Mitigation of Noise from Ships at Berth

Noise exploration program to understand noise emitted by Seagoing ships
# INDEX

## Abstract

3

## 1 Introduction

4

1.1 Project NEPTUNES

6

1.2 Scope and objectives of NEPTUNES

7

1.3 Introductory notes to the Best Practice Guide

7

## 2 Ship-generated noise

8

2.1 Characteristics of noise and annoyance

10

2.2 Challenges regarding (mitigation of) noise from seagoing ships

11

2.3 Impact of noise

11

2.4 Legislation and regulations

12

## 3 Stakeholders

14

3.1 Source

16

3.2 Surrounding areas

17

3.3 Sustainability

18

## 4 Universal Measurement Protocol

20

## 5 Noise label and classification

24

5.1 Execution of measurements

26

5.2 Noise label

26

5.4 Validity of the noise label/classification

27

5.5 Implementation

27

## 6 Best practices

28

6.1 Mitigation at the source

30

6.2 Mitigation in the propagation path

30

6.3 Mitigation at the receiver

31

6.4 Non-acoustic and soft measures

31

6.5 Legislation and regulations

32

6.6 Overview of all measures

32

## Glossary

38

## References

44

## Annexes

48

I Leaflets

48

II Measurement Protocol

94

III General explanation noise

125
Complaints about noise from (seagoing) ships at berth are increasingly becoming an environmental issue. To achieve sustainable port development and operations, there is a desire to overcome these challenges and explore what causes the characteristic sound generated by moored ships and how it can be mitigated.

Eleven ports from north-west Europe, Australia and Canada (see our Project members) have therefore studied what causes the characteristic sound generated by moored seagoing ships and how to mitigate it. This international project is called NEPTUNES: Noise Exploration Program To Understand Noise Emitted by Seagoing Ships.

The following main deliverables have been developed by the NEPTUNES project to improve the understanding of airborne noise emission and mitigation of ships at berth:

- Best Practice Guide on mitigation measures, including ‘noise awareness’ methods to be employed. This Best Practice Guide summarises the results of the NEPTUNES project.
- Leaflets summarizing possible noise mitigation measures (Annex to the Best Practice Guide).
- A universal applicable measurement protocol for the quantification of noise performance.
- Guidelines for noise labelling of a ship, based on its noise performance.

Throughout the project, knowledge was shared between the participating ports, noise consultants and other parties to ensure the highest quality of the results. It is important to further extend and share the knowledge and tools developed in the NEPTUNES project to increase awareness of noise disturbance from seagoing ships at berth.
1 INTRODUCTION
Neptunes

Chapter 1

Introduction
Complaints about noise from seagoing ships at berth are increasingly becoming an environmental issue. This is mainly due to the rising population in residential areas around ports, the increase in the number of residential areas being built closer to the port itself and changing expectations from people living in these residential areas. The intensification of shipping and expansion of ports and ships also play an important role. There are several challenges to be overcome to reduce noise pollution from seagoing ships.

There is currently little recorded information or standardised data relating to noise and nuisance in and around ports (1) or from seagoing ships and there has been no real attempt to design quieter seagoing ships that go further than protect seafarers from noise. In this Best Practice Guide, no specific research has been conducted to reduce nuisance because it is assumed that noise reduction also leads to reduction of nuisance.

To achieve sustainable port developments and operations, there is a desire to overcome these challenges and study what causes the characteristic noise generated by moored ships and how it can be mitigated. Because this problem involves ships calling at various international ports, the NEPTUNES (Noise Exploration Program To Understand Noise Emitted by Seagoing ships) project was launched by eleven ports in north-west Europe, Australia and Canada.

- Amsterdam
- Cork
- Copenhagen Malmo
- Gothenburg
- Hamburg
- Koper
- New South Wales
- Rotterdam
- Stockholm
- Turku
- Vancouver

The purpose of this Best Practice Guide is to summarise the experience and results gained from the NEPTUNES project and to provide a number of proven and applied noise measures that can be used to mitigate ship-generated noise at berth. The measures summarised in this Best Practice Guide can be considered as state of the art.

1.1 Project NEPTUNES

The overall goal of the NEPTUNES project is to increase awareness and gain support to reduce noise from seagoing ships. To meet the overall goal, the project includes quantification, characterisation and classification of airborne noise emissions from individual seagoing ships berthed in ports and best practices to prevent and control noise pollution. The project was divided into several project phases, described below.

Inventory phase
In 2017, the project started with an inventory of the existing knowledge and experiences in the participating ports to obtain insight into noise pollution from seagoing ships. The inventory was useful for gaining a better understanding of the incidences, sources and challenges of nuisance. The outcome of this inventory is summarised in terms of the characteristics of shipping noise and forms the basic knowledge of ship-generated noise (noise emitted by ships at berth, at anchor and manoeuvring to get at berth or leaving the berth).

Measurement protocol
After gaining sufficient insight, a universal measurement protocol for the quantification of noise performance of various ships at berth (e.g. container ships, cruise ships, tankers, RoRo/RoPax and Bulk carriers) was developed by NEPTUNES. There was a need to develop a protocol, due to the fact that there was no internationally agreed method available to measure noise from seagoing ships and very little recorded information or standardised data regarding noise or nuisance in and around ports. The development of the measurement protocol was based on international standards and the experience of acoustic specialists with similar projects. The protocol was then tested in seven ports (23 ships in total, by the end of 2018) to guarantee the satisfactory and objective quality of the results and to prove that the protocol was suitable for the given purpose. A brief summary of the measurement protocol can be found in Chapter 4. The full measurement protocol can be found in Annex II.

Noise label
Guidelines for labelling were developed in the participating ports.
based on measurement results. The aim is to classify the emitted noise from different types of ships based on their overall sound power level and the proportion of low frequency noise. The noise label indicates the noise performance of the ship. A brief summary of the guidelines for labelling can be found in Chapter 5.

Best Practice Guide
This Best Practice Guide (BPG) for noise pollution and nuisance reduction measures was developed to summarise the experiences and results obtained from the NEPTUNES project. Besides a general description of the measurement protocol and suggestions for labelling, the BPG collects leaflets which briefly describe the expected noise sources and the state of the art in noise reduction measures (e.g. measures at the source, measures in the propagation path, measures at the receiver and non-acoustic measures). The various stakeholders (e.g. shipowners, shipping companies, ports and urban planners) can use the BPG and particularly the leaflets to reduce noise pollution proactively and implement reduction measures on seagoing ships.

1.2 Scope and objectives of NEPTUNES

The objectives of project NEPTUNES are:
- Structured insight into the scope, nature and cause of noise pollution from ship-generated noise and a brief description of effective noise mitigation measures that have already been implemented (or are already being implemented in industry fields).
- The presentation of a brief overview of laws and regulations related to noise pollution from ship-generated airborne noise.
- The development of a universal measurement protocol to measure ship-generated airborne noise.
- The development of guidelines for the classification of a ship based on its noise performance.
- The development of a Best Practice Guide including noise reduction measures and noise awareness methods to be employed.

1.3 Introductory notes to the Best Practice Guide

The representations in the BPG, especially the labelling, focus on the noise generated by ships at berth. The noise from loading and unloading with external equipment or maintenance activities (e.g. noise from cleaning activities of chemical, oil or food tankers/ships by means of steam, hot oil or water) is not generally considered in this BPG and also not included in the labelling and only described briefly in the leaflets. One reason is that noise originating from maintenance activities is not reported by the project partners as one of the major reasons for complaints. Furthermore, the noise emitted from maintenance activities is generally a non-stationary noise source which does not belong to the ship and which depends on many factors in different ports or wharfs in the ports. Furthermore, the noise caused by operating cooled containers/reefers on container ships very much depends on several indicators such as the type of the container, type and size of the ship, ship’s cargo and port conditions. Their operation is also part of the cargo handling process of a ship at berth. For this reason, the cooled containers/reefers are not considered in this BPG either (e.g. not included in the labelling and only described briefly in the leaflets).

Annex III of this BPG includes a general explanation about noise and used in this BPG.
2 SHIP-GENERATED NOISE
This chapter gives insight into the characteristics of ship-generated noise, its challenges and limitations regarding the impact of this type of noise. Some attention will be paid to legislation and spatial planning which could be critical when expanding port or residential areas.

2.1 Characteristics of noise and annoyance

Ship-generated airborne noise can vary in strength (noise levels), in time and in frequency (pitch). Ship-generated noise and its perception by the receiver is therefore complex and depends on numerous factors, such as:

- Size of the port: the bigger the port, the more likely that noise will be experienced.
- Number of ship calls: the more calls, the more likely that noise is produced.
- Type of the ship.
- The equipment on board, the cargo and activities on board are relevant for noise emission.
- Meteorological conditions: wind speed and direction (downwind or upwind) and temperature gradient affect noise at receivers.
- Topography: reflections, deflections, diffractions and absorption can attenuate or amplify the noise at the receiver.
- Distance to the residents/receiver in relation to the port/berth side.

Based on an inventory of the available measurement reports, knowledge of the NEPTUNES project partners and first measurement results, the sources listed below are expected to cause the highest noise emission:

- Exhaust funnel outlet(s) of the auxiliary engine(s)
- Openings of the ventilation/fans (e.g. for engine room, the air conditioning of passenger rooms, cooling units and the cargo hold)
- Pumps
- Public Address systems
- Ship horns
- Compressors
- Generators
- Ramps (insofar as they belong to the ship)

Vibration of the ship’s hull caused by equipment in operation or the ship’s propellers when manoeuvring in the ports may also occur. The vibrating ship’s hull can subsequently cause noise to be emitted into the environment (structure-borne noise). However, structure-borne noise is not considered in this Best Practice Guide, because it is only expected to occur in exceptional cases (e.g. if machinery is not properly decoupled from the steel structure of the ship). Noise caused by manoeuvring is included in this Best Practice Guide to a limited extent (a brief description in the leaflet no. 14).

Most nuisance perceived by residents living near the ports is caused by low frequency noise (here described as noise with high energy level in the 1/3 octave frequency bands ≤ 160 Hz). For low frequency noise, how people perceive the loudness and the nuisance factor may be greater than for noise with the highest energy level in the higher frequency range having the same sound pressure level. Subjectively, low frequency noise is often interpreted as a humming or buzzing noise.

Low frequency noise is mainly caused by the funnel exhaust from the auxiliary engines (unless they are fitted with effective silencers). Reasons why sound sources with high low frequency contents are annoying to residents include:

- Low frequency noise is less attenuated on the propagation path than high frequency noise (e.g. due to lower air absorption in the lower frequency range - less screening through less air absorption).
- Low frequency noise is less attenuated by building façades. The noise insulation of buildings usually has lower noise insulation in the low frequency range and higher noise insulation in the higher frequency range. Low frequency noise is therefore less attenuated whilst being transmitted from the outside to the inside of a building than high frequency noise.

Besides low frequency noise, the characteristics of noise can be conspicuous for specific sound sources. The noise may be tonal, intermitting or impulsive. This conspicuous noise can

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4 The noise from maintenance activities (e.g. noise emitted by preparations for painting the ship, noise from cleaning activities of chemical, oil or food tankers/ships by means of steam, hot oil or water) and the noise from cooling containers/reefers is not considered in this BPG.
also lead to increased nuisance among receivers (e.g. residents living near the port). Tonal and/or intermittent noise is often caused by rotating equipment (e.g. pumps, ventilators, compressors, fans, auxiliary engines), while impulse noise may be caused by cargo handling (e.g. containers hitting the ground and/or other containers). The noise sources on the ship that are continuously in operation during berth do not generally cause impulsive noise.

2.2 Challenges regarding (mitigation of) noise from seagoing ships

Complaints relating to seagoing vessels at berth usually originate from residents living near ports. However, complaints are just the tip of the iceberg when considering nuisance (1), (2). Scientific insight into the extent of ship-generated noise at berth and its effects (e.g. nuisance) has rarely been found in literature. Although multiple noise measurements have already been conducted worldwide, the noise data obtained is generally incomparable and even irreproducible because different methods have been used. To be able to compare measurements performed in different ports, a universal measurement standard is required. The NEPTUNES project developed such a standard to standardise the measurements and make them applicable worldwide. See also Chapter 4.

In most cases, knowledge about ambient noise and noise reduction rarely seems to be considered when designing and building ships (especially cargo ships). Even though noise mitigation measures are commonly used and already state of the art in other industrial areas such as petrochemical industry, they have not yet been used in the shipping industry for noise reduction of ships at berth (1),(3),(4),(19).

New ships are sometimes still more noisy than necessary because noise measures on ship’s equipment have not been implemented or because builders did not choose quiet or quieter alternatives when selecting the ship’s equipment. Noise awareness is increasingly taken into account when designing and building cruise ships (to protect staff and guests on the upper decks from noise caused from the funnel outlet, for example), resulting in noise reduction measures on board of the ship aimed to reduce noise at work for seafarers.

Ships with or without major noise reduction measures (such as silencers in the exhaust path) often emit a lot of acoustic energy in the lower frequencies (for 1/3 octave bands ≤ 160 Hz). This makes it quite challenging to design and apply measures that are sufficient to reduce this type of noise. The challenge is to reduce the emission of low frequency noise when designing the equipment. Details and examples of noise reduction can be found in the leaflet Machinery (no. 1) and silencers (no. 2). In summary, it can be concluded that the reduction of ship-generated airborne noise generally poses several challenges due to the lack of sufficient noise data, limited knowledge of avoiding and/or reducing noise, the lack of requirements for noise reduction on seagoing vessels and the phenomenon of low frequency noise.

2.3 Impact of noise

Noise exposure, especially long-term noise exposure to higher noise levels, e.g. above 40 dB LDEN, has an impact on health and economics. This chapter provides a brief overview of the health and economic effects of long-term noise exposure. These represent possible effects that can occur in worst case scenarios. Nevertheless, due to different people’s perception, noise disturbance can even occur at low noise levels, does not always have health or economic effects and is not always covered by legislation and regulations. Noise complaints from residents should therefore always be treated seriously because they indicate a level of disruption to people’s lives. Nuisance occurs when noise is audible to receivers (e.g. residents) and contains information that does not correspond with the receiver’s environment or expectations. This is particularly the case when ship-generated noise levels are high and significantly surpass the residual noise levels (background noise levels).

2.3.1 Health effects

In the worst case scenario, long-term noise exposure can lead to (irreversible) health effects. Experts assume that long-term noise above 42 dB LDEN can lead to annoyance. Noise above 40 dB LNIGHT can result in sleep disturbance (6). These effects are considered stressors. Previous studies based on broadband noise such as traffic noise or industrial noise show that these stressors can have multiple health effects like high blood pressure, strokes, heart attacks, type II diabetes, depression,
loss of concentration or insomnia. It may be assumed that the same applies to nuisance from ship-generated noise. Research on the effects of low frequency noise has also shown that this is a stressor that can lead to headaches, dizziness, insomnia, depression, loss of concentration and distortion of the heart rhythm (7).

2.3.2 Economic damage
In general, long-term noise exposure can lead to economic damage. However, for ship-generated noise, no specific study on the economic impact of marine vessel noise is known. The most important cost items assigned to other types of noise are listed below. It is assumed that this similarly applies to ship-generated noise:

- Cost of harmful health effects such as hospital admissions, medical care and medicines to combat the harmful health effects of long-term exposure to noise. (8).
- Cost of production loss (loss of concentration and communication interference) due to tiredness caused by sleep deprivation/disturbance (9).
- Cost of measures required to reduce the noise such as the costs of barriers, double glazing, insulation, enclosures and dampers or other noise mitigation measures.
- Administrative costs (e.g. deployment of officials, allowances, permits, enforcement and prosecution) (10).
- Costs caused by value loss of property. According to previous research, the value of a dwelling drop with at least € 25/dB per annum and house rents also fall (11). The consequence is less income for communities (lower yield from property tax). Costs of learning disabilities (dropouts who need to repeat their year or even leave school, college or university) are also considered.
- Loss of income due to plots of land exposed to high noise levels and which are unusable for housing (12).
- Cost of noise-related accidents (e.g. poor sleep could lead to tiredness, concentration loss and subsequently to accidents) (13).

2.4 Legislation and regulations
As shown in the report drawn up on behalf of the European Commission which presented an overview of noise legislation introduced in European Member States (14), noise legislation varies considerably in most countries. This was also confirmed in the data reported by the European NEPTUNES partners. The information on legislation provided by the project partners showed a similar picture. It also emerged that, in the majority of cases, the noise of ships at berth was not regulated. The following paragraphs present an overview of legislation in terms of the indicators used for the various 24-hour periods (day-evening-night) and the noise limit values applied. Besides legislation regulating the noise of ships at berth, legislation relating to land use planning that can be transferred in a similar manner to ship-generated airborne noise will also be discussed.

2.4.1 Limitations regarding the impact of ship-generated noise
There is often no legislation or regulations and policies on ship-generated noise in ports. Even if these do exist, not all ship-generated noise is covered. For example, the noise of passing ships, noise caused by manoeuvring or ships’ horns is not considered or is scarcely included in regulations and legislation. In cases where ship-generated noise at berth is covered by legislation, similar indicators are used by the ports involved in the NEPTUNES project. Indicators used in ports are shown in the table below.

<table>
<thead>
<tr>
<th>Table 1: indicators in use in different port</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAeq(day)</td>
</tr>
<tr>
<td>LAeq(evening)</td>
</tr>
<tr>
<td>LAeq(night)</td>
</tr>
</tbody>
</table>

One or more of these indicators are used in most ports worldwide.

Besides similar indicators, limit values imposed by the permit or regulations vary remarkably. In cases where legislation is in place for ship-generated noise, it is often by means of an environmental permit that applies to the terminal or even the entire port. By means of limit values set out in the environmental permit, residents of noise sensitive objects (e.g. houses, hospital, schools, kindergartens, natural habitats) should be protected from unhealthy noise. It appears from Chapter 2.1
that ship-generated noise can manifest itself in many ways. Indicators included in the ports’ permit are not always tailored accordingly. When different types of seagoing ships visit the port, the noise in function of time, frequencies, duration or strength differs.

Where there is no legislation or regulation, it is difficult to force shipowners and liners (haulers) to take measures to reduce noise (for example, where there are not yet any legal, financial or fiscal instruments). Another challenge when designing the required noise mitigation measures is that legislation and regulations vary in different countries or even within different ports in the same country. This makes it difficult to implement standardised noise reduction measures.

2.4.2 Legislation governing spatial developments

When it comes to spatial developments, two major actions are involved. Firstly, all developments in the port area such as intensification and/or expansion of the port’s activities and areas can be considered. Secondly, all developments around the port (e.g. expansion of housing districts, new housing and expansion of protected natural or quiet areas) can be considered. However, where a major expansion of both the port and residential areas are planned, initiators in Europe Union must perform an impact assessment (15).

Nevertheless, the effort required is different for different countries. Some Member States even require a health impact assessment to be carried out before any expansion of port and/or residential areas are planned and completed. Such an environmental impact assessment must identify, describe and appropriately assess the direct and indirect effects of a project for each individual case based on the following factors:

1. People, fauna and flora
2. Soil, water, air, climate and landscape
3. Material assets and cultural heritage
4. The interactions between factors 1-3

The directive also requires a description of the measures envisaged to avoid, reduce and, where possible, offset any significant adverse effects together with an outline of the main alternatives studied by the principal investigator, accompanied by an indication of the main reasons for his choice, taking into account the environmental effects.

A similar directive (16) is in force regarding plans and programmes being developed in the European Member States.

Note: Member States may have stricter standards in their legislation transposed from this directive (2011/92/EC). It is not known in detail which Member States apply these stricter standards. END 2002/49/EC obliges the EU Member States to assess, among other things the sorts of noise, industrial noise (noise maps) for agglomerations every five years. It is unclear, however, whether port noise and ship-generated noise should be included in these maps. The directive can be interpreted in different ways. Some countries or regional authorities have developed legislation or regulations that oblige the initiator of plans and projects aimed at expanding residential areas, port areas, natural areas or any other sensitive object to explore the impact of those plans or projects.

2.4.3 Regulations imposed by the International Maritime Organization

So far there does not exist legally binding regulations governing the permissible airborne emissions for seagoing vessels. With regard to occupational health and safety, requirements on ships are defined in IMO Resolution MSC.337 (22), (3) for outdoor areas (e.g. brides, bride nocks, listening posts and other working and recreational areas). These level requirements can indirectly lead to restrictions of ship generated noise.

2.4.3 Regulations imposed by the European Standard of Technical Specifications for Inland Navigation vessels

In accordance with the European Standard of Technical Specifications for Inland Navigation vessels (ES-TRIN) (23), the noise level of vessels under way shall not exceed 75 dB(A) at a lateral distance of 25 m from the ship’s side. In the case of stationary vessels, a value of 65 dB(A) shall not be exceeded at this distance. These level requirements can also indirectly lead to restrictions of ship generated noise for seagoing vessels.

E.g. a tanker at the quay which unloads for 24 hours may emit less noise than a ship unloading in the same position for only a few hours during the day.
3 STAKEHOLDERS
When considering ship-generated airborne noise, its impact on the environment and its mitigation, many stakeholders can be identified.

