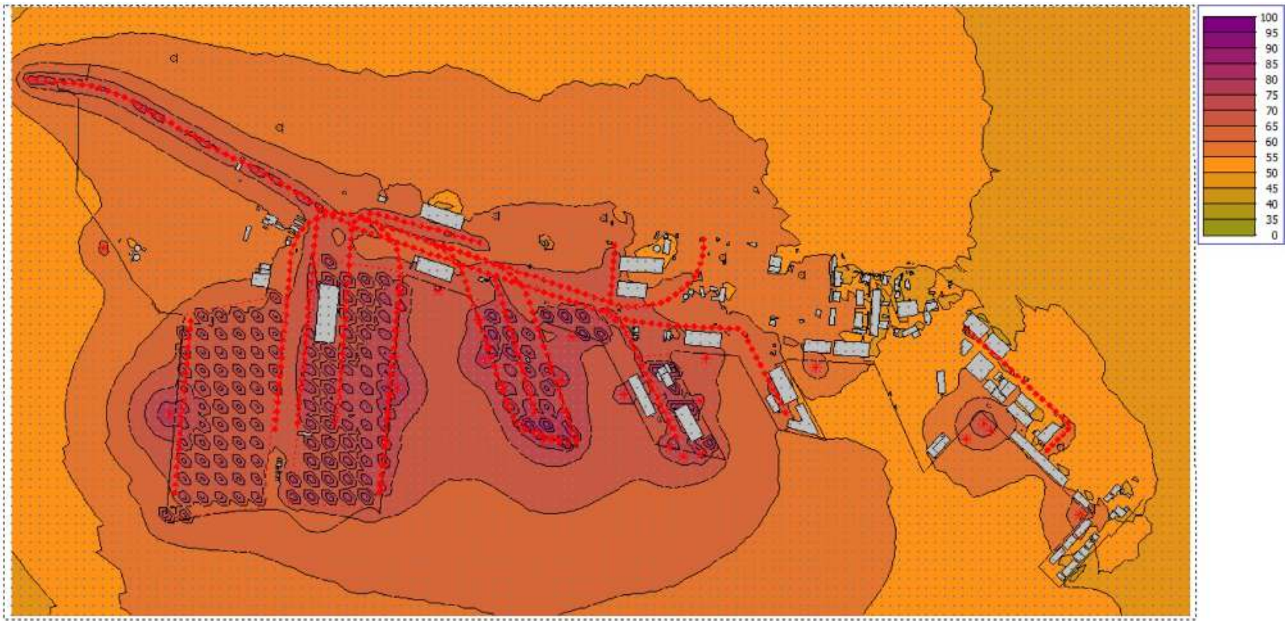

**Figure 4:** Noise map of the Port of Thessaloniki for the most common wind conditions (LDEN)

## 4 Discussion

The methodology used here was based on the one proposed in [7] and is also very similar to the ones used in previously mentioned works, such as [8] and [9], but expanded in order to include various meteorological conditions. Of all meteorological parameters tested, only the wind was shown to have a significant influence on the final results.

As it can be seen from Table 2 and Table 3, the difference in noise levels can be up to 7 dB between the two extreme scenarios. The noise level change of 7 dB represents a significant difference in loudness (around 60%), according to the following formula [24]:

$$x = 10^{\frac{\Delta L}{33.22}} = 2^{\frac{\Delta L}{10}},$$

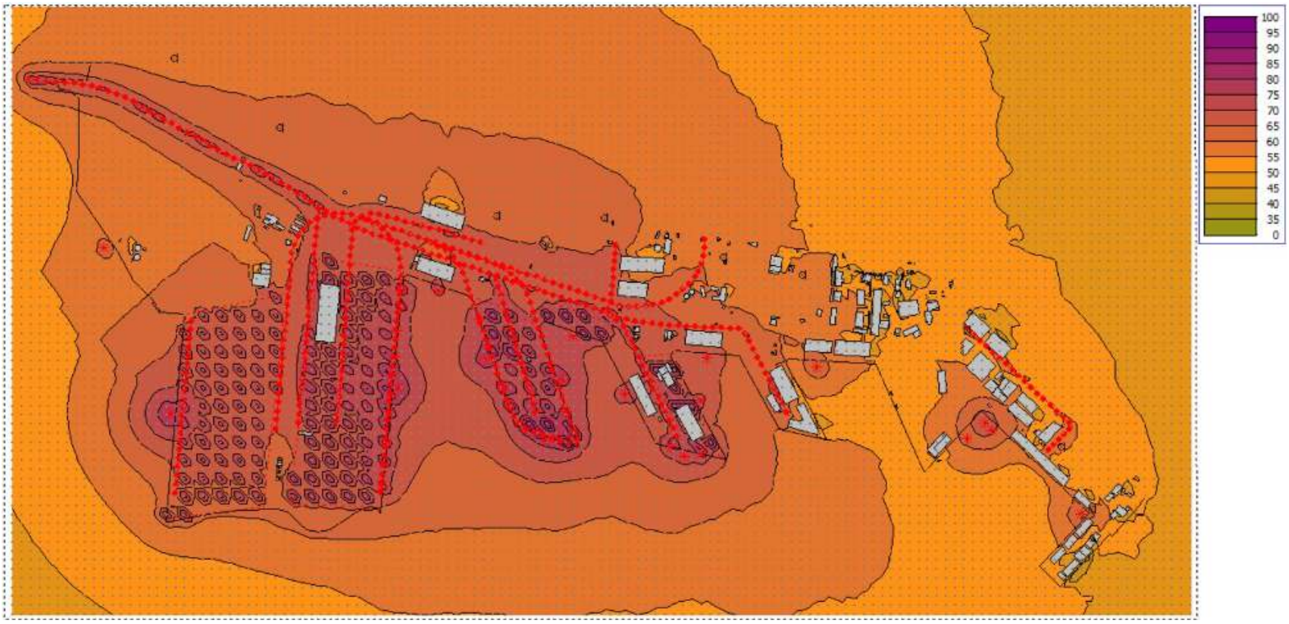

**Figure 5:** Noise map of the Port of Thessaloniki for the worst-case wind conditions (LDEN)

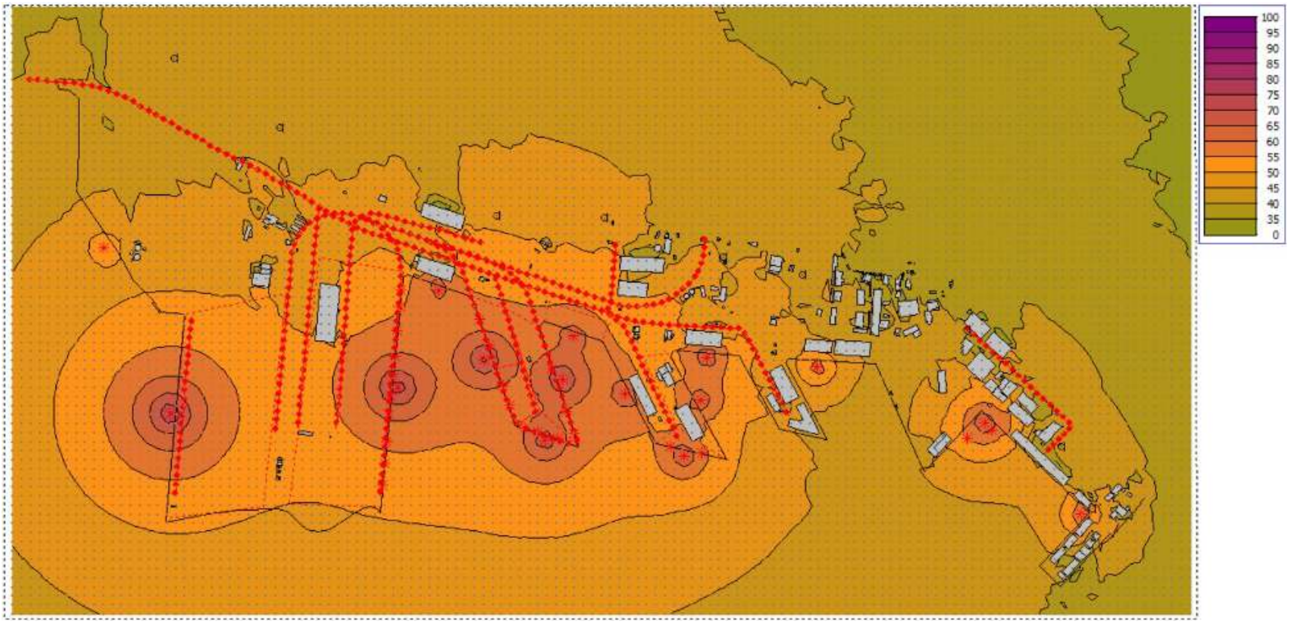

**Figure 6:** Noise map of the Port of Thessaloniki for the scenario without wind influence (Lnight)

Where:
$x$ – loudness ratio
$\Delta L$ – noise level change (dB)

In addition to the noise levels in the receivers, significant differences can be observed by comparing Figures 3, 4 and 5 for $L_{DEN}$ values and Figures 6, 7 and 8 for $L_{night}$ values. It is clear that the noise levels in the upper part of the figures, where the city is located, are significantly higher in the scenario where the wind speed is at its highest and the wind direction is at its most undesirable value. For example, a noise level of 60 dB is exceeded only in the very close proximity to the receivers on Figures 3 and 4, but in the worst-case scenario on Figure 5, the "60 dB zone" stretches a lot more to the upper edge of the figure, where the first buildings are located.

With the difference being so significant, it is clear that influence of the wind needs to be taken into account from several different perspectives, such as those linked with