We apply the following categories for the purpose of identifying the stakeholders and their areas of influence:

1. Source (owners and operators)
2. Propagation path and receiver
3. Non-acoustic influencers/factors

The Stakeholders are described in more detail in the following paragraphs.

3.1 Source

Source-related noise of an operating ship within ports is mainly determined by the ship-generated noise, see Chapter 2.2. Details regarding mitigation at the source can be found in Chapter 6.4.

The Stakeholders that might be addressed in relation to source noise can be subdivided into:
- operational
- technical and
- legal/policy

These will be described in more detail in the following paragraphs.

3.1.1 Operational

Regarding the operations of the ship within ports, the following stakeholders can be identified:
- Captain of the ship or 1st officer
- Crew members
- Shipping companies
- Port authorities
- Terminals
- Stevedores

The captain of the ship or 1st officer decides which engines and which electrical equipment on board will run during manoeuvring and at berth. If different auxiliary engines are on board, he can decide to choose the most silent one(s). In some cases, it is up to the captain whether or not tug boats are used during manoeuvring. Depending on the amount of noise emitted by the tug boat(s) and the main engine, he could choose the most silent operation.

The crew generally chooses the installations needed for loading and unloading the ship. For noise mitigation, it might therefore be possible for the ship’s crew to minimise the power settings/consumption while moored. This could be done by reducing the number or adjusting the power settings of fans/pumps/air conditioning. In the case of passenger ships, the power setting of the speakers for announcements on board can be adjusted in accordance with the noise level in the vicinity of the ship.

Port authorities or terminals are responsible for assigning where and how the ship will be moored. Depending on the noise directivity of the ship, the bow or stern of the ship can point to the closest housing area. The Port Authority can also prescribe the use of Onshore Power Supply and decide to use incentive schemes like Environmental Shipping Index (ESI) and/or Green Award Foundation.

Terminals may or must have environmental permits which set the noise limits. In some countries, the noise from ships at berth and/or when manoeuvring are included in the noise limits. In other cases, noise from ships is excluded. In most cases, (noise) limit values are enforced by environmental authorities acting on behalf of the local, regional and/or national government.

Stevedores choose, together with the crew and taking into account the available equipment at the terminal, the equipment for loading and unloading the ships. In their choices, they could take noise emissions into account.

3.1.2 Technical

Regarding the technical aspects of the ship, the following stakeholders can be identified:
- Shipowner
- Shipbuilders/designers
'Terminals may or must have environmental permits which set the noise limits.'

- Acoustical engineering consultancies
- Manufacturers and suppliers of equipment

The first and most important stakeholders who can reduce ship-generated airborne noise are obviously the shipowners. When having a new ship built, maintained or renovated, the shipowner can impose more stringent noise measures leading to more silent ships.

The shipbuilders, including shipyards, and designers can inform the shipowners about the possibilities and benefits of noise reduction measures.

Acoustical engineering consultancies can help shipbuilders and designers find the best practical solutions for noise reduction, by means of measurements, calculations and following new developments regarding noise mitigation possibilities. Close cooperation between different stakeholders is recommended. When applying noise mitigation measures, for example the shipowner and the shipbuilder/designer should communicate with manufacturers and acoustical engineering consultants about possible noise mitigation measures.

3.1.3 Legal/policy

Regarding the legal and policy aspects, the following stakeholders can play a role:
- IMO
- European Union
- National governments
- Port Authorities

International Maritime Organization (IMO) is a special umbrella organisation which issues legislation regarding international shipping. So far noise on board ships is only an issue that involves a minimum standard for protection of the crew. Noise emissions from ships at berth have not yet been taken into account.

The European Union has developed and enforced the European Environmental Noise Directive (16). The Directive applies to noise to which humans are exposed, particularly in built-up areas, in public parks or other quiet areas in an agglomeration, in quiet areas in open country, near schools, hospitals and other noise-sensitive buildings and areas. The Directive requires Member States to prepare and publish, every 5 years, noise maps and noise management action plans for:
- Agglomerations with more than 100,000 inhabitants
- Major roads (more than 3 million vehicles a year)
- Major railways (more than 30,000 trains a year)
- Major airports (more than 50,000 movements a year, including small aircraft and helicopters)

Industrial noise, including noise from ships in ports, is included in the noise maps of the agglomerations.

When developing noise management action plans, Member State authorities are required to consult the public concerned.

Noise management action plans must be drawn up for all situations with values above Lden > 55 dB(A).

National governments issue national legislation and policies. Noise is an important issue with regard to health, sleep disturbance and prevention of nuisance. Noise targets at the receptor are set in national abatements and play an important role in spatial planning.

Regional and provincial governments can issue policies that go a little further than the national limits. On the other hand, economic interests could result in being less strict when issuing noise limits. In some countries, provinces are the environmental authority responsible for issuing permits for bigger and more complex companies. In these permits, more or less stringent noise limits can be set. Another role or responsibility for regional governments is to improve or preserve the acoustic quality in natural areas based on Natura 2000 and the Habitats directive.

3.2 Propagation path and receiver

When noise is emitted by the ship, it will propagate to the receiver, such as residents living near the ports. Details regarding mitigation at the propagation path and the receiver can be found in Chapter 6.2 and 6.3.
The stakeholders that could be addressed in relation to the propagation path and the receiver can be subdivided into:

- Municipalities/local governments
- Other companies
- Citizens
- Environmental authority

These will be described in more detail in the following paragraphs.

**Municipalities/local governments** can play a more complex role. They often have multiple roles as they generally prepare the spatial plans and have a great interest in developing residential areas, in many cases close to or even in the port area. On the other hand, they may be the owner of the port area. Another role or responsibility for local governments is to improve or preserve the acoustic quality in their residential and natural areas. Possible measures to reduce nuisance are screening by noise barriers or other buildings and insulation of the houses.

**Citizens** are the ones who experience noise from various noise sources. When living close to the port area, they may be annoyed by the noise from the port activities, including the noise from ships at berth and/or when manoeuvring. Citizens influencing politicians can initiate procedures to adjust the noise limits in environmental permits to be granted or even lead to a revision/withdrawal of the environmental permit. It is therefore vital to build up a good relationship with residents living near the port area and or the terminals.

**Other companies** in or close to the port can be sensitive to noise or vibrations caused by ships. High noise levels can disturb office workers in neighbouring terminals or companies. Guests staying at neighbouring hotels may also experience nuisance. Some companies work with very sensitive measuring devices or production lines that are sensitive to vibrations. These companies have the same possibilities to act as described under Citizens.

**Environmental Authorities** are appointed to enforce the permits. In the negotiations to set up the request for the permits and the regulations and limits in the permits, advice from the environmental authorities and/or consultants can produce the right limits and regulations in the permits.

### 3.3 Non-acoustic influencers/factors

Besides the source, propagation path and receiver, other non-acoustic influencers/factors may affect the operation of ships in ports in relation to noise emission and perception. The Stakeholders that could be addressed in relation to non-acoustic influencers/factors can be subdivided into:

- Cargo owners and shipping agents
- NGOs
- Umbrella organisations

Cargo owners and shipping agents play an important role in selecting the ships to transport the cargo. Up until now, noise emitted by a ship at berth has not been an (important) issue in this regard. Shipping agents are often the linking pin between the terminals and the captain/crew of the ship. They can inform the captain/crew about the best conditions for manoeuvring and when at berth to comply with the (noise) regulations and limits set.

Non-Governmental Organisations (NGOs) can be well organised and play an important role regarding noise limits in permits, local, regional, national and even European legislation and policies.

Shipowners are often organised in umbrella organisations, like ICS (International Chamber of Shipping). Many ports are also organised in umbrella organisations like IAPH (International Association of Ports and Harbours), ESPO (European Sea Ports Organisation), AIVP (Association Internationale de Villes et Ports). These organisations play an important role in the communication, lobbying and advice provided with regard to existing and new legislation at the international, national and local level. They also can advise on the best practical solutions. An attempt to provide an overview of all stakeholders is given in the figure below.
Several stakeholders should be involved when mitigating noise.

Figure 1: potential stakeholders
4 UNIVERSAL MEASUREMENT PROTOCOL
Chapter 4
Universal Measurement
So far, there is a lack of a uniform, worldwide applicable measurement standard on how to measure noise from ships. In order to compare and exchange measurements worldwide, the NEPTUNES project started by developing a measurement protocol describing how to measure, analyse, evaluate and classify individual ships (e.g. container ships, cruise ships, tankers, RoRo/RoPax and bulk carriers) with regard to their airborne noise emission when moored at berth in ports.

The measurement protocol will mainly ensure that measurements are performed in the same way in different ports and by different people. The measurements should be carried out by acoustic specialists/measurement institutes that are preferably accredited for the test procedures and standards specified in this measurement protocol according to country-specific requirements. If applicable, the respective country-specific accreditation companies should preferably be assigned to the umbrella association International Laboratory Accreditation Cooperation (ILAC).

Besides providing guidance for performing the acoustic measurements and calculating the sound power level of the ship from the measurement results, the protocol will explain which details need to be documented during the measurements and what results are required as an outcome of each measurement.

The measurement protocol can be found in Annex II of this BPG or downloaded from the NEPTUNES homepage http://www.neptunes.pro

Measurements to determine the sound power level of a ship

The measurements will preferably be performed as noise emission measurements on board the ship concerned. The noise emission measurements on board the ship will be performed to determine the sound power level of the most dominant noise sources on a ship. The total sound power level of the ship will then be calculated from the sound power levels of the individual sound sources. Only in exceptional cases, such as proven denied access to the ship, complementary sound pressure measurements at a certain distance from the ship can be performed to determine the total sound power level of the ship (provided that the requirements for measurements at a certain distance can be met, e.g. low residual noise and accessibility). Besides the broadband total sound power level, the total sound power level for 1/3 octave bands ≤ 160 Hz will be calculated (low frequency total sound power level). Guidance for how to calculate the sound power levels from the performed measurements is also given in the measurement protocol.

Sound sources to be measured

The most dominant noise sources that are in operation at berth and that emit noise into the environment are expected to be:

- The funnel outlet(s) of the auxiliary engine(s), all ship types.
- The opening(s) of engine room ventilation inlet and outlet, all ship types.
- The opening(s) of the cargo holds, ventilation and air conditioning inlet(s) and outlet(s), all ship types.
- The opening(s) of the ventilation and air conditioning of passenger rooms, ship types b) and RoPax d).
- Further relevant ventilation openings (e.g. sanitary or galley exhaust)
- Pumps on deck, ship type c).

Specific recommendations for carrying out the measurements on those noise sources are also given in the measurement protocol.

The operation of cooled containers/reefers on container ships depends strongly on several indicators such as type of container, type and size of the ship, load on board of the ship and

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3 The smaller sound sources like HVAC systems on the bridge and ventilation of galleries etc. will not generally be considered because they do not contribute to the total sound emission of a ship.

4 All further ventilation openings on board should be checked for relevant sound emission.
'In order to compare and exchange measurements worldwide, a measurement protocol was developed.'

port condition. Furthermore, their operation also involves the cargo handling process of a ship at berth. Therefore, the cooled containers/reefers are not considered for measurements or for the calculation of the total sound power level of the measured ship in the measurement protocol. Nevertheless, based on several measurements in the participating ports of NEPTUNES, an average sound power level of approx. $L_{WA} = 91-93$ dB(A) can be expected for one reefer in operation. If there are many reefers on board one ship and in operation during berth, a high level of sound power will be emitted into the environment from the reefers (e.g. for 100 reefers on board, the total sound power level of the reefers will be approx. $L_{WA} = 111-113$ dB(A)).

Operating conditions:
All seagoing ships have at least one main engine and two auxiliary engines. While the main engine(s) is/are used to drive the ship, the auxiliary engines are used to run electrical equipment on board (pumps, fans, reefers, lighting, etc. and many others). On a moored ship, the main engine(s) is/are switched off, whereas the electrical consumers are usually driven by only one or two auxiliary engine(s). Most electrical equipment is controlled by ship automation according to cargo handling requirements. The load of the auxiliary engine(s) can usually only be manually changed by the activation or deactivation of consumers. During cargo handling, this can only occur in a limited range.

The operating conditions thus strongly depend on many factors that cannot easily be controlled in the respect port conditions (e.g. current load of the ship, number of reefers, temperature, etc.).

During the measurements, the ship will therefore be operating in the characteristic/normal load of the ship at berth. The load condition during measurements must be chosen in such a way that the measured sound emissions are not exceeded at berth in any calling port (in most cases during high/maximum load conditions of the ship). It is important that the electrical load is kept as constant as possible during all measurements.
5 GUIDELINES FOR A NOISE LABEL
Based on the results obtained from measurements in the participating ports of the NEPTUNES project, a guideline for a noise label was developed that can be used to classify different ships with respect to their noise emission at berth. The noise label can be used for issuing permits and for spatial planning purposes in the port and may be used in ports worldwide.

The noise label is based on the measured noise emission of the ship at berth, especially the
- broadband total sound power level of the ship, and the
- sound power level of the ship for the 1/3 octave frequency band ≤ 160 Hz (low frequency total sound power level).

The above-mentioned sound power levels of the ship will be established from measurements following the NEPTUNES measurement protocol. For the purpose of labelling, the measurements will preferably be commissioned by the shipping companies/shipowners.

The noise label is developed in such a way that it can be used in all ports worldwide. Individual factors for different ports, such as environmental concerns, is not part of the noise label and where necessary may be considered in the classification system of each port.

Details regarding the noise label are provided below. The label is based exclusively on the noise emission of ships at berth. Other noise sources, such as noise from cargo handling, noise from reefers/cooling containers or manoeuvring, are not considered for labelling.

5.1 Execution of measurements

To assign a noise label to a ship at berth, the noise emission of the respective ship must be measured. The measurements should be based on the NEPTUNES measurement protocol, see Annex II. Suitable measurement situations and operating conditions must be chosen based on the regulation of the measurement protocol (e.g. low residual noise level, required operating conditions of the ship, etc.).

5.2 Noise label

The noise label is based on a point system (total airborne noise score) ranging from 0 to 100, similar to already known rating systems (e.g. air emission from the environmental ship index (ESI), (17)). The more points a ship receives, the lower the noise emission and thus the lower the expected noise disturbance of the ship.

The points will be based on the following three different categories:

Part 1 - Total broadband airborne noise emission:
The total combined broadband A-weighted sound power level of all relevant noise sources on board. The frequency range includes the 1/3 octave bands from 25 Hz to 10 kHz.

Part 2 – Total low frequency airborne noise emission
The total combined low frequency A-weighted sound power level of all relevant noise sources on board. The frequency range includes the 1/3 octave bands from 25 Hz to 160 Hz. The low frequency part of the noise emission can be considered the most relevant aspect for nuisance and is therefore weighted higher within the total noise score than the broadband noise emission.

Part 3 – Availability of a comprehensive measurement report
The availability of a comprehensive measurement report containing measurement data and a description of the operational conditions of the ship according to the NEPTUNES measurement protocol.

Calculation of the total airborne noise score
In the following the calculation of the total airborne noise score is shown. The basis for the calculation of the noise score is the respect measurement report for the individual ship following the measurement protocol, see also chapter 4.
Table 2. Formulas for calculation of the total airborne noise score

<table>
<thead>
<tr>
<th>Part</th>
<th>Relevant Parameter</th>
<th>Formula</th>
<th>Score range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Broadband sound power level $L_{WA,total}$</td>
<td>$\text{Broadband-Score} = 1 \times \frac{(118 - L_{WA,total})}{\text{Points } \geq 0}$</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Low frequent sound power level $L_{WA,total,\leq160\text{Hz}}$</td>
<td>$\text{Low frequent-Score} = 2 \times \frac{(108 - L_{WA,total,\leq160\text{Hz}})}{\text{Points } \geq 0}$</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Availability of a measurement report</td>
<td>Report-Score: Measurement report existing?</td>
<td>Points = 0 or 20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes = 20 points; No = 0 points</td>
<td></td>
</tr>
</tbody>
</table>

In which:

- $L_{WA,total}$ = Total broadband airborne sound power level of the ship for the 1/3 octave bands from 25 Hz to 10 kHz in dB(A)
- $L_{WA,total,\leq160\text{Hz}}$ = Total low frequent airborne sound power level of the ship for the 1/3 octave bands from 25 Hz to 160 Hz in dB(A)

The calculation of the parameters $L_{WA,total}$ and $L_{WA,total,\leq160\text{Hz}}$ is explained in detail in the measurement protocol, see also chapter 4. The total airborne noise score will be calculated out of the individual parameters from table 2 as follows:

Total airborne noise score

\[
= \text{Broadband Score} + \text{Low frequent Score} + \text{Report Score} \leq 100 \text{ points} \\
= (118 - L_{WA,total}) + 2 \times (108 - L_{WA,total,\leq160\text{Hz}}) + \text{Report Score} \leq 100 \text{ points}
\]

Possible use of the noise label for classification in a specific port

After allocating an independent and individual noise label (number of points) for each ship, the ports can choose different rating factors to account for their individual (noise) situation. Reasons for choosing individual rating scores in different ports might be the existence of individual regulations, legislation and/or restrictions in different ports. Furthermore, the location and noise classification of residential areas near the port may vary for different ports. Therefore, points that should be achieved for a specific port may be based on individual factors in each port.

The port could use the total score and benefit ships visiting their ports based on a specific score (e.g., if a ship reaches a certain score). Furthermore, if in low frequency disturbance of residents in a certain port/berth location within a port is of great interest, only the low frequent score may be used or can be further restricted with a score to be reached for the specific condition.

Moreover, ports may also use the score system for their berth management. Noisy ships that do not reach a certain score could be berthed further away from residents living near the port.

The noise label can especially be used to reward efforts by shipping companies to implement noise mitigation measures on their ships and to persuade shipping companies which do little in terms of noise mitigation to apply mitigation measures on their ships in the future.

5.4 Validity of the noise label

The noise label will be valid for a period of 5 years or until significant modifications/changes are made to the ships that affect the overall noise emission of the ship at berth. If this period is exceeded, the measurements must be repeated to prove/review the noise label of the ship. A certificate must be provided stating the number of points obtained from each category and the overall points obtained for the noise label.

5.5 Implementation

In December 2018 it was decided during an ESI meeting to incorporate a separate noise module, based on the Neptunes systematics. This separate ESI module is expected in the second half of 2019.
6 BEST PRACTICES
By best practice, it is meant an intervention or measure that has been shown by research and experience to produce optimal results, established or proposed as a standard suitable for widespread adoption. Best Technical Means (measures that are still on the drawing board) are not considered in this Best Practice Guide. Besides considering best practices already applied on ships or in port areas, best practices that have been proven and established in other industrial sectors (such as machines or equipment provided with noise mitigation measures) are also studied. The experience gained from such implementation can usually be transferred directly to the noise situation of ships. The aim of the best practices is to give a brief overview of possible noise mitigation measures. Not all the mitigation measures described in this BPG and the leaflets have the same significance for emissions into the environment at each source and for each ship type. It is therefore important that mitigation measures are planned for each individual case by professionals (acoustic specialists, manufacturers of noise mitigation measures, city planner etc.). In many cases, communication between different stakeholders is essential and can sometimes even solve problems at an early stage. The measures or interventions to mitigate noise, documented in the best practices, are divided into four categories:

- Mitigation at the source (on board the ship).
- Mitigation in the propagation path.
- Mitigation at the receiver.
- Non-acoustic measures (most soft measures, like interventions related to relation management).

### Figure 2: from noise source to receiver

![Diagram showing the propagation path from noise source to receiver](image)

The four categories of measures or interventions listed above are described in more detail in the following paragraphs. For each measure or intervention, the following factors are reported in a corresponding leaflet (shown in the Annex I):

- Brief description
- Expected reduction
- Expected costs
- Conditions (safety, maintenance, etc.)
- Applicability in new, existing or retro-fitted situations
- Lessons learned and worst practices

The leaflets are assigned a relative cost estimation (relative to other noise mitigation measures, as presented in other leaflets) which is structured in the following categories (24):

- **Category A** indicates that the noise mitigation measure is probably the least complex to implement, the least time-consuming and the least costly.
- **Category B** indicates that the noise mitigation measure is probably of moderate complexity to implement, moderately time-consuming and moderately costly.
- **Category C** indicates that the noise mitigation measure is probably the most complex to implement, the most time-consuming and the most costly.

#### 6.1. Mitigation at the source

Noise reduction of the machinery on board a ship is the first and most important step to reduce noise emissions from ships into the environment. In most cases, revision of existing noisy machinery on board is difficult to achieve (e.g. limited accessibility and space in the exhaust duct for implementation of a silencer) and thus costly. Noise mitigation measures, particularly regarding existing machinery, could also have contrary effects of operating parameters. Noise mitigation measures for machinery elements should therefore preferably be considered as early as possible, at least during the design and building phase of the ship. An overview of the leaflets assigned to mitigation at the source including the addressed stakeholders and possible phases of implementation can be found in Chapter 6.6.

#### 6.2. Mitigation in the propagation path

When the noise is emitted from the source (e.g. machinery on board ships at berth), it will propagate (e.g. through air) to the receiver (e.g. residents living near the port area). The propagation path can influence the noise in different ways, leading to attenuation or amplification of the noise towards the receiver. The most effective ways to reduce noise in the propagation path are found in changing the distance between ships at berth...
and residents and changing the shielding. Both methods are described in more detail in the leaflet Propagation of noise (no. 5). Besides mitigation of ship-generated airborne noise, changes in the propagation path are especially suitable for mitigating port noise itself (e.g. noise emitted from cargo handling). An overview of the leaflets assigned to mitigation in the propagation path including the addressed stakeholders and possible phases of implementation can be found in Chapter 6.6.

6.3. Mitigation at the receiver

When expanding the port activities or when noise levels at the façades of existing houses are too high and remediation is needed, or when building a new residential district or houses in areas acoustically influenced by the port activities, it is often necessary to apply or integrate noise mitigation measures near or at the façades of the dwellings. Depending on the situation that occurs, the responsibility varies as follows:

A When the noise levels at the façades of the dwellings remains too high during port expansion and even after applying measures, the port could be responsible.

B When building new dwellings in an area with high noise levels caused by port or ship-generated noise, the initiator, often the municipality, is responsible. Measures near or at the buildings should be integrated into the plan.

C In cases where dwellings already exist and the noise emitted by the port is too high and measures near or at the façades should or must be applied, the responsibilities are shared.

D Re-considering the limit values of the environmental permit of the port or companies situated in the port could be an option to reduce the noise to the preferred levels. Applying measures at or near the existing dwellings could also be an option or even a combination of these two options. In such cases, the responsibilities are shared.

Port Authorities should be aware that they could and should be responsible in some of these situations and be alert in those situations where new housing districts are planned or developed near the port area. In the latter situations, ports could opt for an active role, contributing ideas to create a good living environment fulfilling national and regional noise regulations. A good environment in these situations can also be enhanced by employing non-acoustic factors, see leaflet no. 15. The measures listed in the leaflet will be helpful to the Port Authorities in the four situations described above (A-D).

Note: When expanding or intensifying port activities or even developing new port areas, initiators are often obliged to take legislation and procedures into account. Even though measures at the receiver are a good way to minimise and counteract noise disturbance experienced by residents, the feasibility of these measures may be in conflict with legislation. This often implies that an impact assessment should be conducted, see Chapter 2.4 on legislation. Internal zoning (acoustic optimisation of port activities) can be used to limit the environmental impact. This could also involve acoustic optimisation (18),(20). There exist many different noise mitigation measures that can be taken at the receiver, depending on the situation. These include measures that can be applied in the existing situation, i.e. dwellings and other sensitive objects6, or in a new situation where new buildings and districts are planned. In the first situation, (new) measures can be integrated into the plan; in the latter these involve rather more end-of-pipe solutions. Besides technical and planning measures, there are also “measures” as interventions, having the character of plans/programmes/activities that soften the perception, thus leading to less nuisance or sleep disturbance and subsequently to a less adverse impact. These interventions are described in the leaflets. Leaflets regarding the reduction at the receiver include measures that can be taken within the community by local authorities and planners. An overview of the leaflets assigned to mitigation at the receiver, including the addressed stakeholders and possible phases of implementation, can be found in Chapter 6.6.

6.4. Non-acoustic and soft measures

Besides the group of measures and interventions described above, some noise mitigation measures are difficult to categorise. These measures include non-acoustic factors that can influence people’s perception or measures that are not directly related to ship-generated airborne noise. Non-acoustic factors depend on attitude, beliefs and opinions of individual people. However, they also depend on lessons learned, past
experiences and last but not least expectations as well as individual preferences such as social relationships (respect, control, etc.). Epidemiological research has found that the following non-acoustic factors can play a role in the perception of groups of people. It is assumed that this can also be used to mitigate the perceived nuisance among the people exposed, but it does not have any impact on sleep disturbance. Leaflet 15 lists the best known acoustic factors in more detail, such as visual aspects, contextual factors, compensation, framing and priming and Corporate Social Responsibility (CSR). These measures or interventions can be used by the Port Authorities and the enterprises based in or visiting the port. These parties are part of society as a whole (local, regional, national and even worldwide). As such, their behavior relating to their CSR goals should be visible or tangible, not only for the in-crowd but for society as a whole and they should accept the challenge of being an important and responsible part of society.

An overview of the leaflets assigned to non-acoustic and soft measures including the addressed stakeholders and possible phases of implementation can be found in Chapter 6.6.

6.5 Legislation and regulations

An instrument already in use in a number of ports concerns the environmental permit for all or parts of the port, which also includes ship-generated noise. An important point in this respect is compliance and surveillance. This means that inspections must be systematically carried out and that, where necessary, enforcement actions must be taken in situations where the noise levels imposed cannot be met. An important point of discussion is what noise level to be imposed. Even when noise mitigation measures are applied, the noise level requirements that are generally used for industrial noise cannot be complied with in all cases and/or compliance involves disproportionately high costs. In those cases, communication between stakeholders is very important. In particular, communication with approval authorities (such as cities and municipalities) is essential to fulfill national and regional legislation and regulations. The assistance of acoustic specialists should be considered for communication between stakeholders.

6.6 Overview of all measures

The following table provides an overview of the mitigation methods assigned to the respective mitigation categories. The respective leaflets can be found in Annex 1.

<table>
<thead>
<tr>
<th>Leaflet title</th>
<th>Measures/interventions</th>
<th>Expected reduction</th>
<th>Phase of implementation</th>
<th>Audience</th>
<th>Leaflet no.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mitigation at the source</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machinery</td>
<td>Measures at the auxiliary engine(s) (e.g. silencer in the exhaust duct(s) and resilient mounting, etc.)</td>
<td>1-30 dB (depending on the measure)</td>
<td>D, C1, R</td>
<td>Shipowners, shipbuilders, shipping companies, ship engineers (designers/architects) and maintenance staff</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Measures at the fan(s) (e.g. acoustically optimised fan design, silencer(s) and optimised air flow)</td>
<td>1-20 dB (depending on the measure)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The assistance of acoustic specialists should be considered for communication between stakeholders.

<table>
<thead>
<tr>
<th>Leaflet title</th>
<th>Measures/interventions</th>
<th>Expected reduction</th>
<th>Phase of implementation</th>
<th>Audience</th>
<th>Leaflet no.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mitigation at the source</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machinery</td>
<td>Measures at the pump(s) (e.g. installation inside the ship’s hull, avoidance of cavitation and low noise design)</td>
<td>1-20 dB (depending on the measure)</td>
<td>D, C, R</td>
<td>Shipowners, shipbuilders, shipping companies, ship engineers (designers/architects) and maintenance staff</td>
<td>1</td>
</tr>
<tr>
<td>Silencers</td>
<td>Implementation of a silencer inside the exhaust air duct of the auxiliary engine(s). Silencer types: reactive silencer, absorption silencer and combination of both</td>
<td>1-30 dB (depending on the implementation)</td>
<td>D, C, R</td>
<td>Shipowners, shipbuilders, shipping companies, ship engineers (designers/architects), silencer manufacturer and maintenance staff</td>
<td>2</td>
</tr>
<tr>
<td>External Power Supply</td>
<td>Using an external power supply instead of internal power from the ship’s auxiliary engine(s), such as LNG power pac, LNG power barge and shore power</td>
<td>1-10 dB</td>
<td>D, C, R</td>
<td>Shipowners, shipbuilders, shipping companies, ship engineers (designers/architects), terminal owners, port authorities, ship’s crew (captain) and maintenance staff</td>
<td>3</td>
</tr>
<tr>
<td>PA-systems</td>
<td>Hardware measures on the PA systems, such as skilful arrangement of the loudspeakers, optimisation of warning signals, building sound barriers on board Soft measures, such as careful use of the PA system, limitation of use at certain times, using radio equipment instead, training of crew members for careful use</td>
<td>Measures do not directly influence ship-generated airborne noise. Nevertheless, the nuisance of residents can be reduced.</td>
<td>D, C, R, P, B</td>
<td>Shipowners, ship-builders, shipping companies, ship engineers (designers/architects), terminal owners, port authorities, ship’s crew (captain) and maintenance staff</td>
<td>4</td>
</tr>
<tr>
<td><strong>Mitigation in the propagation path</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Propagation of Noise</td>
<td>Measures on the propagation path from ship at berth to receiver (e.g. residents) in terms of changing the distance and/or shielding</td>
<td>6 dB per doubling of distance</td>
<td>P</td>
<td>Shipowners, shipping companies, terminal owners, port authorities and maintenance staff</td>
<td>5</td>
</tr>
</tbody>
</table>

<p>| 1-10 dB for shielding |</p>
<table>
<thead>
<tr>
<th>Leaflet title</th>
<th>Measures/interventions</th>
<th>Expected reduction</th>
<th>Phase of implementation</th>
<th>Audience</th>
<th>Leaflet no.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mitigation at the receiver</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insulation</td>
<td>Passive mitigation measures, e.g. by improving building facades and windows</td>
<td>Measures do not directly influence ship-generated airborne noise. Nevertheless, they can reduce the sound pressure level inside buildings by 1-30 dB</td>
<td>P</td>
<td>Port authorities, city planners, real estate owners and investors, building owners and contractors</td>
<td>6</td>
</tr>
<tr>
<td>Expectation Management</td>
<td>Informing residents about the arrival of noisy ships, berthing of ships at specific quays, duration, sources, action to avoid repetitions, incidents, measures applied and reductions achieved.</td>
<td>Acceptance/perception</td>
<td>C2</td>
<td>Port Authorities, terminals, governments as port owners</td>
<td>7</td>
</tr>
<tr>
<td>Mutual Gains Approach</td>
<td>The process that creates added value and mutual “wins” for all stakeholders when developing a major habitat (e.g. expansion of port, residential or natural areas)</td>
<td>Acceptance/perception/compensation</td>
<td>P,D</td>
<td>Port Authorities, terminals, governments</td>
<td>8</td>
</tr>
<tr>
<td>Urban Planning</td>
<td>Zoning (buffer between the port and residential area)</td>
<td>6 dB per distance doubling</td>
<td>P,D</td>
<td>Authorities, architects and urban planners</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Shielding noise by planning non-sensitive building</td>
<td>5-15 dB</td>
<td>P,D</td>
<td>Authorities, architects and urban planners</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>The orientation of the sensitive buildings</td>
<td>Depends on the situation</td>
<td>P,D</td>
<td>Authorities, architects and urban planners</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Noise reducing façades</td>
<td>20-30 dB indoor</td>
<td>P,D,R</td>
<td>Authorities, architects and urban planners</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Layout of the sensitive building</td>
<td>15-20 dB indoor</td>
<td>P,D,R</td>
<td>Authorities, architects and urban planners</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Non-complaint declaration</td>
<td>‘acceptance’</td>
<td>O</td>
<td>Local authorities and residents</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Masking (fountains, etc.)</td>
<td>Affects perception</td>
<td>P,D,R</td>
<td>Authorities, architects and urban planners</td>
<td>9</td>
</tr>
<tr>
<td>Leaflet title</td>
<td>Measures/interventions</td>
<td>Expected reduction</td>
<td>Phase of implementation</td>
<td>Audience</td>
<td>Leaflet no.</td>
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</tr>
<tr>
<td><strong>Mitigation at the receiver</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban Planning</td>
<td>Quiet Urban Places</td>
<td>Compensate, the bustle of the ports</td>
<td>P,D,R</td>
<td>Authorities, architects and urban planners</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Covenants/agreements</td>
<td>Depends on the mutual efforts to be made</td>
<td>P,D,R</td>
<td>Local authorities and Port authorities</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Sufficient green, see also leaflet no. 18</td>
<td>Compensate, the bustle of the ports</td>
<td>P,D,R</td>
<td>Authorities, architects and urban planners</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Innovative measures (e.g. barriers, façades)</td>
<td>10-20 dB indoors</td>
<td>P,D,R</td>
<td>Authorities, architects and urban planners</td>
<td>9</td>
</tr>
<tr>
<td><strong>Awareness</strong></td>
<td>Information leaflet</td>
<td>Depends on the type of work being done</td>
<td>B, C2</td>
<td>Sailors, port authorities, terminal staff, captains tugs, shipowners</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Training terminal staff</td>
<td>Depends on the type of work being done</td>
<td>B, C2</td>
<td>Terminal staff</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Use of role models</td>
<td>Depends on the influence of role model and type of work</td>
<td>B, C2</td>
<td>Sailors, terminal staff,</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Incentives</td>
<td></td>
<td>B, C2</td>
<td>Sailors, port authorities, terminal staff, shipowners</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Physical measures or obstacles which force employees to work more quietly</td>
<td>Depends on the type of work being done</td>
<td>B, C2</td>
<td>Sailors, port authorities, terminal staff</td>
<td>10</td>
</tr>
<tr>
<td><strong>Complaint management</strong></td>
<td>A complaint registration system (CRS),</td>
<td>Acceptance</td>
<td>C2</td>
<td>Port Authorities and/or (local) authorities</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>A management protocol on how handle complaints</td>
<td>Acceptance</td>
<td>C2</td>
<td>Port Authorities and/or (local) authorities</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>A policy document</td>
<td>Acceptance</td>
<td>C2</td>
<td>Port Authorities and/or (local) authorities</td>
<td>11</td>
</tr>
<tr>
<td><strong>Organizational and planning measures</strong></td>
<td>Berthing programme</td>
<td>6 dB per distance doubling</td>
<td>P, C2</td>
<td>Port authorities, terminal staff</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Prioritisation scheme</td>
<td>Incentive to quieter ships</td>
<td>P</td>
<td>Port authorities, terminal staff</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Mandatory use of OPS</td>
<td>1-10 dB</td>
<td>P</td>
<td>Port authorities, terminal staff</td>
<td>12</td>
</tr>
</tbody>
</table>
### Mitigation at the receiver

<table>
<thead>
<tr>
<th>Leaflet title</th>
<th>Measures/interventions</th>
<th>Expected reduction</th>
<th>Phase of implementation</th>
<th>Audience</th>
<th>Leaflet no.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Organizational and planning measures</strong></td>
<td>Mandatory use of Shore-Tension or magnetic mooring</td>
<td>Avoids the whining noise from winches</td>
<td>P</td>
<td>Port authorities, terminal staff</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Re-allocation</td>
<td>6 dB per distance doubling</td>
<td>O</td>
<td>Port authorities, terminal staff</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>No bookings</td>
<td>No noise</td>
<td>O</td>
<td>Port authorities</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Mooring the ship behind stapled containers.</td>
<td>Max. 1-20 dB (depends on the height of sources and the stapled containers)</td>
<td>P, O</td>
<td>Terminal staff</td>
<td>12</td>
</tr>
</tbody>
</table>