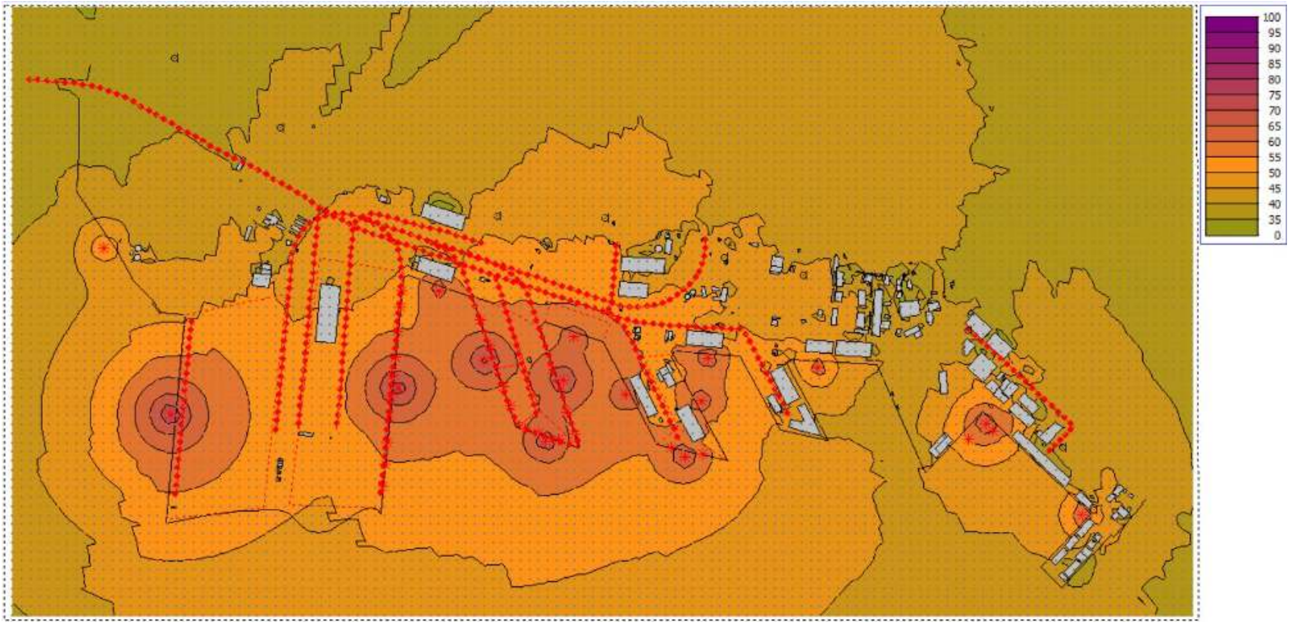

**Figure 7:** Noise map of the Port of Thessaloniki for the most common wind conditions (Lnight)

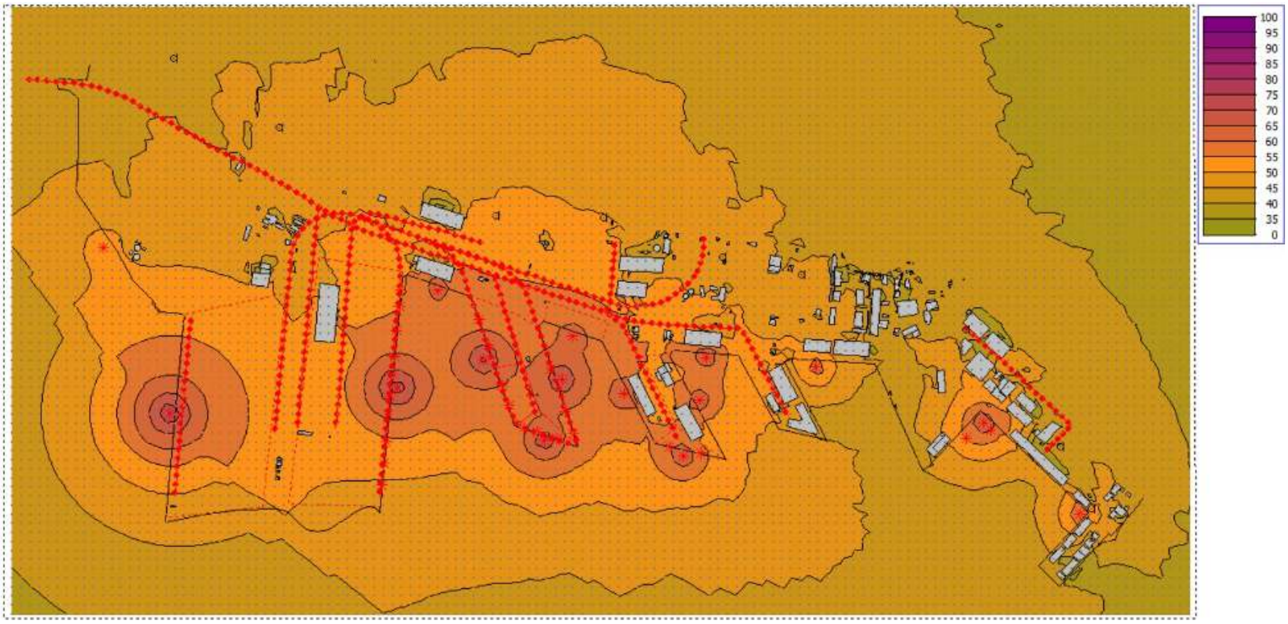

**Figure 8:** Noise map of the Port of Thessaloniki for the worst-case wind conditions (Lnight)

noise measurements, noise mapping and noise reduction procedures. The first of these issues are noise measurements. It is not an uncommon practice to make measurements on different days and in very different meteorological conditions. One of the examples of such practice is the modelling of noise in the Port of Thessaloniki [15]. In it, the measurements were used for the validation of the simulation results, resulting in several deviations between them, as seen on Figure 9 ($L_{DEN}$) and Figure 10 ($L_{night}$) (the simulation used for comparison uses several sources outside of the port, hence the higher values).

The measurements were taken during several days, probably due to lack of available sensors, and those conditions were mentioned in each of their measurement reports, but the wind conditions changed so significantly (for example, the wind direction changed from north to south during two days) that those results were basically useless for direct comparison between them and the sim-

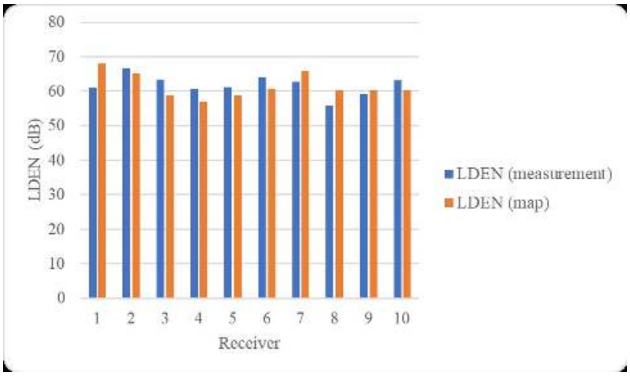

**Figure 9:** Differences between measured and calculated values for LDEN in the Port of Thessaloniki yearly report [15]

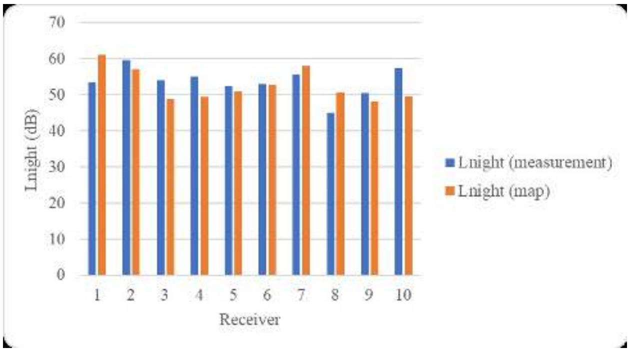

**Figure 10:** Differences between measured and calculated values for Lnight in the Port of Thessaloniki yearly report [15]

ulated values. Two direct solutions can be proposed for this problem. The first one is that measurements should be taken on the same day, which can be hard if there are not enough sensors available. The other solution is to measure noise levels during different days, but when the conditions are similar. There is also an issue with this solution, as the measurements are usually done by outside contractors and it would be complicated (and financially inconvenient) for the ports to do it. There is also the third solution that can be used and that is the adjustment of the measured values for the comparison with simulation. The adjustments can be made based on the simulations like the one done in this article.

As for the use in simulations, it is pretty much a similar situation, only inverted. In that case, measurements were already taken, and simulation needs to be validated based on those results. The simplest solution is to make several simulations, one for each different set of meteorological parameters.

Use of noise dispersion models in noise reduction procedures is one of their most significant uses, as it is possible to check different scenarios without losing too much time or money. By testing different wind speeds and directions, as well as studying the most frequent meteorological conditions in an area (in this case – the Port of Thessaloniki), it is possible to take adequate steps to reduce the negative influence of the wind. For example, noise barriers can be built on the side from which the wind blows most frequently to prevent higher noise levels in workplaces. Also, it is possible to address the issue of ports' noise pollution outside of the port borders and take adequate steps to reduce it. Such a study would need to be made on a larger level (for a larger area), such as the one presented in [10].

## 5 Conclusion

Different wind speeds and directions were shown to have a significant influence on both the values of noise levels and the distribution of those levels. The higher the wind speed is, the higher the difference compared to the scenario with no wind. Although the wind did not cause overshoot of the noise level limits regulated by law in this case, the differences are large enough that they should be taken into account in any similar noise level assessment. It also shows that meteorological conditions should be considered whenever making on-site measurements and that, even if the limits are not exceeded during the measurement, they might be exceeded in less favourable meteorological conditions.

The simulations for the chosen port were made for all the significant cases. However, there are still several subjects for future analyses. Most importantly, the emphasis was on the creation of the noise dispersion model for the port area, without the estimation of the influence on the local population. As only the noise from the port was assessed, without taking into account the noise that results from nearby roads and places for social activities, future work would be to expand the existing model to include nearby noise sources and to obtain information about the nearby residential areas and other areas that could be affected by high noise levels (schools, hospitals etc.).

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