### Non-acoustic and soft measures

<table>
<thead>
<tr>
<th>Leaflet title</th>
<th>Measures/interventions</th>
<th>Expected reduction</th>
<th>Phase of implementation</th>
<th>Audience</th>
<th>Leaflet no.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cargo</strong></td>
<td>Measures for external operation (on the harbour side), such as reducing noise from cranes and cargo handling</td>
<td>Measures do not directly influence ship-generated airborne noise. Nevertheless, the nuisance of residents can be reduced.</td>
<td>P</td>
<td>Shipowners, shipbuilders, shipping companies, ship engineers (designers/architects), terminal owners, port authorities, cargo handling operators, ship's crew and maintenance staff.</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Measures for internal operation (on the ship), such as reducing noise from cranes on the ship and cargo handling</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Manoeuvring</strong></td>
<td>Hardware measures, such as noise mitigation measures at the machinery</td>
<td>Measures do not directly influence ship-generated airborne noise at berth. Nevertheless, the nuisance of residents can be reduced</td>
<td>P</td>
<td>Shipowners, shipbuilders, shipping companies, ship engineers (designers/architects), terminal owners, port authorities, ship's crew (captain) and maintenance staff.</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Soft measures, such as supporting manoeuvring by tugs, education of the ship's crew for careful manoeuvring</td>
<td>Noise mitigation by using hardware measures ranges from 1-20 dB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaflet title</td>
<td>Measures/interventions</td>
<td>Expected reduction</td>
<td>Phase of implementation</td>
<td>Audience</td>
<td>Leaflet no.</td>
</tr>
<tr>
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</tr>
<tr>
<td><strong>Mitigation at the receiver</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-acoustic factors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>port side</td>
<td>Use of visual aspects, well-maintained port and</td>
<td>Positively affects perception</td>
<td>C&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Port Authorities, terminals, municipalities</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>companies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cleanliness</td>
<td>Positively affects perception</td>
<td>D</td>
<td>Port Authorities, terminals, municipalities</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Green (plants, trees, greens, etc.)</td>
<td>Positively affects perception</td>
<td>D, R, C&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Port Authorities, terminals, municipalities8</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Colourful and use of attractive materials</td>
<td>Positively affects perception</td>
<td>D, R, C&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Port Authorities, terminals, municipalities8</td>
<td>15</td>
</tr>
<tr>
<td><strong>At the residential side</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Safety, security.</td>
<td>Positively affects perception</td>
<td>D, R, C&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Municipalities, Urban Planners, Police</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Sufficient facilities and amenities (e.g. playgrounds).</td>
<td>Positively affects perception</td>
<td>D, R, C&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Municipalities, Urban Planners</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Sufficient green, blue and grey (quiet) areas</td>
<td>Positively affects perception</td>
<td>D, R</td>
<td>Municipalities, Urban Planners</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Compensation</td>
<td>Positively affects perception</td>
<td>R, C&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Port Authorities, terminals, municipalities</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Priming and framing</td>
<td>Positively affects perception</td>
<td>R, C&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Port Authorities, terminals, municipalities</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Corporate Social Responsibility</td>
<td>Positively affects perception</td>
<td>C&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Terminals, Port Authorities</td>
<td>15</td>
</tr>
</tbody>
</table>
GLOSSARY
<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACNA</td>
<td>Always Check Never Assume</td>
</tr>
<tr>
<td>Airborne Noise</td>
<td>Noise transmitted when it arises from the actual impact of an object on a building element such as a wall, floor or ceiling</td>
</tr>
<tr>
<td>AIVP</td>
<td>Association Internationale de Ville et Ports</td>
</tr>
<tr>
<td>Awareness</td>
<td>Vigilance that bodies produce so they can navigate their environs and survive</td>
</tr>
<tr>
<td>Barge</td>
<td>type of vessel which is mainly used for the purpose of carrying cargo</td>
</tr>
<tr>
<td>BATNA</td>
<td>Best Alternative To a Negotiated Agreement</td>
</tr>
<tr>
<td>BIT</td>
<td>Behavioural Insights Team</td>
</tr>
<tr>
<td>BPG</td>
<td>Best Practice Guide</td>
</tr>
<tr>
<td>BTM</td>
<td>Best Technical Means</td>
</tr>
<tr>
<td>Cognitive impairment</td>
<td>When having trouble remembering, learning new things, concentrating, or making decisions that affect their everyday life</td>
</tr>
<tr>
<td>CRS</td>
<td>Complaint Reporting System</td>
</tr>
<tr>
<td>dB</td>
<td>decibel</td>
</tr>
<tr>
<td>dB(A)</td>
<td>Noise level weighted with the A-filter, see Annex X</td>
</tr>
<tr>
<td>dB(C)</td>
<td>Noise level weighted with the C-filter, see Annex X</td>
</tr>
<tr>
<td>Diabetes 2</td>
<td>Long-term metabolic disorder that is characterized by high blood sugar, insulin resistance, and relative lack of insulin</td>
</tr>
<tr>
<td>Directive</td>
<td>Legal act of the European Union which requires member states to achieve a particular result without dictating the means of achieving that result.</td>
</tr>
<tr>
<td>Directivity</td>
<td>The angle of space over which the sound emanates from the source (part of the sphere)</td>
</tr>
<tr>
<td>Duct</td>
<td>Tube or passageway in a building or machine for air, liquid, cables, etc</td>
</tr>
<tr>
<td>EAST</td>
<td>Stands for Easy Attractive, Social and Timely elements for influencing</td>
</tr>
<tr>
<td>EC</td>
<td>European Commission</td>
</tr>
<tr>
<td>EEA</td>
<td>European Environmental Agency</td>
</tr>
<tr>
<td>EIA</td>
<td>Environmental Impact Assessment</td>
</tr>
<tr>
<td>END</td>
<td>Environmental Noise Directive</td>
</tr>
<tr>
<td>EPS</td>
<td>External Power Supply</td>
</tr>
<tr>
<td>ESI</td>
<td>Environmental Ship Index</td>
</tr>
<tr>
<td>ESPO</td>
<td>European Shipping and Port Organisation</td>
</tr>
<tr>
<td>European Commission</td>
<td>Institution of the European Union, responsible for proposing legislation, implementing decisions, upholding the EU treaties and managing the day-to-day business of the EU.</td>
</tr>
<tr>
<td><strong>European Union</strong></td>
<td>A political and economic union of still 28 member states that are located primarily in Europe.</td>
</tr>
<tr>
<td>-------------------</td>
<td>------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Framing</strong></td>
<td>Example of cognitive bias, in which people react to a particular choice in different ways depending on how it is presented</td>
</tr>
<tr>
<td><strong>Frequency</strong></td>
<td>Pitch</td>
</tr>
<tr>
<td><strong>Funnel</strong></td>
<td>Metal chimney on a ship</td>
</tr>
<tr>
<td><strong>GAF</strong></td>
<td>Green Award Foundation</td>
</tr>
<tr>
<td><strong>Gamification</strong></td>
<td>Application of game-design elements and game principles in non-game contexts.</td>
</tr>
<tr>
<td><strong>GSR</strong></td>
<td>Government Social Research United Kingdom</td>
</tr>
<tr>
<td><strong>Habitat directive</strong></td>
<td>Directive that ensures the conservation of a wide range of rare, threatened or endemic animal and plant species</td>
</tr>
<tr>
<td><strong>HIA</strong></td>
<td>Health Impact Assessment</td>
</tr>
<tr>
<td><strong>Hindrance</strong></td>
<td>Something that makes it more difficult for you to do something or for something to develop:</td>
</tr>
<tr>
<td><strong>Hull</strong></td>
<td>Skin of a vessel</td>
</tr>
<tr>
<td><strong>Hz</strong></td>
<td>Herz, see also Annex 3</td>
</tr>
<tr>
<td><strong>ICS</strong></td>
<td>International Chamber of Shipping</td>
</tr>
<tr>
<td><strong>ILAC</strong></td>
<td>International Laboratory Accreditation Cooperation</td>
</tr>
<tr>
<td><strong>IMO</strong></td>
<td>International Maritime Organisation</td>
</tr>
<tr>
<td><strong>Insertion loss</strong></td>
<td>Reduction of noise level at a given location due to placement of a noise control device in the sound path between the sound source and that location.</td>
</tr>
<tr>
<td><strong>Insomnia</strong></td>
<td>Sleep disorder that is characterized by difficulty falling and/or staying asleep.</td>
</tr>
<tr>
<td><strong>ISO</strong></td>
<td>International Standardisation Organisation</td>
</tr>
<tr>
<td><strong>KTH</strong></td>
<td>Royal Institute of Technology Stockholm</td>
</tr>
<tr>
<td><strong>Labeling</strong></td>
<td>Display of information about a product on its container, packaging, or the product itself. For several types of consumer and industrial products</td>
</tr>
<tr>
<td><strong>Lden</strong></td>
<td>Annual average weighted noise burden</td>
</tr>
<tr>
<td><strong>LNG</strong></td>
<td>Liquid Natural Gas</td>
</tr>
<tr>
<td><strong>LWA</strong></td>
<td>A-weighted sound power level in dB(A)</td>
</tr>
<tr>
<td><strong>Masking</strong></td>
<td>Addition of sound by special digital generators, distributed by normally unseen speakers through an area to reduce distractions or provide confidentiality where needed.</td>
</tr>
<tr>
<td><strong>MGA</strong></td>
<td>Mutual Gains Approach</td>
</tr>
<tr>
<td><strong>MINDSCAPE</strong></td>
<td>Mnemonic that stands for Messenger, Incentives, Norms, Defaults, Salience, Priming, Affect and Ego</td>
</tr>
<tr>
<td><strong>Morphology</strong></td>
<td>Shape, structure or form of things</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Muffler</td>
<td>Device for reducing the noise emitted by the exhaust of an internal combustion engine.</td>
</tr>
<tr>
<td>MW</td>
<td>Megawatt</td>
</tr>
<tr>
<td>Natura 2000</td>
<td>Network of nature protection areas in the territory of the European Union under Habitat directive.</td>
</tr>
<tr>
<td>Negative disconfirmation</td>
<td>Disconfirmation is hypothesized to affect satisfaction, with negative disconfirmation leading to dissatisfaction</td>
</tr>
<tr>
<td>NEPTUNES</td>
<td>Noise Exploration Program To Understand Noise Emitted by Seagoing ships</td>
</tr>
<tr>
<td>NGO</td>
<td>Non Governmental Organisation</td>
</tr>
<tr>
<td>Noise</td>
<td>Unwanted or unexpected sound</td>
</tr>
<tr>
<td>Non-acoustic factors</td>
<td>Contextual factors that affect one’s perception of acoustics</td>
</tr>
<tr>
<td>OPS</td>
<td>Onshore Power Supply</td>
</tr>
<tr>
<td>PA</td>
<td>Public Address system</td>
</tr>
<tr>
<td>Positive disconfirmation</td>
<td>Disconfirmation is hypothesized to affect satisfaction, with positive disconfirmation leading to satisfaction.</td>
</tr>
<tr>
<td>Priming</td>
<td>Priming is a technique whereby exposure to one stimulus influences a response to a subsequent stimulus, without conscious guidance or intention.</td>
</tr>
<tr>
<td>Quiet Urban Places</td>
<td>A place in a town or city that is quieter than the surrounding areas</td>
</tr>
<tr>
<td>Receptor</td>
<td>Receiver</td>
</tr>
<tr>
<td>Reefer</td>
<td>Cooling device mounted on a container</td>
</tr>
<tr>
<td>Retrofitting</td>
<td>Providing a component or accessory not fitted during manufacture</td>
</tr>
<tr>
<td>Shore Tension System</td>
<td>Dynamic mooring system, see <a href="http://www.shoretension.com">www.shoretension.com</a></td>
</tr>
<tr>
<td>Spatial planning</td>
<td>Land use planning</td>
</tr>
<tr>
<td>Stack</td>
<td>One or more containers that are inserted and removed according to the last-in first-out</td>
</tr>
<tr>
<td>Stakeholder</td>
<td>Person, group or organization that has interest or concern in an organization</td>
</tr>
<tr>
<td>Stand der Techniek</td>
<td>State of the Art in Technology</td>
</tr>
<tr>
<td>Stroke</td>
<td>Sudden death of brain cells due to lack of oxygen,</td>
</tr>
<tr>
<td>Structure born noise</td>
<td>Noise transmitted when sound arises from the actual impact of an object on a building element such as a wall, floor or ceiling</td>
</tr>
<tr>
<td>Thermocouple</td>
<td>Sensor used to measure temperature</td>
</tr>
<tr>
<td>Transmission loss</td>
<td>Accumulated decrease in intensity of a waveform energy as a wave propagates outwards from a source, or as it propagates through a certain area or through a certain type of structure</td>
</tr>
<tr>
<td>VDI</td>
<td>Verein Deutsche Ingenieurs</td>
</tr>
<tr>
<td>Zoning</td>
<td>Buffer area between source and receiver</td>
</tr>
</tbody>
</table>
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22. RESOLUTION MSC.337(91) (adopted on 30 November 2012) CODE ON NOISE LEVELS ON BOARD SHIPS
23. European Standard laying down Technical Requirements for Inland Navigation vessels (ES-TRIN), European Committee for drawing up Standards in the field of Inland Navigation (CESNI)
ANNEX I
LEAFLETS
1 MACHINERY

Category
“Mitigation at the source”

Addressed to
Shipowners, shipbuilders, shipping companies, ship engineers (designers/architects) and maintenance staff.

Brief description
Noise reduction of the loudest machinery on board a ship is the most important step to reducing noise emission from ships into the environment.

Several machine elements (such as funnels and fans) directly emit noise into the environment (airborne noise) while others cause excitations of structural elements which subsequently emit noise into the environment (structure-borne noise), for example, vibrations from the auxiliary engine(s) in operation that are transmitted into the ship’s hull.

One of the most dominant noise sources in operation while berthed is the exhaust funnel outlet of the auxiliary engine(s), the ventilation openings (e.g. for the engine room, the air-conditioning of passenger rooms, cooling units and the cargo hold) and the pumps on deck (tankers). Therefore, noise mitigation measures should focus first on reducing the noise emitted from these noise sources.

Structure-borne noise radiating from the hull rarely causes disturbing noise radiation into the environment and can usually be prevented by effective resilient mounting of the machinery. Some general suggestions for designing and/or retrofitting the most dominant machinery elements to reduce the emitted noise from the ship are shown as follows.¹

Estimated reduction
The reductions of noise cannot be specified in a general way for such mitigating measures. Noise reduction of the emitted noise into the environment ranges from a few decibels (e.g. by retrofitting fans) to 10-20 dB (well-designed silencer in the exhaust system of an auxiliary engine) up to a complete reduction of the emitted noise (proper installation of pumps inside the ship’s hull).

Costs
Similarly, the costs cannot be specified in a general way for such mitigation measures. The expected costs are of category A/B when designing new machinery. When retrofitting the ship, the expected costs can range from category A-C.

Conditions
In most cases, the revision of existing noisy machinery on board creates difficulties in implementation (e.g. limited accessibility and space), which can lead to high costs. In some cases, the available space is claimed by different structures along the machinery elements (e.g. exhaust duct is implemented through the steel structure, so that a subsequent installation of a muffler is difficult/impossible).

¹ Not all mitigation measures mentioned are applicable with the same significance for the radiation into the environment at each source and for each ship type.
Auxiliary engine(s)
- Muffler(s)/silencer(s) in the exhaust duct(s) matched to the compression ignition sequence frequency of the engine(s). See also leaflet Silencers (no. 2).
- Use of acoustically optimised auxiliary engine(s) with low exhaust noise.
- Resilient mounting of the auxiliary engine(s).
- Resilient mounting of the exhaust system including the duct(s).
- Improved sound insulation by utilising an enclosure around the auxiliary engine(s).

Fan(s)
- Fan(s) with a possibly high number of blades, and/or
- Fan(s) with a possibly low peripheral speed, and/or
- Fan(s) with acoustically optimised profiled blades.
- Pipe muffler or baffle silencers in the air inlets and outlet(s). See also leaflet Silencers (no. 2).
- Low-noise drive motors.
- Optimisation of the air flow.
- Soft compensator in the connected pipe(s) at the inlet(s)/outlet(s), if emitted into the environment.
- Resilient mounting of the fan including the motor.
- Absorbing material inside the fan room or the ventilation ducts.
- Frequent maintenance to avoid e.g. unbalances, wear and pollution.
- Adapting the air flow based on air volume needed (often temperature-based).

Pump(s)
- Installation of the pump(s) inside the ship’s hull.
- Use of acoustically optimised pump(s).
- Running the pumps in optimum operating condition.
- Avoidance of cavitation in the pumps.
- Low-noise drive motors.
- Low-noise gears.
- Improving sound insulation by means of an enclosure around the pump and/or drive motor.
- Sound reduction cladding around the connected pipe(s) at the inlet(s)/outlet(s).
- Soft compensator in the connected pipe(s) at the inlet(s)/outlet(s).
- Resilient mounting of the pump(s) and drive motor(s).
- Improved sound insulation by means of an enclosure around the pump(s) and/or engine(s), if pumps are installed on the outer deck.

Noise mitigation measures, particularly relating to existing machinery, could also entail contrary effects of operating parameters. For example, a silencer in the exhaust system could produce a loss of pressure, resulting in lower engine efficiency.

Noise mitigation measures relating to the machinery elements will therefore be considered as early as possible, preferably during the design phase of the ship.

The mitigation methods described in this leaflet represent a very brief summary of possible mitigation measures relating to the machinery.
Specific mitigation measures, such as a muffler in the exhaust system, require special knowledge to match the muffler to the compression ignition sequence frequency of the engine(s). Thus building new machinery does not automatically result in quiet machinery. It is therefore important that professionals/acousticians design/define noise mitigation measures to the individual case.

Lessons learned

Noise mitigation relating to the machinery should preferably be incorporated in the design and construction phase of new ships in consultation with acoustic specialists. Communication between different stakeholders is important. When ordering a new ship, for example, shipping companies could agree with shipbuilders on maximum sound power levels for various machineries/sources.

Some of the above-mentioned mitigation measures are already state of the art in other branches of industry. Furthermore, there are regulations to reduce the noise on ships, such as the codes on noise levels from IMO, which aim to reduce the noise disturbance for the crew.

Stakeholders should therefore draw on existing experiences with building similar machinery and/or noise mitigation measures for operation on ships or for operation in other industrial sectors, such as petrochemical and power plant construction.

Remarks

Stakeholders are shown in Figure 1 of Chapter 3 of this Best Practice Guide.

Besides the mentioned machinery, there may be other secondary noise sources, such as reefers on container ships and compressors. Those secondary noise sources do not always operate continuously or are not part of the machinery elements of a ship itself. These secondary noise sources are therefore not considered for noise mitigation in this leaflet.
2 SILENCERS

Category
“Mitigation at the source”

Addressed to
Shipowners, shipbuilders, shipping companies, ship engineers (designers/architects), silencer manufacturers and maintenance staff.

Brief Description
Silencers (or mufflers) are equipment to mitigate noise emissions close to the source. They are built to reduce sound propagation in ducts, pipes and openings while permitting flow. The most critical applications of silencers for ships are:

1. Exhaust silencers integrated into the exhaust ducts of combustion engines (propulsion and auxiliary engines) to reduce the exhaust noise at the funnel exhaust outlet.
2. Silencers in air ducts to reduce the intake noise of engines or noise from the air inlets and outlets.

Silencers can be categorised according to the operating principle or the case of application. The most important operating principles are:
- Reactive silencers (reflective silencers and resonance silencers), and
- Absorption silencers.

Combinations of these types are possible and common. The general principles of both absorber types are described in the following:

Reactive silencers:
Reactive silencers react to the sound-waves travelling through the silencers by exploiting effects like reflections, resonances and interferences. Absorption is typically negligible. Reactive silencers are typically effective in the low frequency range and in a narrow frequency band. See also Figure 9. The application of reactive (resonator) silencers in the exhaust channel of the auxiliary engines is one of the most common measures to reduce noise emission from the funnel outlet of a ship when berthed.

Figure 6. Sketch of a possible interior of a reactive silencer causing attenuation due to different effects like reflections, resonances and interferences.
Reactive silencers:
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Absorption silencers:
Absorption silencers basically consist of pipes or ducts lined with sound absorbing material. To enlarge the effective surface, large ducts or openings can be divided by absorbing silencer elements into two or more parallel ducts (splitter silencers). The highest reduction is in the mid and high frequency range. Absorption silencers re-act over a larger frequency band (broad-band) than reactive silencers. See also Figure 9. On ships, absorption silencers can be applied to mitigate the noise emission of air ducts, inlets and outlets.

Estimated Reduction
The noise reduction of sound pressure inside a silencer is exemplary shown in Figure 2 in leaflet 1. The reduction cannot be specified in a simple way, since it depends on the frequency characteristics of the source and of the silencer itself (which depends on the type and the precise layout of the silencer, available space, etc.). The mitigation of noise sources with significantly high sound energy in the low frequency range (e.g. below 200 Hz) requires more effort in terms of silencer dimension (especially volume and length of the silencer). Noise reductions of a few decibels to over 40 dB can be achieved, depending on the implementation (for a more detailed description see section Conditions below).

Costs
The overall cost of installing a silencer on board a ship comprises the cost of constructing the silencer itself and the cost of on-board integration. Construction cost depends on the engineering and production effort. Both can be minimised, if commercial off-the-shelf solutions for a specific problem are available. Integration and construction costs are related to the complexity of the installation situation. Furthermore, a subsequent implementation on existing ships will be much more expensive than implementation in the design and/or construction phase of a new ship. For example, a subsequent implementation could also require a modification or even reconstruction of the surroundings. A subsequent construction may sometimes not even be possible to meet all requirements for implementation. It is important to find well-balanced solutions for different noise sources to avoid both over-dimensioned and under-dimensioned silencers. The overall cost of implementing a silencer can therefore vary from category A to C.

Conditions
For the design and integration of silencers, the following requirements should be taken into account. Selecting the type of silencer should start with the frequency range in 1/3 octave bandwidth that needs to be attenuated and the required amount of reduction. The required noise reduction of a silencer should be specified as a frequency dependent quantity (transmission loss and insertion loss\(^2\)). Furthermore, operational characteristics such as exhaust back pressure, exhaust gas temperature, volume flow rate, flow velocity, composition of exhaust gas etc. must be specified for the construction of the silencer.

The constructional space within machinery rooms, exhaust ducts, air inlets and air outlets is often limited. The silencer should be designed in close consultation with the architect, shipyard, engine manufacturer, silencer manufacturer and a noise consultant. For newly developed products, it is recommended that evidence is provided of the acoustic properties of a silencer in a test stand or insitu.

In some cases, silencers compete with other components for available constructional space. One important case is ex-haust gas treatment equipment (scrubbers or diesel soot filter) which are also integrated in the exhaust canal. In such cases, it is useful to incorporate the acoustic properties of the gas treatment equipment into the design process.

\(^2\) The quantities Transmission and Insertion loss particularly relate to the sound pressure difference due to the silencer (e.g. in front and behind the silencer (transmission loss) or with and without a silencer (insertion loss)).
Lessons Learned

Adequate dimensioning of the silencer for the respective application is essential. A wrongly designed silencer will not mitigate the emitted noise sufficiently. There are several companies involved in the design and dimensioning of silencers which should be consulted when constructing a silencer. The acoustic quantities (e.g. required transmission loss and/or insertion loss) should be agreed between different stakeholders as early as possible to ensure the intended requirements for noise mitigation.

Remarks

Besides the general types of silencers mentioned above, there are also special silencers with limited usage (e.g. active silencers). Due to their limited field of use on ships, these silencer types are not listed in this leaflet. For some special operational purposes, however other silencer types should also be considered. Details about the machinery and possible necessary mitigation measures are shown in the leaflet Machinery (no. 1).

The constructional space within machinery rooms, exhaust ducts, air inlets and air outlets is often limited. The silencer should be designed in close consultation with the architect, shipyard, engine manufacturer, silencer manufacturer and a noise consultant. For newly developed products, it is recommended that evidence is provided of the acoustic properties of a silencer in a test stand or in situ. In some cases, silencers compete with other components for available constructional space. One important case is exhaust gas treatment equipment (scrubbers or diesel soot filter) which are also integrated in the exhaust canal. In such cases, it is useful to incorporate the acoustic properties of the gas treatment equipment into the design process.

Lessons Learned

Adequate dimensioning of the silencer for the respective application is essential. A wrongly designed silencer will not mitigate the emitted noise sufficiently. There are several companies involved in the design and dimensioning of silencers which should be consulted when constructing a silencer. The acoustic quantities (e.g. required transmission loss and/or insertion loss) should be agreed between different stakeholders as early as possible to ensure the intended requirements for noise mitigation.

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References

1. Noise from ships in ports, Possibilities for noise reduction - Environmental Project No. 1330 Miljøprojekt, Lloyd’s Register ODS, 2010
2. Stand der Technik bei der Lärmminderung in der Petrochemie (German version only, English: State of the art for noise mitigation in the petrochemical industry) - Umweltforschungsplan des Bundesministers des Inneren, Forschungsbericht Nr. 79-105-03-302, 19
4. ISO 7235: Acoustics – Laboratory measurement procedures for ducted silencers and air terminal units – insertion loss, flow noise and total pressure loss, 2010
5. ISO 11820 Acoustics – Measurement on silencers in situ, 1996
3 EXTERNAL POWER SUPPLY

Category
“Mitigation at the source”

Addressed to
Shipowners, shipbuilders, shipping companies, ship engineers (designers/architects), terminal owners, port authorities, ship crew (captain) and maintenance staff.

Brief description
When a ship is berthed, there are several electrically-driven devices on board a ship in operation (e.g. fans, reefer container, air conditioning and pumps). In most cases, the electric power is provided by one or more auxiliary engines on board. The noise emission of the auxiliary engine(s), especially their funnel outlet(s), represents one of the main noise sources responsible for the overall noise emission of a ship.

Besides mitigation measures on the auxiliary engine(s) itself, see leaflet Machinery (no. 1) and leaflet Silencers (no. 2), noise mitigation could be achieved by providing an alternative power supply (external power supply). Using an external power supply, ships can switch off their own auxiliary engine(s) when berthed.

Currently, there are several concepts and implementations of external power supplies.

In further developments of external power suppliers, noise mitigation measures should be considered as early as possible, e.g. during the design or construction phase.

Three different external power suppliers are most widely used in the current stage. These three options are described briefly here:

Becker LNG PowerPac®
The LNG PowerPac provides energy by means of a gas-powered generator (driven by LNG) with an output of approx. 1.5 MWel. The generator is located inside a 40 foot high cube container; the tank and auxiliary equipment (e.g. air coolers) are placed in another connected container. When a container ship is berthed, the PowerPac will be placed on board by STS crane and connected to the power line of the ship.
To ensure adequate noise mitigation, the power pack should be acoustically optimised, e.g. taking into account the noise mitigation measures described below.

**NG Power Barge**

The LNG Power Barge in the existing design provides power by means of five gas-powered generators (driven by LNG), each having an output of approx. 1.5 MWel. However the updated design of the barge shall provide up to 50 MWel to the customer and serve multiple cruise vessels in parallel. The generators are placed on a barge that can be moved to the berth location and connected either from the landside via the cable infrastructure in the pier or from the seaside to the power-line of a ship (proven concept in Port of Hamburg, supply of AidaSol).

To ensure adequate noise mitigation, the LNG barges should be acoustically optimised, e.g. taking into account the noise mitigation measures described below.

**Shore Power**

By using shore power, the external power is supplied by a power facility (power output of approx. 7-11 MWel) on the shore side of the port (alternatively provided from a nearby power facility). Shore power is connected to the powerline of the ship by using cables that are laid under the quay. Currently, the onshore power is used for the external power supply of different ship types (e.g. cruise ships and container ships) in several ports worldwide. The power facility on the shore side can be built in different ways (e.g. by using LNG or diesel based generators or the onshore power grid). To ensure adequate noise mitigation, the shore power should be acoustically optimised, e.g. taking into account the noise mitigation measures described below.

**Noise mitigation measures**

The following noise mitigation measures\(^3\) for reducing the emitted noise from the external power suppliers (e.g. PowerPac, LNG Power Barge and shore power) could be taken into account during the design and/or retrofitting of external power suppliers:

- Improved sound insulation of the container walls (LNG PowerPac), barge walls (LNG Power Barge) or power facility (shore power).
- Resilient mounting of the generators and the auxiliary equipment, such as air coolers.
- Muffler(s)/silencer(s) in the exhaust duct(s) of the external power supply (facilities). See also leaflet Silencers (no. 2).
- Mitigation measures at the air inlets and outlets of the external power supply (facilities). See also leaflet Machinery (no. 1 – fans).

**Estimated Reduction**

If noise mitigation measures are effectively planned and installed, the use of external power supplies can have enormously positive effects on the mitigation of noise, especially for exhaust noise. The overall emitted sound power level of a ship at berth could be reduced by up to 5 to 10 dB by replacing the use of auxiliary engine(s) with external power suppliers. See also paragraph conditions. Relevant noise sources from the external power suppliers (e.g. using shore power) could also be shifted to a less sensitive area/away from residents (e.g. by using shore power facilities far away from residents or smart placing of the PowerPac in a location turned away from residents).

**Costs**

The costs of implementing an external power supply system in a port are very high (Category C). The savings in the long term are very small and are merely the result of better efficiency of new power suppliers. One of the main challenges is also the conversion of cycles (60 Hz/50 Hz voltage). Because ships and/or ports can run on different cycles, conversion is essential. The costs of implementing a conversion system (transformer) are also very high (Category C).

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\(^3\) Not all the mitigation measures mentioned are applicable with the same significance for emission into the environment at each source and for each type of external power supplier.
Conditions
Using shore power, one of the major noise sources on board a ship (the auxiliary engine(s) with their funnel exhaust) can be switched off. This can significantly reduce the noise emitted from ships at berth.

The implementation of noise mitigation measures on the external power supply equipment requires special knowledge in acoustic design and or retrofit. It is therefore important that noise mitigation measures (e.g. enclosures, intake silencers) are planned for each individual case by professionals in consultation with acoustic specialists.

Lessons learned
Although the aim of external power supply is currently the reduction of air pollution, noise mitigation measures should preferably be part of the design and construction phase of external power supplies. Sufficient space for implementing a silencer in the exhaust system of the external power supplier should be provided. Communication between different stakeholders is important, for example communication between the port and the shipping companies to implement a unique or standard interface for connection between the external power supplier and the internal powerline of a ship.

Remarks
Stakeholders are shown in Figure 1 of Chapter 3 of this Best Practice Guide.

Using an external power supply does not affect further dominant noise sources on board a ship, such as openings of ventilation (e.g. for the engine room, the airconditioning of passenger rooms and the cargo hold), the reefer containers and the pumps. These noise sources will still operate unchanged and are not affected by this noise mitigation measure.

Besides the mentioned methods, there may be further external power suppliers in a design or trial phase. Noise mitigation should be planned for those power suppliers in a similar manner.

References
1. Leaflet Becker LNG PowerPac – Clean and mobile power for the maritime industry, from HPE Hybrid Energy GmbH & Co. KG
2. Leaflet Becker LNG Power Barge – Clean power for cruise ships in port, from HPE Hybrid Energy GmbH & Co. KG
4 PUBLIC ADDRESS SYSTEM

Brief description

Public Address Systems (PA systems) on board a ship can be implemented for different purposes. Besides communication between crew-crew, crew-passengers and communication for emergency/evacuation purposes (all ship types) using an Intercom system, a PA system can be used for entertainment such as music and passenger announcements (mainly on cruise ships, for example embarking and disembarking information).

The sound from the PA systems, independent of the type, can be perceived as disturbing by residents when a ship is at berth. Noise mitigation measures should therefore be examined and implemented, such as:

1. At berth, a PA system should only be used when necessary (for urgent communication between crew members and possible evacuation announcements). The volume of non-emergency announcements should be as quiet as possible and as loud as necessary.
2. The use of the PA system for entertainment purposes should be minimised at berth. Especially during the night, the system should be switched off in ports. On some cruise ships, a “Silent Party” has been introduced for open areas. At a “Silent Party”, passengers only hear music via headphones, producing less nuisance from music played via loudspeakers.
3. Skilful arrangement of the loudspeakers on deck, e.g. using directional loudspeakers and/or arranging multiple smaller loudspeakers over a wider area rather than fewer loudspeakers that are intended for sonication of wider areas. By using a smart arrangement, the volume can be reduced and will be perceived as less annoying by the residents (whispering voice system).

Furthermore, the loudspeaker’s directionality will preferably be aligned away from the shore side and only towards the listener(s) on board.
4. Alarms can be acoustically optimised to be less annoying (e.g. broadband noise instead of narrowband tones).
5. Building sound barriers on board the ship (e.g. housing of the music areas on the upper decks of cruise ships).
6. Instead of using intercom systems with loudspeakers, radio equipment should preferably be used.
7. Training crew members to use the PA system more carefully and as little and as quietly as possible at berth. See also leaflet Awareness (no. 10).

Estimated Reduction

Noise mitigation measures for the PA system do not directly affect the stationary noise sources on board a ship (such as funnel exhaust, reefer containers, ventilation etc.). Nevertheless, the noise radiated from an intercom system and/or a PA system for entertainment purposes can cause annoyance among residents near the berth location. By implementing organisational measures, such as using the PA system only for
emergency and safety announcements during night, the annoyance can be reduced, respectively fully eliminated.

**Costs**

The costs of implementing organisational measures are very small (category A). The costs for the implementation of a skilful arrangement of the PA system can vary, depending on factors such as the type of implementation (e.g. replacement of an existing PA system or implementation of a silent PA system during the design or construction phase of a ship (category A-C).

**Conditions**

PA systems are most used on cruise ships and less on other ships, such as container vessels and tankers. Cruise ships in particular often berth close to residential areas (most attractive berth location for passengers). The noise disturbance thus occurs due to the short distance between ship(s) and residents. Smart port management (e.g. choosing a berth location further away from residents, if possible) can also minimise annoyance among residents caused by the PA system. See also Leaflet Propagation of noise (no. 5) and leaflet Organisational (planning) (no 12).

**Lessons Learned**

Traveling on cruise ships is becoming increasingly popular. Consequently, noise disturbances that occur at berth in ports close to residents are increasing. Smart organisational planning and choice of PA system on board a ship can mitigate the noise and thus the disturbance of residents from cruise ships at berth.

Communication between different stakeholders is important, for example communication between the port and the shipping companies to inform them of problems and complaints by residents in the respective port. Good complaint management can be very useful for recognising noise disturbance at an early stage. See also leaflet Complaint Management (no. 11). Careful training of crew members to mitigate the noise from PA systems is essential.

**Remarks**

Stakeholders are shown in Figure 1 of Chapter 3 of this Best Practice Guide. Implementing noise mitigation measures for the PA system, safety concerns (e.g. required noise levels for announcements in the event of an emergency or required design of noise tones) should be prioritised before noise mitigation. Safety testing should preferably be executed during daytime and at berth places far away from residents.
5 PROPAGATION OF NOISE

Category

“Mitigation on the propagation path”

Addressed to

Shipowners, shipping companies, terminal owners, port authorities and maintenance staff.

Brief Description

Once the sound is emitted from the source (ships at berth), it will propagate (e.g. through the air) to the receiver (residents). The propagation path will influence the noise in different ways, which can lead to attenuation or amplification. In the following, a brief description of the influence of the propagation path on the emitted noise will be given, followed by possible noise mitigation measures.

The propagating noise will especially be influenced (amplified or attenuated) by:

- Geometrical spread (distance between the noise source and the receiver).
- Shielding (deflection, diffraction and/or absorption by obstacles in the propagation path).
- Reflections by obstacles on the propagation path.
- Air absorption.
- Ground effects (absorption, deflection and/or reflection from the ground).
- Meteorological conditions (air temperature, humidity and wind direction).
- The morphology of the built environment (size, structure, rooftops, etc.).

With respect to the noise emitted by ships at berth, most of the above-mentioned factors cannot, or rather can only be influenced to a very small extent. The meteorological conditions as well as the air absorption cannot be influenced by the ports for example. Changes of the ground effects can only be achieved by a change of soil texture and are therefore not usually feasible. The most effective noise mitigation measures are changes in the distance between ships at berth and residents and changes in shielding. These are described in more detail in the following:

Distance:

With increasing distance from the noise source(s), the sound pressure level decreases.

A possible noise mitigation measure for reducing the annoyance of residents from ships at berth is to increase the distance between both, for example by choosing a berth location possibly far away from the complainants (residents). See also leaflet Organisational (planning) (no. 12).

Shielding:

A possible method to reduce the propagating noise from the source (ship at berth) to the receiver (residents) is the construction of a noise barrier in the propagation path. To be acoustically effective (minimising influence of diffraction over the upper edge), the noise barrier must fulfil the following requirements:

The noise barriers should be built as close as possible to the noise source(s) (alternatively as close as possible to the receiver(s)). Source(s) and receiver(s) must be well below the upper or the side edge of the barrier. The height and length of the noise barrier must be large compared to the longest wavelength (on the lowest frequency component) of the noise which to be mitigated. The parameter describing the attenuation of noise is called the Insertion loss $D_e$. Details for calculating the insertion loss...
depending on the horizontal distance between the source and receiver, the detour over the upper edge of an obstacle and the wavelength are shown e.g. in ISO 9613-2 and VDI 2720. Noise barriers can be built in different ways, such as:

- Closed container stacks.
- Concrete walls.
- Soundproofed walls (multiple layers filled with absorptive material).
- Buildings.

A noise barrier can be an effective measure to mitigate the noise from the port side (e.g. caused by cargo handling and noise from vehicles close to the ground) on the propagation path.

When designing a noise barrier, the following general guidelines should be considered:

- The area-based mass of the barrier should be \( m^\prime \geq 10 \text{ kg/m}^2 \).
- The inner surfaces of the barrier should preferably be sound-absorbent (especially to avoid disturbing reflections from the barrier).
- Openings and leaks in the barrier must be avoided.

**Estimated Reduction**

The estimated reduction depends on the type of measure applied in the sound propagation path.

**Distance:**

Generally speaking, it can be concluded that with each doubling of distance, the sound pressure level is reduced by 6 dB.

**Shielding:**

The efficiency of using shielding elements depends on many factors. See the indications listed above. The acoustic effectiveness cannot therefore be generalised. Noise reduction can range from none (if not designed properly, e.g. too small) up to 20 dB, if placed close to relevant noise sources and properly built.

**Costs**

Costs for influencing the distance (e.g. by a smart choice of berth location) can range from very small (Category A) to medium (Category B), depending on the possibilities of implementation. Factors influencing the costs can be change of harbour management, extra costs for tugs, changed sailing routes for ships etc. Costs for establishing shielding can vary between medium (Category B) to expensive (Category C), depending on the type and target of implementation. Sound barriers built from old container stacks, for example, are a medium expensive measure (Category B), while special soundproofed walls can be expensive (Category C).

**Conditions**

Noise mitigation in the propagation path between source and receiver can be an effective measure to reduce annoyance among residents. Nevertheless, the implementation of mitigation measures at the source(s), see leaflets Machinery (no. 1) and Silencers (no. 2), should be considered prior mitigation on the propagation path, because they generally represent the most efficient noise mitigation measure.
The change of distance could be considered, especially for ships that are known to cause noise problems among residents (e.g., discovered from noise complaints or from measurements). For constructing shielding elements, sufficient space needs to be provided. This might be difficult to achieve in most ports.

**Lessons Learned**

Besides the classic design of noise barriers, a positive effect of noise shielding could also be achieved by implementing smart harbour management (e.g., placing cargo container and/or other ships between the noisy ship at berth and the residents).

Port noise (e.g., due to cargo handling) in particular can be mitigated by shielding the noise towards the residents. Positive shielding effects can also be achieved by smart berthing of the ship. If relevant noise sources (e.g., ventilation units) are placed only on one side of the ship, the ship could be turned in order to locate the noise sources away from the complaints (most relevant for cruise ships and RoRo/RoPax). The noise could then (partially) be shielded by the ship itself. Furthermore, smart placing of the ship can result in good shielding of port noise (e.g., noise emitted from cargo handling, etc.).

**Remarks**

Stakeholders are shown in Figure 1 of Chapter 3 of this Best Practice Guide.

The efficiency of shielding to reduce the noise emitted by ships at berth is low. Very often, it is not possible to create noise shielding between the ship at berth and the residents (e.g., due to insufficient space on the port side and/or undesired large noise barriers very close to the residents). Furthermore, the most dominant noise sources of a ship at berth are mostly located high up (e.g., funnel exhaust height of > 10 m). Furthermore, the funnel exhaust tends to emit noise in the low frequency range (for 1/3 octave bands with center frequencies ≤ 160 Hz). The noise barrier would therefore need to be very large, which is not feasible in practice.

Besides benefits, a change of the berth location can cause additional problems. The noise sources might move closer towards other residents, for example. Furthermore, the change of berth location can produce a significant change in cargo handling (e.g., longer distances of cargo transport at the port side). Possible disadvantages should therefore be considered when planning noise mitigation measures in the propagation path. Noise mitigation measures should be planned by acoustic specialists.

**References**

1. VDI 2720 - Noise control by barriers outdoors, Verein deutscher Ingenieure (VDI), 1997
6 INSULATION

Category

“Mitigation at the receiver”

Addressed to

Port authorities, city planners, real estate owners and investors, building owners and contractors.

Brief description

One of the last options for mitigating nuisance caused by ship-generated noise is the insulation of houses and other sensitive buildings.

Sound insulation of buildings, as part of a “passive” noise protection method, basically affects the noise situation inside buildings. A first step to achieve the targeted level of noise protection usually requires the resident to close the window(s).

Technically, sound insulation of buildings is a nontrivial task. As a very general rule, the sound insulation effect of an external building component (walls, roofs, windows) rises with increasing mass per unit area of the respective component and is generally more effective for noise reduction in the higher frequency range (approx. above 500 Hz) than in the lower frequency range.

Windows and the related window constructions are usually the most relevant element for additional insulation measures. Better insulation can be achieved by double or even triple glazing and even better with special window constructions. See leaflet no. 9.

Increasing the insulation of walls and ceilings is appropriate in cases where the actual wall, roof and/or ceiling design are not a solid stone or concrete construction but have low sound insulation, such as wooden facades for example.

Estimated Reduction

Generally speaking, a partially opened window has an insulation of approx. 15 dB between the outside airborne noise level and the inside noise level. By contrast, a closed single pane window can already have an insulation effect of more than 25 dB.

The reduction that can be obtained further depends on the existing insulation of the facade. In cases where the windows are the main “entrance” for external airborne noise (the weakest insulation in the whole façade), a reduction of up to 20 dB can be obtained with some effort (e.g., by using double glazing instead of single glazing). With a high effort, reductions up to 40 dB inside the building can be achieved (e.g., by using more complex window constructions).

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4 E.g., bedrooms in hospitals and sanatoriums, classrooms in schools and universities or similar educational institutions, offices and meeting rooms.
5 For example, an indoor noise level ≤ 30 dB(A) at night.
6 In the mid and high frequency range.
7 E.g., traffic noise from streets and railways and to a lesser extent, industrial noises, construction noise etc.
Costs

The costs vary according to the number of houses to be fitted with improved sound insulation, the existing state of the building structures and the required noise reduction. Furthermore, providing improved sound insulation for buildings to be developed will probably be much cheaper than improving the sound insulation of existing buildings.

Overall, the costs can vary in a large range from category A to C.

Conditions

In the simplest case, better sound insulation can be achieved by replacing old windows with new ones. Already in this simple case, further aspects of building physics and structural engineering may be necessary.

State-of-the-art window constructions are usually more airtight and present very good thermal insulation. Thus, a new window may significantly alter the air ventilation, the inside thermal balance and humidity. This also may require a controlled domestic ventilation system. It is therefore advisable to consult architects and civil experts/engineers before implementation.

Lessons Learned

The additional insulation must be applied very accurately. If there are any cracks or points of leakage, for example, the insulation becomes less effective or not effective at all. Planning and construction of building elements providing high noise insulation should be carried out by experts (in consultation with architects, civil experts/engineers and/or acoustic specialists).

Additional noise insulation is obviously only necessary if the respective building is not already sufficiently equipped. Since urban noise is a major cause of disturbance in many cities, sufficient passive noise abatement is desirable for the residents and often legally mandatory. Urban development planning may set prior standards for the noise insulation of (planned) buildings within a new residential district.

Sometimes national and/or local legislation and restrictions may not allow passive noise mitigation in the buildings to protect the residents from port noise and only permit noise mitigation at the source and in the propagation path. The possibility of sound insulation to mitigate the noise disturbance must therefore be checked for each individual case and port before any action is taken.

Remarks

Noise insulation can also have beneficial side effects, such as thermic insulation.

The design of houses in a noisy environment can benefit from avoiding bedroom façades facing the noise, for example. See also the leaflet on Urban Planning (no. 9).

Outside areas with a residential function, such as open balconies, loggias, gardens etc., cannot be protected with passive methods.

To gain an adequate reduction of low frequency noise inside the building, further and more complex measures may be required. Insulation of listed historic buildings designated as cultural heritage is more complicated because the exterior facade may not be altered.

Nowadays there are also special window constructions that allow windows to be opened, while achieving an appropriate noise reduction on the other side of approx. 20-25 dB, such as the “HafenCity-Fenster”. See also Hamburger Leitfaden. Sensitive building may vary in different countries.

References

3 Hamburger Leitfaden – Lärm in der Bauleitplanung 2010, Behörde für Stadtentwicklung und Umwelt Hamburg,
7 EXPECTATION MANAGEMENT

Category

“Relation management communication” aimed at achieving mutual understanding and possibly less annoyance among residents, pressure groups, NGOs and avoid annoyance when there are changes in the port.

Addressed to

Port Authorities, terminals, government authorities as port owners.

Brief description

Expectation management is part of the communication strategy. Expectations are strong beliefs that something is happening or will happen or will be the case in the future.

Managing expectations is important to reduce resistance to modifications of port activities (licence to grow), to reduce the perceived annoyance now or in the future and to enhance the image and credibility of the port. Even when no expansion or intensification is planned, expectation management plays a role (maintenance level). When residents lodge complaints, for example, the competent authorities should be transparent with regard to the follow-up (informing, action, terms, etc.). When a change is planned in the port which will have an impact on the surroundings, it is important to know the position and interests of stakeholders and interest groups. Ad-hoc or regular annual meetings (1 à 2 times/yr.) with all stakeholders are therefore recommended to keep informed of their interests, needs and expectations.

When complaints are lodged or are expected, the procedure can be quite simple. Inform residents, preferably in advance, about:

- Arrivals and mooring times of ships that could cause annoyance (start and end).
- The cause, source and characteristics of the noise and the duration of the possible annoyance or sleep disturbance.
- The expected noise levels that will occur and whether the existing limit values can be met or not.
- Actions to avoid repetitions.
- Possible incidents and/or events relating to the ship that might cause annoyance and/or sleep disturbance and what mitigating measures can be taken.
- Measures that have been applied and reductions that have been achieved.

In the case of changes in the port, certain activities, events or incidents which may have an impact, different communication strategies can be deployed. One strategy is to take a distributive approach. A second strategy is the integrative track. Steps to be taken are:

- Identify the stakeholders.
- Categorise them as neutrals, supporters and opponents.
- Select the stakeholders that really count.
- Classify the selected stakeholders in defensive or offensive stakeholders.
Taking the distributive approach, initiators could take one of the following decisions:

A. Fulfil the requests of the stakeholders.
B. Reject the requests and objections of the stakeholders.
C. Work on a solution together with the stakeholders that satisfies both.

### Table 1: prioritisation diagram stakeholders

<table>
<thead>
<tr>
<th>Power of the SH</th>
<th>Score 1-5</th>
<th>Weighting (default = 1)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>The legitimacy of the SH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The urgency of the SH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potential influence SH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Threats</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooperativeness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oppositiveness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supportiveness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Average score</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: It is also possible to have a mix of a, b and c.

As shown in Table 1, stakeholders should be identified and classified in order to find the stakeholders that count the most. Depending on the situation, a weighting of the items might be considered. The following steps should be taken:

1. Identify and prioritise potential stakeholders (not every stakeholder counts) and select them using Table 1.
2. Make a further distinction between stakeholders that are opponents, supporters or neutrals.
3. Categorise the stakeholders with respect to their behaviour when debating or when having defensive and offensive discussions.
4. Select the stakeholders that really count and keep an eye on those stakeholders that are not selected.
5. Invite and involve the selected stakeholders to join the plan that is to be developed or already in progress or those who are sending negative messages regarding the port.
6. Starting the dialogue or discussion.
7. When encountering opposite standpoints or interests do not promise matters that are not achievable (overpromising).
8. Provide all information relevant to the stakeholders and interest groups on a website or by letter (the latter can be seen as old school).

### Estimated Reduction

Expectation management can have an impact on the perception of residents/stakeholders when annoyance or sleep disturbance is perceived or expected. It reduces the extent of annoyance, distrust and irritation among stakeholders. Much more support and satisfaction are generated when an integrative approach is taken (win-win or consensus). However, it is impossible to give numbers because this depends on multiple factors as well as on the course of the project or trajectory.

In the case of plans for expansion or intensification of the ports, expectation management can at least avoid future annoyance to a certain extent because people are informed and do not have too high or unrealistic expectations.

### Costs

Expectation management saves costs because stakeholders are informed and the ports know the needs and expectations of the stakeholders and can define answers.

Involvement of the prioritised stakeholders means general support, an improved reputation and fewer objections, appeals or lawsuits.

### Conditions

Work together as closely as possible with the communication departments of the Port Authorities.

### Lessons Learned

Monitoring and evaluation should be part of the expectation management process. Information needs among stakeholders are important. Thorough preparation is indispensable. Trust in the approach, the stakeholders and the port organisation itself is vital.

Stakeholders are most sensitive to expected impact (annoyance, sleep disturbance, health, and economic damage). Beside the table about prioritisation a procedure taking into account their interests and transparency is recommended.

Messages should be as simple as possible, avoiding jargon and preferably communicated by independent experts or organisations as there might be some mistrust among residents towards authorities.

---

*Remember that stakeholders may change from supporters to opponents or from defensive to offensive and vice versa.

*In that case, invite them at an early stage.*
Remarks

Stakeholders form their expectations often on previous or historical experiences so it is important to work on a positive reputation.

High performance leads to positive disconfirmation and high expectations to negative disconfirmation.

For governmental bodies, it is easier to exploit loss-making behaviour patterns as long as they are backed by their political and public constituency, than for private organisations.

Stakeholders are shown in Figure 1 of Chapter 3 of this Best Practice Guide. Stakeholders can also represent owners of natural areas as referred to in the Habitat or Natura 2000 guidelines. Initiators should not overpromise or feed expectations. Arousing false expectations and under-delivering to stakeholders will lead to disappointment, frustrations and image damage.

Such measures may also affect how people experience other environmental problems.

References

1 Handbook Strategic Environmental Management (MGA), applied in the Port of Rotterdam, M. Wesselink et al. (2010).
2 Strategic Management of expectations; role of disconfirmation sensitivity and perfectionism.
3 Evaluation wind farm Houten, University Utrecht (2015)
4 Customers, employees, NGO’s which stakeholder do really count? Grunert et al. University of Westphalia (2012)
5 The expectation management theory, etc. C. Shaller. University of Paderborn (undated)
8 MUTUAL GAIN APPROACH

Category

“Reduction at receivers” aimed to achieve mutual understanding among residents, pressure groups, NGOs and avoid annoyance when enlarging or intensifying the port.

Addressed to
Port Authorities, terminals, governments (as owners of ports).

Brief Description

The Mutual Gain Approach (MGA) is an alternative to hard bargaining during negotiations. Hard bargaining with threats, political mobilisation or bluff based on power or position could lead to frustration, disappointment, litigation and loss of credibility and reliability. By adopting an approach that is beneficial to all concerned, these negative effects can be avoided or reduced. Parties can gain some wins in this approach by adding components to the original plan that pleases the parties with other interests. Especially in cases of projects or when planning major enlargements, intensification of the port or activities which involve more impact, different communication strategies can be deployed. Strategy one is to take a distributive approach. Strategy two is the integrative track. In both strategies the following outcomes are possible:

A Fulfil the requests of the stakeholders.
B Reject the requests and objections of the stakeholder.
C Work on a solution together with the stakeholder that satisfies all.

Note: It is also possible to employ a mix of the strategies mentioned under a, b and c.

Table: 1 Stakeholder inventory scheme

<table>
<thead>
<tr>
<th>Stakeholders (SH)</th>
<th>Issue 1</th>
<th>Issue 2</th>
<th>Issue 3</th>
<th>Average</th>
<th>Level of communication</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standpoint</td>
<td>Interest</td>
<td>Standpoint</td>
<td>Interest</td>
<td>Interest</td>
</tr>
<tr>
<td>SH1</td>
<td>Has some objections</td>
<td>No</td>
<td>Has some objections</td>
<td>Economic growth</td>
<td>Doesn’t care</td>
</tr>
<tr>
<td>SH2</td>
<td>Is against</td>
<td>Health threats</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SH3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SH4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
In the policy-making arena, the distributive approach to negotiating is often common practice in the discourse, meaning that option b is preferred (the hard bargaining methodology). Option a is rarely used. When working according to option c, initiators could opt for MGA. This implies the following actions to be carried out by the initiating party. See also Table 1:

- First list the issues before making an inventory of potential stakeholders and their interests and standpoints.
- Prioritise and select the stakeholders.
- Pay most attention and efforts to the most critical stakeholder.
- Invite and involve the selected stakeholders to join the plan to be developed or which is already in progress. If necessary, expand the plan aimed at creating extra added value (enlarge the pie) for all parties.
- Expand the number of solutions or directions to find solutions.
- Resolve constraints and obstacles that hinder finding a solution (biases, attitudes).
- Work on joint fact finding when opinions and standpoints differ (conflicts). Use criteria that are objective, unbiased.
- Share all information available to stakeholders.
- Developing the Best Alternative to a Negotiated Agreement in collaboration with the stakeholders (BATNA).
- Deliver all information relevant for the stakeholders and interest groups via a website or by letter (the latter might be seen as old school).
- Under pressure: don’t admit without considerations.

### Note: Work together as closely as possible with the communication departments of the Port Authorities.

### Estimated Reduction

The Mutual Gain Approach creates support and satisfaction with a focus on the process and the outcomes. Mitigating the noise, annoyance or sleep disturbance should be taken into account. Where there are major plans for expansion or intensification of the ports and its activities, noise and annoyance can at least be avoided to a certain extent or compensated by widening the project goals (creating added value or enlarging the pie) when working with MGA.

Thus, one of the many outcomes of MGA could be reduction of noise, annoyance and/or sleep disturbance. However, it is impossible to give numbers because this depends on multiple factors, as well as on the course of the project.

### Costs

MGA experiences have shown that cost savings can be achieved. Involvement of the prioritised stakeholders generally means support for the plan, no objections or appeals and no or fewer lawsuits. The one-off costs for contracting an independent project leader who is familiar with MGA depends on the size, duration, number of relevant stakeholders and complexity of the project.
Conditions

Management board of the initiators (e.g. port authorities) must back the mutual gain approach which means transparency about the plans, data, expectations and interests of the port. Willingness to collaborate with the stakeholders, listening to them and being prepared to adjust the initial plans or ideas is an important condition. If there are limitations in adjustments, offering compensation could be a way out. Other relevant conditions or principles are:

- The process should be led by an independent project leader, experienced in MGA.
- Avoid demonization and polarisation.
- Active listening and respecting each other’s view is also a part of the dialogue.
- Convincing someone to do something that is not in their best interests is not the way.
- It is better to have a dialogue exploring one’s position, beliefs and interests than immediately embarking on a discussion.
- The MGA process benefits from a good structure.
- Try to minimise the environmental impact.
- Be credible in all situations.
- Focus on building sustainable relationships.
- Stakeholders are not the same as the problems to be solved.
- Focus should be on interests rather than positions.
- Be clear about your interests.

Lessons Learned

Frequent monitoring and evaluation should be part of the MGA process. Information needs among stakeholders are important. Thorough preparation is vital. Trust in the approach, the stakeholders and the organisation itself is required.

Always Check the facts that are on the table. Never Assume (ACNA).

When it comes to noise, stakeholders are most sensitive to expected impact (annoyance, sleep disturbance, health, economic damage), so taking their interests into account and transparency are key.

Communication should be as simple as possible, avoiding jargon and preferably communicated by independent experts or organisations.

Remarks

Stakeholders are shown in Figure 1 of Chapter 3 of this Best Practice Guide. Stakeholders can also represent owners or natural areas as referred to in the Habitat or Natura 2000 guidelines.

References

3. The expectation management theory, etc. C. Shaller. University of Paderborn (undated)
9 URBAN PLANNING

Category

“Reduction at the receivers” aimed to achieve a good acoustic climate in new or refurbished residential areas and/or to design a good acoustic indoor climate in the sensitive rooms of the dwellings.

Addressed to

Authorities with the power to implement policies and tasks to initiate and develop spatial planning, including architects and urban planners.

Brief description

In the design of the district or buildings, measures can be taken to mitigate or avoid noise, annoyance and sleep disturbance in new residential districts. (See also Chapter 6.3 in this Best Practice Guide):

- Zoning noise emitted by port areas (including ship-generated noise) by creating distance between the noise sources and the sensitive buildings (houses, hospitals, schools, etc.).
- Shielding noise by planning non-sensitive buildings or any other mass such as an embankment or a barrier on the fringes of the planned residential districts.
- Design the orientation of sensitive buildings to ensure that they have at least one quiet side/façade which alters the perception of the resident.
- Different types of noise-reducing façades (closed or blind façades, double façades, smart façades or creative façades) (10).
- Layout of the sensitive building (non-sensitive rooms on the noisiest side of the dwelling).
- Non-complaint declaration.
- Objects that mask noise, such as fountains, aviaries, waterfalls, playgrounds, etc.

- Quiet Urban Places like pocket or large city parks, inner courtyards, etc. that compensate the hustle and bustle of the city (13).
- Apply absorption to or near the façades of dwellings situated in narrow streets (street canyons) avoiding reflections.
- If there is no legislation, make a covenant or agreements between the Port Authorities and the local or regional government encompassing obligations for the signatories when developments are planned in the residential districts as well the port areas.
- Sufficient green (e.g. parks, trees, plants, green façades, green roofs, roof gardens) and blue (e.g. canals, ponds, etc.) in the new districts to affect the human perception. See also leaflet on non-acoustic factors (no. 15).
- Innovative measures like barriers with an interesting shape or colours, adaptive façades that close when noise is too high near the façade.
- Shape of the building roofs which work as diffractors reducing the noise.
Estimated Reduction

Most of the urban planning measures mentioned above and described in more detail in literature (10,11,12) are aimed at preventing noise and annoyance in the planned districts either through the configuration of the district or by means of special façades or a well-thought-out design of the layout. It is rather complicated to predict reductions that can be achieved when planning a new district or housing block. By integrating the noise measures mentioned above, noise will be avoided in order to comply with a limit value set by the government, annoyance will be reduced and fewer complaints will be reported. To a certain extent, it also avoids annoyance and/or sleep disturbance. In the case of zoning and screening, no further noise reductions are required if the zone is set at the preferred limit value and the building mass provides sufficient shielding. When applying double or innovative façades, reductions of 20-40 dB can be achieved inside. Adaptive façades can give an extra reduction of 10-15 dB.

Costs

The costs of zoning are mainly administrative costs and depend on the size of the area enclosed by the zone.

The initial costs could be quite high (category C) while the costs of maintaining and monitoring the zone are moderate (category B). The costs of (internal) screening and choosing a different orientation or layout are minimal because this is performed during the design phase of the district and the building. The cost of a double façade depends on the dimensions of the building.

Conditions

Zoning is often based on legislation. However, it can also be based on a voluntary agreement between the industry and the local government. Some kind of (legal) document should be the basis of zoning. The zone should be shown on a geographical map and published. A guiding document should give the maximum noise levels allowed on the fringes of the zones and possible exemptions to deviate from the noise limit values set. Cooperation between local authorities, urban planners, architects and experts in acoustics is needed to develop the measures listed above.

Lessons Learned

With regard to the non-complaint declaration, it has been found that people cannot imagine living in an environment with noise levels above a certain level. After living there for a while or after a family expansion (children), parents tend to use the public space more and become aware of the noise levels. Most people do not know what for example 60 dB LDEN is or its impact in the long term. One pitfall regarding the non-complaint declaration might be a conflict with national legislation. A second pitfall when developing these measures is that architects and urban planners will not cooperate because important changing visual aspects in planning by adding visible insulation and changing orientation (disregarding wind and sunshine) are unfavourable.

Remarks

Screening or shielding port noise can be achieved by installing a barrier or embankment, or by constructing buildings higher than the houses behind them. See also leaflet no. 5. If the noise is shielded by an embankment, functions for this embankment other than shielding the noise might be considered, e.g. multi-storey car park, a shop or other non-sensitive function on the noisy side.

One should be aware that noise emitted by seagoing ships often contains a lot of low frequencies. Because low frequencies tend to bend better over and along obstacles, experts in acoustics must be involved in planning the above-mentioned measures. Where noise sources are situated very high above the ground or the deck, such as funnels and cranes, an embankment or noise barrier has its limitations.

Warning: some of the measures reported above might be in conflict with national, regional or local legislation! Some of these measures may be beneficial to air quality and safety, while some may also affect how people experience or perceive other environmental burdens.

References

3 Urban Sound Planning, SONORUS EU FP7 project, (2016)
4 QSIDE project, http://www.qside.eu/
5 https://business.gov.nl/regulation/zoning-plan/
7 Effectiveness measures at local noise policies: shielding a part of the façades. GGD Amsterdam. Van den Berg et all (2017)
8 Building façades optimisation at preliminary design stage for outdoor noise mitigation Calleri et al EURONOISE 2018
11 Ontwerpen met geluid, Leidraad geluidbelast bouwen, Cauberg 2010.
12 Sound reduction by vegetated roof tops (green roofs): a measurement campaign, van Renterghem, 2011.
13 www.quadmap.eu
10 AWARENESS

Category

“Soft measures” to achieve sustainable change in awareness, perception, attitude, intention and behaviour.

Addressed to

Sailors, port authorities, terminal staff, tug captains, shipowners.

Brief description

Awareness of how operational behaviour contributes to the noise situation is the first step towards a sense of responsibility to contribute to a quieter situation through behavioural change. The following measures can be taken to work more consciously and quietly:

- Information by means of a leaflet or factsheet containing simple information, avoiding jargon or hassle factors. This information should address human activities (unnecessary shouting, use of the PA or horn11) and how to operate the equipment on board and off-board (e.g. right balance between demand and load of the ventilation).
- Standards with instructions on how to work quietly.
- Training, education or tutorials on quiet work procedures (e.g. lessons at maritime institutes or educational facilities of shipowners12).
- Use of role models and networks. Providing good examples of quiet operations13.
- Where possible, introduce incentives for quiet operation, reward quiet operation by means of lower port fees, better services or better places on quays.
- Inviting the noise producers to visit local residents and listen to the noise there.

Example: diesel auxiliary engines make more noise when the demand for electricity is high. Switching off as much of the power demands as possible reduces noise levels. Similar effects can be achieved in other auxiliaries. See leaflet no. 1.

Estimated Reduction

Noise reduction due to behavioural change, in contrast to physical measures such as silencers and noise barriers, is more difficult to express in exact numbers (decibels). However, there will certainly be less noise and hindrance if people are willing to work quietly. People living or working in the neighbourhood often recognise immediately whether employees are working in a responsible, sustainable and quiet way or not. This also applies to the machines and equipment that are operated.

Costs

There are on-off costs and recurring costs that depend on the number of ships, companies and terminals involved and also whether external (medical) acoustic and/or social expertise are consulted. Costs classification: A (one-off costs to provide information materials). Recurring costs cannot been estimated and may vary depending on many factors (size enterprise, number of stakeholders, etc.).

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11 See also factsheet about Public Address equipment
12 Could be done by means of gamification, role play or working with actors.
13 Could be based on noise data collected by noise measurements or volume of complaints.
Conditions

Remember that raising awareness and behavioural change can be a long-term and continuous process.

The successful implementation of awareness and behavioural change depends on the full commitment of the shipowners.

Lessons Learned

As good intentions to work less noisily may fade over time, it is recommended that the process of behavioural change be actively monitored and, if necessary, adjusted.

Remarks

Quiet working and acting can be achieved in many ways with many tools. When developing an approach to behavioural change, it is recommended that experts with both a (medical) acoustic and a social background are involved. Working or operating equipment less noisily can also improve air quality and reduce noise at work. Because the crew often use ear protection at work, they may not be totally aware of the noise that is produced.

Power consumption cannot be reduced in every situation. Basic power consumption will be necessary for lights, ballast pumps, etc.

References

1. EAST, four simple ways to apply behavioural insights. BIT(2015)
2. MINDSCAPE, Influencing behaviour through public policy, BIT (2010).
3. White paper communication. De Baak (undated)
4. Towards sound agenda setting. Souren et al. (2011)
7. The Stockholm congestion charges; an overview. Jonas Eliason, KTH Royal Institute of Technology 2014
11 COMPLAINT MANAGEMENT

Category

“Soft measures” aimed at listening, taking action and providing feedback to reduce the actual nuisance or perceived nuisance.

Addressed to

Port Authorities and/or (local) authorities with the powers to act on complaints or feel responsibility to act.

Brief description

Complaint management is important to achieve and retain a good overview about the perception, support and acceptance among residents, living in the sphere of influence and experiencing the adverse effects of exploiting the port. It can be used as a tool for policy making and maybe more importantly as an instrument to re-enforce support and acceptance among residents living in the vicinity of the port. To achieve this, an ideal complaint management system could be (re)developed or adopted that should include the following elements. See also Figure 1:

I. A complaint registration system (CRS), preferably at a central point, accessible to complainants and port authorities working in that particular port area. This CRS point should be accessible by phone (free of charge), Internet or e-mail, preferably 24/7 and manned.

The CRS system (database) should have the following entries, preferably in a template with or without pull-down or pop-up menus, easy to fill in:

- **Category**
  - “Soft measures” aimed at listening, taking action and providing feedback to reduce the actual nuisance or perceived nuisance.

- **Addressed to**
  - Port Authorities and/or (local) authorities with the powers to act on complaints or feel responsibility to act.

- **Type of noise sources that cause the annoyance/sleep disturbance, including ship-generated noise. A more detailed description is recommended (ship at berth, ship at anchor and ship manoeuvring).**
  - The CRS template could offer to upload photos, videos, recordings or documents.
  - The CRS template could also contain fields for localisation of the noise annoyance or if possible, the source, e.g. pump, ventilator, funnel, winches, generator, compressor, reefer, crane, etc.
  - The CRS template could also contain fields for the characterisation of the noise annoyance, such as music, bass, thumping, banging, roaring, squeaking, blowing, hissing, whizzing, etc. This will simplify the localisation of the source.
  - The CRS template should also have entries for: personal data of the complaint, telephone number and e-mail address of the complainant, operator CRS, date and time that complaint was submitted, date and time the annoyance started and stopped and a brief description of the complaint (optional) and a field that indicates the actions and progress (in progress or completed)

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14 If no central complaint registration point is feasible, an arrangement might be considered with bodies that receive and register complaints (e.g. environmental protection agencies, authorities, police) whereby the complaints are sent to a central point.

15 Industrial, traffic, rail, airport, leisure, industry, etc.
II. A management protocol on how to handle complaints should be based on a policy and contain tasks, roles and responsibilities of the stakeholder involved, procedures and a threshold for actions.

III. A policy document describing policy on complaints related to ship generated noise.

Note:
It might be considered periodically publishing a report about all the complaints submitted over the past year/semester/trimester, action(s) performed and reductions achieved and comparisons with the number of complaints related to other noise sources.

Estimated Reduction

Registering complaints does not reduce noise, annoyance or sleep disturbance. Only when the complainant registers a complaint on the phone is it possible for the CRS operator to provide information about the noise, the duration and what the competent body is planning to do. Receiving information reduces the annoyance and worries.

Costs

The costs of complaint management are the one-off costs involved in designing and building a CRS database with application software and recurring costs (mainly staff, maintenance and service costs of the CSR application and the depreciation costs of the hardware and software). The one-off costs and the recurring costs are estimated to belong to category A when choosing a tailor-made CRS. It is also possible to use an Excel application. Then the one-off costs are estimated in category B.

Conditions

A good instruction for complainants is crucial. The more relevant the information provided, the easier it is to identify the culprit. A threshold for action is recommended in order to save man hours. This threshold could be 3 complaints in general. Exemptions should be allowed, however, depending on the context.

Lessons learned

For complainants, it is hard to distinguish whether the source belongs to the port or whether it is ship-generated noise. The noise is noticed in or around the dwelling and complainants do not usually perform research to find the cause. By completing all the fields of the template or by requesting more information from the complainant, it becomes easier to localise the noise source when action is taken by an inspector or acoustician.

When offering residents the opportunity to submit their complaints by e-mail or social media (e.g. Twitter), the information is often not complete and the CRS operator has to call the complainant to obtain more information. This is inefficient and costly because of the man hours involved.

When analysing the complaint data stored, it is often noticed that more than 50% of the complaints are submitted by 10-20 percent of the complainants (hockey stick phenomenon). This might be due to people’s noise sensitivity (about 15% of people are more sensitive to noise than others) or persistent complainants who have opposite interests.

Remarks

When introducing a new or renewed CRS, the introduction of a test period is recommended. After the system is implemented, an evaluation is required after some time (1 or 2 years) in order to explore whether there is some room for improvement or whether adjustments are required due to developments in the port area.

One should be aware that complaints are not a good indicator for perceived annoyance or sleep disturbance. Only a small percentage of the people who are annoyed or suffer disturbed sleep complain. This may be due to laziness, not knowing where to file the complaint or a lack of confidence in the authorities to resolve anything (4).

The complaint system can also be used for other forms of annoyance such as street dirt, litter, air, soil and water pollution, etc.

When sending in complaints, apps on mobile devices can be helpful and support the complainant. (Easy handling and independent of place and time).
Figure: Complaint procedure

- Receiving complaint
  - phone
  - email
  - social media

- Verbal response
  - how the complaint will be managed

- Registration in database
  - time, duration, expected source, description of the noise
  - meteorological items
  - data complainant
  - name desk officer

- Action
  - conducting additional research (nature, location, duration, etc.)
  - contacting the source owner or agent if measures are possible (short of term)
  - (optional) actions to reduce the noise
  - Check whether the noise is reduced

- Including the information and actions in the database

- Providing feedback to complainant(s)
12 ORGANISATIONAL (PLANNING)

Category

to achieve a sustainable change in awareness, perception, attitude, intention and behaviour.

Addressed to

Sailors, port authorities, terminal staff, tug captains, shipowners.

Brief Description

Noise and annoyance can be avoided, mitigated or reduced by organisational or planning measures. The following organisational or planning measures can be taken:

Berthing programme that ensures that the noisiest ships berth at the farthest locations. See leaflet no. 5 in noise propagation. Prioritisation scheme whereby less noisy ships will be processed faster, earlier or will be given better conditions in the port.

The orientation of the ship may also be included in the berthing programme. This means turning the helm from port to starboard or vice versa, for example. This can be planned in advance based on the known noise emission of the ship or in response to complaints received.

Ships at berth must use external or on-shore equipment (EPS) for supplying power or unloading activities.

Ships must use Shore-Tension technology (for explanation see glossary) or magnetic mooring facilities available in the port. If many complaints are received, an already moored ship will be relocated further away from the sensitive buildings. This may be a one-off response or a permanent arrangement. No admittance for noisy ships (no bookings). This is based on previous calls or noise label or any other register containing information about noise.

Estimated Reduction

Berthing ships further away means less noise. The general principle that can be used for the attenuation (delta, Δ) is Δ = 20 log R1/R2. R1 is the shorter distance and R2 the longer distance. Doubling the distance means approximately 6 dB reduction in the noise. See also leaflet no. 5.

Mooring the ship behind stapled containers as a noise barrier to shield noise emitted by the ship, see Figure 1 and leaflet no. 5.

Figure 1: Container barrier
Changing the orientation cannot always be estimated because it depends on the directivity of the equipment in use. See also the remarks below. Using Shore-Tension or the magnetic mooring technology could reduce the noise emitted by winches, bow thrusters and tugs. Tug boats and bow thrusters are no longer needed when manoeuvring to reach the berth. Using EPS significantly reduces the total noise emission. Not all ships can benefit from it, depending on the capacity, type and age of the ship. Reductions of up to 9 dB can be achieved. Not all noise can be omitted, due to other noise sources on board, like ventilation.

**Costs**

With advanced planning to berth ships further away or with a port instead of starboard orientation, the costs are negligible. Turning or re-allocating the ship involve rather higher costs (category B/C). The re-allocation will also increase the port fee (ship spends more time in the port). The cost of using onshore equipment like Shore-Tension or other capacity could also be very high. When using EPS, costs are related to the instalment of the EPS. Some conversions of the ship due to the cycles (60-50 Hz) and the voltage may also be required (category C++). See also leaflet on External Power Supply (no. 3).

**Conditions**

Information about noise emissions and about noise restrictions must preferably be available prior to arrival (e.g. by sending the incoming vessel the regulations of the port ordinance including the request to deliver this information).

**Lessons Learned**

Changing the orientation is not always possible (due to location of the cargo to be loaded or unloaded and the cranes) or does not reduce noise because of (almost) omnidirectional radiation (360°) of the source.

**Remarks**

EPS is available to a limited extent in ports but the number of EPS facilities are expected to increase following EU Directive 2014/94/EC which states that by 2025 Member States must ensure that the need for shore-side electricity supply for inland waterway vessels and seagoing ships in maritime and inland ports is assessed in their national policy frameworks. Such shore-side electricity supply will be installed as a priority in the ports of the TEN-T Core Network and in other ports by 31 December 2025, unless there is no demand and the costs are disproportionate to the benefits, including environmental benefits.

EPS could be based on electric power taken from the local grid or using a (mobile) generator fuelled by gas (LNG).

The effect of changing the orientation of the ship cannot be estimated because it very much depends on whether the dominant source is the funnel (little influence) or ventilation (may be of influence due to screened location) or other sources.

Barriers made of containers only work when situated close to the source.

**References**

3. EU Directive 2014/97/EC
4. EPS Masterplan for Spanish Ports project. Study of potential acoustic benefits of on-shore power supply at berth, TECNALIA. Santander EURONOISE2018, Crete.

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16 Installed in a container. To deliver more capacity, containers could be connected with each other.
13 CARGO HANDLING

Brief Description

The process of cargo handling itself is not taken into account for the noise emissions of a ship at berth. Nevertheless, the emitted noise from a ship during cargo handling can be perceived as disturbing by residents living near the port area.

This leaflet therefore provides a brief description of the expected noise sources and general suggestions for possible noise mitigation measures during cargo handling in ports. Cargo handling can mainly be described in terms of external operation (using external equipment) and internal operation (using internal equipment on the ship itself). The following noise sources are expected to be the main cause of noise emissions during cargo handling:

External operation:
- Noise generated by crane operation (container cranes and portal cranes) on the shore side (e.g. crane drive and crane movements).
- Cargo containers or deck hatches hitting the ground/other structures (e.g. container hitting other containers and/or steel structures while handled with cranes).
- Bulk cargo dropped from a crane
- Noise generated by carriers (straddle carriers, van carriers, reach stackers and transtainers) moving cargo, bulldozers.
- Forklift trucks and front and side shovel loader moving cargo.
- Cars and cargo rolling over an external ramp (RoRo/RoPax).

Internal operation:
- Crane operation and cargo handling on ships (e.g. containers, bulk carriers and hose handling on tankers).
- Cars and cargo rolling over an internal ramp of the ship (RoRo/RoPax).
- Pumps on a tanker for oil loading and discharging.
- Opening/closing access ramps for RoRo/RoPax ships.

The following noise mitigation measures could be applied for cargo handling:
- Use of electric driven cranes, carriers, forklift trucks and loaders.
- Training of operators for careful cargo handling (e.g. crane and carrier operators). See also leaflet Awareness (no. 10).
- Automated cargo handling (cranes and carriers).
- Improved ramp design (e.g. reducing the gap between the ramp and the quay and inserting rubber linings and insulations).
- Lowering the speed of cars and cargo rolling over the ramps (RoRo and RoPax).
- Improved choice of berth locations (e.g. possibly further away from residents). See also leaflet Organisational (planning) (no 12).

Category

“Soft measure”

Addressed to

Shipowners, shipbuilders, shipping companies, ship engineers (designers/architects), terminal owners, port authorities, operators of cargo handling, ship crew and maintenance staff.
• Time restrictions on cargo handling times at certain berth locations.
• Use of rubber materials on cargo and/or cargo transportation objects to reduce impulsive noise from dropping cargo.
• Shielding (see leaflet no. 5).

Estimated Reduction
Noise reductions cannot be specified in a general way for such mitigating measures and may vary depending on the applied measure.

Conditions
The noise from cargo handling is not directly related to the noise emitted from a ship. Nevertheless, reducing the emitted noise caused by cargo handling may have a positive influence on residents, because most residents will not distinguish between the noise from a ship at berth and the noise from cargo handling.

If the implemented noise mitigation measures are communicated/published by the port authorities to the residents, the residents could also gain better understanding and acceptance of the noise reduction effort by the port. See also leaflets Awareness (no. 11) and Complaint Management (no. 12). Noise mitigation measures for cargo handling can be applied in many different ways. Some methods also have advantages in addition to mitigating the emitted noise. Automation of cargo handling, for example, is currently being used in different ports to optimise the operational process. Other benefits include faster and more precise handling of cargo. Automated cargo handling will probably also lead to fewer severe collisions of cargo containers on steel and other cargo elements that can otherwise only be achieved by well trained and experienced operators.

Lessons Learned
Especially when the berth location is situated close to residents, noise mitigation measures are essential to ensure quiet cargo handling. Due to the area of conflict between residents and ports, close cooperation and communication between different stakeholders is essential.

Remarks
Stakeholders are shown in Figure 1 of Chapter 3 of this Best Practice Guide. This leaflet only provides a brief description of possible noise mitigation measures during cargo handling. There might be more mitigation measures related to cargo handling. It is important that noise mitigation measures are planned for individual cases by professionals, such as acousticians. Besides cargo handling, other noise sources exist on the port side, such as car and truck traffic, railway, working machinery. These further noise sources should also be considered when mitigating the noise emitted by ports.

References
1 Five Baltic ports together: forecasts, trends and recommendations, publications of the centre for maritime studies, university of Turku, A68 - 2013
14 MANOEUVRING

Brief Description
In most ports, incoming and outgoing ships need to perform a berthing manoeuvre to reach or leave the berth location. The process of manoeuvring itself is not considered as noise emission of a ship at berth. Nevertheless, the emitted noise from a ship during manoeuvring may be perceived as disturbing by residents living near the port area due to the specific character of the noise. This leaflet therefore provides a brief description and general suggestions for possible noise mitigation measures of the expected noise sources during manoeuvring in ports. When manoeuvring large ships without the assistance of a tug, the following main noise sources are expected to contribute to the overall noise emission of the ship:

- Funnel exhaust from the propulsion (for direct drives).
- Possibly the funnel exhaust(s) of the auxiliary engine(s) and diesel generators for the diesel-electric drive (if also in operation during manoeuvring).
- The opening(s) of ventilation (e.g. for the engine room, the air-conditioning of passenger rooms and the cargo hold).
- The reefer containers.
- Noise radiation from the propeller, e.g. due to cavitation.
- Noise radiation from the use of thruster(s) (bow and stern), e.g. due to cavitation.
- Mitigation of the noise emitted during manoeuvring can be achieved with the following measures:

  - Muffler/silencer in the exhaust duct of the main engine that matches the compression ignition sequence frequency of the engine. See also leaflet Silencers (no. 2).
  - Measures at the fans. See also leaflet Machinery (no. 1).
  - Avoiding cavitation at the main propeller and side thrusters, operation with low rotational speed.
  - Resilient mounting of the main propeller and side thrusters.
  - Supporting the manoeuvring by tugs.
  - Use of shore-tension systems and winches for berthing.
  - Education of the ship's crew to perform careful manoeuvring (e.g. cautious use of the main propeller and side thrusters or smart navigation such as a quicker manoeuvring). See also leaflet Awareness (no 10).

Estimated Reduction
The reductions of noise cannot be specified in a general way for such mitigating measures. Noise reduction of the emitted noise into the environment ranges from a few decibels (e.g. by retrofitting fans) to 10–20 dB (e.g. well-designed silencer in the exhaust system of the main engine and/or support by tugs).

17 Manoeuvering is not always present and relevant for each port/berth location.
Costs

Similarly, the costs cannot be specified in a general way for such mitigation measures. The expected costs are in category A/B when designing new machinery. When retrofitting the ship, the expected costs can range from category A-C. The use of tugs will probably involve extra costs for the port compared with using only the main engine. Furthermore, the purchase of shore-tension systems and winches creates extra costs for the port. The use of noise mitigated thrusters and resilient mounted thrusters will probably be disproportionately expensive.

Conditions

Noise mitigation measures relating to the machinery elements shall be considered as early as possible, for example during the design phase of the ship.
The manoeuvring of ships can cause annoyance of residents with various different perceptions. The operation of the main engine, for example, can cause low frequent nuisance, while cavitation can cause high frequency or broadband nuisance. Specific mitigation measures, such as a muffler in the exhaust system, require special knowledge to match the muffler to the compression ignition sequence frequency of the engine(s).
Hence, building new machinery does not automatically yield quiet machinery. It is therefore important that noise mitigation measures are planned for the individual case by professionals, such as acousticians.

Lessons Learned

If complaints by residents in response to manoeuvring are received, noise mitigation for the manoeuvring will be taken into account. Besides technical measures to reduce noise sources on board, careful instruction of the crew, especially the captain, is essential. In this regard, manoeuvring can be performed faster and with careful use of main propeller and side thrusters. Furthermore, for known noisy ships, a tug boat can be used to support the manoeuvring.

Remarks

Stakeholders are shown in Figure 1 of Chapter 3 of this Best Practice Guide. Besides positive effects on the emitted noise, some measures could also have positive effects on the machinery hardware. Avoiding cavitation, for example, could also lengthen the life of the propellers.

Besides the main machinery, there might be further secondary noise sources, such as reefers on container ships and compressors. Those secondary noise sources are not always continuously in operation or do not belong to the machinery elements of a ship itself during manoeuvring. These secondary noise sources are therefore not considered for noise mitigation in this leaflet.
15 NON-ACOUSTIC FACTORS

Brief Description

Non-acoustic factors are factors that affect and reduce annoyance in people. Research has found that the following non-acoustic factors could play a role in perception in groups of people:

On the port side:
- Use of visual aspects such as well-kept terminals, harbours, ships and port areas.
- Cleanliness (ref. to the broken windows theory).
- Adding greenery (trees, plants, parks).
- Use of colour and certain materials (e.g. natural, organic) could also affect people’s perception.
- Well-kept time intervals communicated to residents about noisy situations (residents know what to expect, see leaflet no. 7).

On the residential side:
- Contextual aspects such as a safe and secure district, good public transport, playgrounds and various facilities and amenities (schools, shops, sporting facilities). Offering green, grey and blue areas that are relatively quiet compared with the immediate surroundings.
- Compensation, offering people or a community financial or other material compensation such as better insulation of façade or walls, adoption of events, subsidising sports clubs, etc. The port or terminals could facilitate the adoption of a park or a playground or anything else with added value for the district.
- Priming and framing could also play a positive role, emphasising the added value of the port and its companies for the (local) society (employment, successes, etc.) could lead to a positive attitude and even pride among the local residents (e.g. having the largest, greenest or most innovative port in the world).

Category

“Other measures” aimed at influencing people’s perceptions and achieving better acceptance by people.

Addressed to

Ports, terminals, local governments

---

15 Especially when the port is owned by the local government, the government should consider that adding these elements is important and contributes to the wellbeing of residents. Ports could adopt or support the creation of quiet places.

19 Priming is a subconscious form of human memory concerned with perceptual identification of words and objects. It refers to activating particular representations or associations in memory just before carrying out an action or task.

20 Framing is a cognitive bias where people react in different ways to the same choice depending on how it is presented to them. For example, depending on whether a positive or negative spin is given to a particular choice, people’s reaction to it might differ accordingly.
Corporate Social Responsibility is not only important for employees but also for the local residents. Good CSR means maintaining a healthy relationship with residents and NGOs. It is part of image building.

Estimated Reduction

Use of non-acoustic factors does not reduce noise, it only affects the perception and/or acceptance by people. The reduction in the number of annoyed people cannot be reported because this varies in each situation.

Costs

There are one-off costs and recurring costs. One-off costs are related to offering initial compensation. Recurring costs have not been estimated and may vary depending on many factors (e.g. size of the port, district, noise levels) and are often internalised in the communication strategy (framing) or in the CSR strategy. The contextual aspects are the responsibility of the local government or project developer that initiates the new or renewed district. The extra costs should be included in the project costs.

Conditions

When districts are (re)developed or houses are built in areas with a noise level above a preferred level (exemptions are granted to build there), future residents should be informed about the noise levels in their new habitat. This can be done by traditional means (leaflet, information included in the spatial plan, letters) or by means of audio or Virtual Reality or augmented reality instruments.

Lessons Learned

There is no guarantee that compensation works in the long term. See also the leaflet on Urban Planning.

Remarks

Evidence that non-acoustic factors affect people’s perception is found for groups of people, meaning that it does not always apply to individuals. Predictability and influenceability are also important. Knowing that noise will occur (see leaflet expectation management, no. 7) makes people less sensitive. If people feel that they can have some influence on the noise, annoyance is often decreased.

References

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2 Broken windows theory, Wilson et al. (1969)
3 https://zoek.officielebekendmakingen.nl/gmb-2016-156882.html
4 http://www.nrp.nl/nieuws/bouwen-op-geluidbelaste-locaties-doof-is-niet-het-antwoord/
5 https://www.psychologytoday.com
6 Inventarisatie Stedenbouwkundige Soundscape projecten in Nederland, RIVM 2018
Noise exploration program to understand noise emitted by eagoing ships
Chapter 1 
Introduction
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Preliminary remarks</td>
<td>98</td>
</tr>
<tr>
<td>2</td>
<td>Normative references</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>Definitions and symbols</td>
<td>102</td>
</tr>
<tr>
<td>3.1</td>
<td>Terms</td>
<td>104</td>
</tr>
<tr>
<td>3.2</td>
<td>Level parameters</td>
<td>104</td>
</tr>
<tr>
<td>4</td>
<td>Measuring equipment</td>
<td>106</td>
</tr>
<tr>
<td>4.1</td>
<td>Acoustic measuring equipment</td>
<td>107</td>
</tr>
<tr>
<td>4.2</td>
<td>Additional measuring equipment</td>
<td>107</td>
</tr>
<tr>
<td>5</td>
<td>Classification of ships and sound sources</td>
<td>108</td>
</tr>
<tr>
<td>5.1</td>
<td>Ship types</td>
<td>109</td>
</tr>
<tr>
<td>5.2</td>
<td>Sound sources on board of the ships</td>
<td>109</td>
</tr>
<tr>
<td>5.3</td>
<td>Operating conditions during sound measurements</td>
<td>109</td>
</tr>
<tr>
<td>6</td>
<td>Measuring instructions</td>
<td>110</td>
</tr>
<tr>
<td>6.1</td>
<td>General overview</td>
<td>112</td>
</tr>
<tr>
<td>6.2</td>
<td>Measuring conditions for all measurements</td>
<td>112</td>
</tr>
<tr>
<td>6.3</td>
<td>Sound emission measurement on board of the ship</td>
<td>112</td>
</tr>
<tr>
<td>6.4</td>
<td>Complementary measurements at a certain distance from the ship</td>
<td>116</td>
</tr>
<tr>
<td>7</td>
<td>Documentation of results</td>
<td>120</td>
</tr>
<tr>
<td>7.1</td>
<td>Formal details in the report</td>
<td>121</td>
</tr>
<tr>
<td>7.2</td>
<td>Content to be documented in the report</td>
<td>121</td>
</tr>
<tr>
<td>8</td>
<td>Contributors</td>
<td>124</td>
</tr>
<tr>
<td>Appendix</td>
<td>Exemplary calculation of the measurement position MP 1</td>
<td>125</td>
</tr>
</tbody>
</table>
Neptunes

Annex II
Noise measurement protocol moored ships
1 PRELIMINARY REMARKS

This measurement protocol has the objective to provide a uniform, worldwide applicable measurement standard describing how to measure, analyze, evaluate and classify individual ships (e.g. container ships, cruise ships, tankers, RoRo/RoPax and bulk carriers) concerning their airborne noise emission when moored at berth in ports.
The measurement protocol shall especially ensure that the measurements are carried out in a comparable manner in different ports and by different persons. The measurements should be carried out by acoustic specialists / measurement institutes that are accredited for the test procedures and standards specified in this measurement protocol or according to country-specific requirements. If applicable the respective country-specific accreditation companies should be assigned to the umbrella association International Laboratory Accreditation Cooperation (ILAC).

The measurements shall preferably be performed as sound emission measurements on board of the respective ship. The noise emission measurements on board of the ship will be performed to determine the sound power level of the most dominant noise sources on this (respective) ship. The total sound power level of the ship will then be calculated from the sound power levels of the individual sound sources.

Only in exceptional cases, such as proven denied access to the ship, complementary sound pressure measurements at a certain distance from the ship can be performed to estimate the total sound power level of the ship (provided that the measurement requirements for measurements at a certain distance can be met).

Apart from providing guidance for carrying out the acoustic measurements, the protocol will inform about which details need to be documented during the measurements and what results are required as an outcome of each measurement to be used for a noise label.

The results of each measurement need to be documented in a separate short report and filled in an Excel-spreadsheet provided by NEPTUNES.
2 NORMATIVE REFERENCES


7 ISO 3746: Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Survey method using an enveloping measurement surface over a reflecting plane. 2011-03.


3 DEFINITIONS AND SYMBOLS
Chapter 1
Introduction

Annex II
Noise measurement protocol moored ships
3.1 Terms

The acoustic quantities used in this document are stated in Table 1 together with their symbol and the SI unit.

Table 1. Applied acoustic quantities and symbols.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>(SI) unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound pressure</td>
<td>$p$</td>
<td>Pa</td>
</tr>
<tr>
<td>Sound power</td>
<td>$P$</td>
<td>W</td>
</tr>
<tr>
<td>Sound intensity</td>
<td>$I$</td>
<td>W/m²</td>
</tr>
<tr>
<td>Sound pressure level</td>
<td>$L_p$</td>
<td>dB</td>
</tr>
<tr>
<td>Sound intensity level</td>
<td>$L_I$</td>
<td>dB</td>
</tr>
<tr>
<td>Sound pressure level</td>
<td>$L_p$</td>
<td>dB</td>
</tr>
<tr>
<td>A-weighted sound pressure level</td>
<td>$L_{pA}$</td>
<td>dB(A)</td>
</tr>
<tr>
<td>A-weighted sound intensity level</td>
<td>$L_{IA}$</td>
<td>dB(A)</td>
</tr>
<tr>
<td>A-weighted sound power level</td>
<td>$L_{WA}$</td>
<td>dB(A)</td>
</tr>
<tr>
<td>C-weighted sound pressure level</td>
<td>$L_{pC}$</td>
<td>dB(C)</td>
</tr>
<tr>
<td>95 % percentile A-weighted sound pressure level</td>
<td>$L_{A,95}$</td>
<td>dB(A)</td>
</tr>
<tr>
<td>Maximum sound pressure level</td>
<td>$L_{p,max}$</td>
<td>dB(A)</td>
</tr>
</tbody>
</table>

Further level quantities together with their definitions are given in section.

3.2 Level parameters

For this measuring instruction, especially the level parameters as defined in the following apply:

- $L_{A,eq}$ A-weighted continuous sound level for continuous sound signals,
- $L_{C,eq}$ C-weighted continuous sound level for continuous sound signals,
- $L_{IA}$ A-weighted continuous sound intensity level for continuous sound signals,
- $L_{AF,95}$ 95 % exceedance level,
- $L_{AF,10}$ 10 % exceedance level,
- $L_{A,max}$ maximum sound pressure level during the measurement interval,
- $L_{WA}$ A-weighted sound power level.

The applied level quantities are in accordance with the definitions given in ISO 3746 (7) and ISO 9614-2 (8), but are not identical with these.

3.2.1 Time-averaged sound pressure level (equivalent continuous sound pressure level) $L_{eq}$

$$L_{eq} = 10 \log \frac{1}{T} \int \frac{p(t)^2}{p_r^2} dt$$

in dB  \hspace{1cm} (1)

where

- $L_{eq}$ is the time-averaged sound pressure level (equivalent continuous sound pressure level) in dB,
- $p(t)$ is the sound pressure in Pa,
- $p_r$ is the reference sound pressure (here $p_r = 20 \mu$Pa) and
- $T$ is the averaging time in s.

1 According to the standards of DIN, IEC and ISO, the described physical level quantities have to be marked by a corresponding index. Besides, information on the weighting and other supplements (like time and frequency weightings) have to be added to the evaluated quantity, and not to the (pseudo) unit dB. Nevertheless, the non-standard notation dB(A) can still be found in textbooks or legislative texts and should be stated here.

2 The weighted levels will be stated with an additional subscript, e.g. $L_{A,eq}, L_{C,eq}$.

3 According to ISO 1996-1 the equivalent continuous sound level can also be marked with the index T, $L_{eq,T}$.
3.2.2 Sound intensity level $L_{\text{in}}$

$$L_{\text{in}} = 10 \log \left( \frac{1}{T} \int_{0}^{T} \frac{1}{r(t)} \cdot \hat{n} \cdot \hat{n} \, dt \right) \quad \text{in dB}$$  

where
- $L_{\text{in}}$ is the time averaged sound intensity level,
- $\hat{f}(t)$ is the instant flow of sound energy through an area unit in the direction of local momentary sound velocity,
- $\hat{n}$ is the unit normal vector, which is defined to point out of the space enclosed by the measuring surface,
- $\hat{r}$ is the reference intensity (here $\hat{r} = 10^{-12} \text{W/m}^2$) and
- $T$ is the averaging time.

3.2.3 Sound power level $L_{W}$

$$L_{W} = 10 \log \left( \frac{P}{P_0} \right) \quad \text{in dB}$$  

where
- $P$ is the sound power and
- $P_0 = 1 \text{ pW}$.

3.2.4 95 % exceedance level $L_{\text{AF95}}$

The 95 % exceedance level $L_{\text{AF95}}$ represents the A-weighted sound pressure level, which is present or exceeded during 95 % of the measurement interval (measurement time), measured with the time weighting fast.

3.2.5 Residual noise or background noise

Residual noise or background noise describes an extraneous sound which can be heard while listening to or monitoring other sounds. For example, when measuring the sound emission from individual sound sources on a ship residual noise from e.g. cargo handling during loading and unloading can be heard and recorded.
4 MEASURING EQUIPMENT
4.1 Acoustic measuring equipment

The equipment for acoustic measurements must consist of:

- Integrating sound level meter with a microphone, (cable) and windscreen, in compliance with IEC 61672-1 (1) and IEC 61672-2 (2), class 1.
- Acoustic calibrator in compliance with IEC 60942, class 1 (3).
- Optional equipment: Sound intensity probe in compliance with IEC 61043 (4).

The microphones need to be equipped with a windscreen (diameter ≥ 6 cm) for each measurement.

The calibration of the measuring system needs to be checked with the sound calibrator before and after each measurement series.

For post-processing, analysis software is required comprising the following methods:

- Third-octave band analysis according to IEC 61672-1 (1).
- Frequency weighting, time weighting and averaging.

During all measurements the time weighting fast will be used.

Optional equipment: If sound intensity measurements are carried out, a 12 mm spacer between the microphones for all sound sources and especially for measurements at the funnel outlet additionally a 50 mm spacer necessarily need to be used for the respective frequency response of interest.

4.2 Additional measuring equipment

Besides the acoustic measuring equipment, the following equipment is needed for the measurements:

- Distance measurement device (accuracy of 2 % with results from 0.1 to 600 m).
- Photo camera.
- Tripod with a height of at least 6 m.
- Optional equipment: Grid airflow measurement device (10 % accuracy).
- Optional equipment: Wind speed measurement device (anemometer) and wind direction measurement device at a height of 10 m or higher in free field (10 % accuracy). Preferably these data should be recorded by the ship crew during the measurements.
- Optional equipment: Headphones for monitoring of the measured signal
- Optional (recommended) equipment: connecting bar and extension cable for positioning the microphone or the intensity probe at remote positions

---

* Post-processing might already be part of the sound level meter.
5 CLASSIFICATION OF SHIPS AND SOUND SOURCES
5.1 Ship types

This measurement protocol shall especially be applicable for the following ship types:

- a Container ships
- b Cruise ships
- c Tankers
- d RoRo/RoPax
- e Bulk carriers
- f General cargo/service ship

5.2 Sound sources on board of the ships

The overall sound emission radiated from each ship can be traced back to several individual sound sources on board of the ship. Some of these individual sound sources exist for all aforementioned ship types, whereas others can only be found for specific ship types/ships.

Based on experience the most relevant sound sources that have to be measured are listed below. The sources are assigned to the ship types from section 5.1.

1. The funnel outlet(s) of the auxiliary engine(s), all ship types (a) to (f).
2. The opening(s) of engine room ventilation inlet and outlet, all ship types (a) to (f).
3. The opening(s) of the cargo holds ventilation and air conditionings inlet(s) and outlet(s), all ship types (a) to (f).
4. The opening(s) of the ventilation and air-conditioning of passenger rooms, ship types b) and RoPax d).
5. Further relevant ventilation openings (e.g. sanitary or galley exhaust)\(^*\)
6. Pumps on deck, ship type c).

The operation of cooled containers / reefers on container ships is strongly depending on several indicators such as (cooling) type of the container, type and size of the ship, ships load and port conditions. Furthermore, their operation is also belonging to the cargo handling process of a ship at berth. Therefore, the cooled containers / reefers are not considered for measurements and will not be considered for the calculation of the total sound power level of the measured ship in this measurement protocol.

5.3 Operating conditions during sound measurements

During the measurements, the ship shall be operating in the characteristic/normal load of the ship at berth. It must be ensured that the load condition during measurements is chosen in such a way that the measured sound emissions will not be exceeded at berth in any further calling port (in most cases during high / maximum load conditions of the ship).

It is important that the electric load is kept as constant as possible during all measurements.

To adjust the electric load of the auxiliary engine(s) to the representative load, consumers on board might need to be switched on or off. Consumers that (in most cases) can be controlled manually are, e.g.:
- cargo hold fans,
- engine room fans,
- fans and air-conditioning of passenger rooms and
- further fans on board.

Furthermore, the operating conditions during all measurements need to be documented in detail, see also section.

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* The smaller sound sources like HVAC systems on the bridge and ventilation of galleries etc. will typically not be considered because, in general, they do not contribute to the sound emission of a ship in total.
* All further ventilation openings on board should be checked for relevant sound emissions.
6 MEASURING INSTRUCTIONS
Annex II
Noise measurement protocol moored ships
6.1 General overview

The measurements for each ship to be measured shall be performed as

1 Sound emission measurements on board of the respective ship and/or
2 In exceptional cases only: Complementary acoustic measurements at a certain distance from the ship (provided that the measurement requirements for measurements can be met at a certain distance; e.g. low residual noise and accessibility).

The sound emission measurements should preferably be performed on board. Nevertheless, if due to not predictable circumstances (such as proven denied accessibility to the ship) measurements on board of the ship cannot be performed, the acoustic measurements at a certain distance can complementary be performed. The performance of measurements at a certain distance presupposes certain stricter requirements to the measurement environment (e.g. low residual noise and accessibility). Details are shown in chapter 6.4.

The two measurement methods are described in detail in the following chapters 6.2 and 6.3

This report gives a general recommendation for carrying out measurements for both methods. If the measurements cannot be strictly carried out in the given manner, they shall be performed in a close approximation to these instructions. Each deviation from the measuring instructions needs to be carefully documented (see also section 4.1). Among other things, possible reasons for deviation from the measuring instructions could e.g. be limited accessibility to measurement positions and too high residual noise at the measurement positions.

The measurements should be carried out by acoustic specialists / measurement institutes that are accredited for the test procedures and standards specified in this measurement protocol according to country-specific requirements. The respective country-specific accreditation companies should preferably be assigned to the umbrella association International Laboratory Accreditation Cooperation (ILAC).

6.2 Measuring conditions for all measurements

The required operating conditions of the ship during measurements are specified in section 5.3. The measuring system must have a calibration certificate and a valid calibration status at the time of the measurement. The measuring system is to be calibrated (single point calibration) before and after the measurements. The calibration signal must be recorded accordingly (see also section 4.1). Residual noise is to be avoided as far as possible in the vicinity of the measuring positions. It must be assured that the measurements are not distorted by ambient noise (e.g. from cargo handling or port noise). If possible, the berthing site for the ship shall be chosen in such a way that the residual noise level is as low as possible during the measurements. Measurements shall only be performed when no rain or snow is present (≤ 0.1 mm/m²). Further conditions for the individual measurements are shown in chapter 6.4.1 and 6.3.1.

6.3 Sound emission measurement on board of the ship

6.3.1 General remarks

The sound emission measurements on board of the ship will be performed to identify the most dominant sound sources on a ship. Furthermore the measurement results will give an overview of the sound power level of the individual sound sources on board of the ship.

During measurements the wind speed shall be below 6 m/s for all measurements on board of the ship. The flow velocity at the measurement positions (e.g. caused by the exhaust of the funnel or the fans of the ventilation systems) shall be as low as possible, preferably below 6 m/s. If the flow velocity is too high at the measurement positions, another measurement surface with lower flow velocity needs to be chosen (e.g. sideways from the ventilation opening). The divergent measurement surface preferably needs to be chosen following a comparable measurement surface as stated in section x. Each deviation must be documented including a sketch of the alternatively chosen measurement surface, see also section x.
If not stated differently in the following, measurements shall be performed as sound pressure measurements in accordance with ISO 3746 (7) or alternatively as sound intensity measurements in accordance with ISO 9614-2 (8).

Note: Sound intensity measurements have the advantage that the present environment is basically not influencing the measurements (e.g. measurements can be performed even if there is a high residual noise from other sound sources). Furthermore, measurements in the near field of the sound sources are less susceptible to interferences. Nevertheless, for sound intensity measurements advanced measurement equipment and advanced acoustic knowledge are required. If such equipment and advanced acoustic knowledge are available, sound intensity measurements are to be preferred.

6.3.2 Measuring instructions
If not stated otherwise in the following, the measurements shall preferably be performed by continuous meandering averaging over the surface area (both horizontally and vertically), as shown in Figure 1. The averaging shall take place with a speed of between 0.1 m/s and 0.5 m/s. If the averaging surface is divided into several segments, the averaging needs to be performed subsequently for all segments to obtain one averaged sound pressure level for the whole measurement surface area. The averaging time for each segment shall not be shorter than 20 s. Further details on the measurement method can be found in ISO 9614-2 (8).

Note: To simplify the measurement effort, the continuous meandering averaging shall be applied in the same manner for the sound pressure measurements in accordance with ISO 3746 (7). Alternatively, measurements at several discrete measurement positions distributed over the measurement surface can be chosen in accordance with ISO 3746 (7). This method can, for example, be advantageous for measurements on a hemispherical measurement surface, as suggested for measuring the sound emission of cooled containers/reefers. There may be a large number of sources for each source type (e.g. a great number of ventilation inlet and outlet openings from the cargo hold of a container ship). To minimize the number of separate measurements, it will be sufficient to measure up to three representative sound sources for each source type (e.g. three different openings of ventilation outlets from the cargo hold), implying that all sources have a similar subjective sound emission. The overall sound power level of those sources needs to be subsequently extrapolated to the number of such sources in operation during measurements. In the following, the preferred measurement surface(s) for the most relevant sound sources from section 5.2 are described in detail.

A Funnel outlet of the auxiliary engine(s), all ship types
The sound emission of the funnel outlet of the auxiliary engine(s) shall be measured in accordance with DIN 45635-47 (9). Following DIN 45635-47 (9), the sound pressure will be measured at two measurement positions (MP 1 and MP 2) as shown in Figure 2. The distance from the outer wall of the funnel outlet to the measurement positions will be 1 m. The arrangement of the measuring points in the horizontal direction is arbitrary. The measurement time for each measurement position shall be at least 30 seconds. The measurement positions (1) and (2) from Figure 2 shall be chosen from the axis of the opening. The calculation of the surface areas S1 and S2 is shown in Figure 2.

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7 This represents a simplified measuring method. According to (7) and (8) each segment of the measuring surface shall be measured separately and the overall sound power level will be calculated as the logarithmic sum of all individual sound power levels from all segments.
8 The measurement procedure described in DIN 45635-47 (9) is similar to the approach described in ISO 6798 (10).
9 The choice of two measurement positions (in front and behind of the outlet) is especially important for the comparability with additional measurements (e.g. measurement on the deck house and measurements in a certain distance from the ship).
10 The influence of directivity in horizontal direction is negligible.
Note: In the near field of sound sources, the sound pressure and the sound velocity are out of phase, which can lead to unusual high sound pressure levels that are measured in the near field. Especially high care should be taken to this phenomenon when measuring at the funnel outlet, since it is very often radiating high sound emissions in the low frequency range (especially for 1/3 octave frequency bands ≤ 160 Hz). When measuring at a distance of one meter from the funnel outlet the determined sound power level could, therefore, be higher than the actual sound power level relevant for the noise radiation into the environment. Alternatively, sound intensity measurements in the near field and/or sound pressure measurements in a larger distance (recommended ≥ 10 m) from the funnel outlet can lead to more precise measurement results.

B Opening of ventilation inlets and outlets
The measurement surface shall be chosen in the plane of the shape of the opening at a distance of 0.25 m ≤ dv ≤ 0.5 m in front of the opening. The surface area S corresponds to the surface area of the opening (mostly rectangular or round surfaces are expected) and is calculated by $S = ab$ where a and b are the side lengths of a rectangular surface, or $S = \pi r^2$ where r is the radius of a round surface.

Alternative approach for ventilation openings
The ventilation openings are not always accessible or sometimes only hardly accessible (such as the outlets of the engine room ventilation). In such situations the following alternative approach can be used for passive ventilation openings that are accessible from the inside, unless the fans are directly connected to the opening itself.

The spatial average sound pressure level inside and in front of the respect opening shall be measured in 1 m distance to the opening. The determined sound pressure level will then be used for calculating the sound power level that is radiated from the opening into the environment in accordance with ISO 12354-4 (12).

Alternative approach for ventilation openings with high air flow
If due to high air flow (flow speed ≥ 6 m/s) measurements in front of the ventilation openings on the above mentioned measurement surface are not possible, a suitable alternative measurement surface should be chosen. As an alternative measurement surface, a hemisphere with a radius of 0.5 m ≤ r ≤ 2 m from the acoustic centre of the opening could be chosen. The surface area S will then be calculated by $S = 2\pi r^2$.

C Cooled containers/reefers
The sound emission of the cooling containers/reefers (sound source (5) from section 5.2) is mainly caused by the sound emission from the fan and the compressor next to the fan. As measurement surface, a hemisphere with a radius of 1 m ≤ r ≤ 2 m from the acoustic centre between the fan and the compressor shall preferably be chosen. The surface area S will then be calculated by $S = 2\pi r^2$. 

A sketch of the measurement surface is shown in Figure 4.

Figure 4. Sketch of the hemispherical measurement surface for measuring the sound emission of a cooled container. The contour of the measurement surface is marked red.

6.3.3 Acoustic data to be recorded
During each individual measurement the following data shall be recorded:
- $L_{Aeq}$ equivalent A-weighted continuous sound pressure level,
- $L_{Amax}$ maximum sound pressure level during the measurement interval.

All data shall be recorded as 1/3 octave band level from 25 Hz to 10 kHz and total level including those 1/3 octave bands; the $L_{Amax}$ only needs to be recorded as the total level.

D Pumps
The measurement surface shall preferably be a square with a distance of $d_p = 1$ m from the contour of the pump to each side including the drive. The surface area $S$ will then be calculated by $S = (a + b) \times 2 \times c + a \times b$. In a suitable measurement environment (especially low residual noise) a hemispherical measurement surface with a radius of $1 \leq r \leq 2$ m can alternatively be chosen. The surface area $S$ will then be calculated by $S = 2 \cdot \pi \cdot r^2$. A sketch of a rectangular measurement surface is shown in Figure 5.

Figure 5. Sketch of the square measurement surface for measuring the sound emission of pumps. The contour of the measurement surface is marked red, the pump is marked gray.

6.3.4 Evaluation of the measurement results – sound power level $L_{WA}$
From sound pressure level measurements (A-weighted equivalent continuous sound pressure level $L_{Aeq}$) the sound power level of the specific sound source ($i$) need to be calculated in accordance with ISO 3746 (7) for each 1/3 octave frequency band from 25 Hz to 10 kHz by

$$L_{WA,i} = L_{Aeq} - K \cdot 10 \log_{10} \frac{S}{S_0}$$

where
- $L_{WA,i}$ is the A-weighted sound power level in dB with a reference sound power level of $10^{-12}$ W for the specific sound source ($i$),
- $L_{Aeq}$ is the A-weighted equivalent continuous sound pressure level averaged over the measurement surface area $S$,
- $S$ is the area, in square meters, of the measurement surface,
- $S_0$ is the reference surface of 1 m² and
- $K$ is the correction factor for residual noise and environmental issues (in this measurement protocol $K = 0...3$ dB).

From sound intensity measurements (A-weighted sound intensity level $L_{AI}$) the sound power level of the specific sound source ($i$) will be calculated in accordance with ISO 9614-2 (8) for each 1/3 octave frequency band from 25 Hz to 10 kHz by

$$L_{WA,i} = L_{AI} - K \cdot 10 \log_{10} \frac{S}{S_0}$$

in dB (5).
where $L_{WA,i}$ is the sound power level in dB with a reference sound power level of 10-12 W for the specific sound source (i),

$L_{AI}$ is the sound intensity level averaged over the measurement surface area $S$.

As an exception, the sound power level of each measured funnel outlet (j) will be calculated as shown in equation (4) separately for the measurement surfaces $S_1$ and $S_2$. The total sound power level of each funnel outlet (j) will then be calculated as shown in equation (6) for each 1/3 octave frequency band from 25 Hz to 10 kHz,

$$L_{WA, funnel,j} = 10 \log \left( \frac{\sum_{i=1}^{m} L_{WA,1,i} + \sum_{i=1}^{m} L_{WA,1,j}}{10^{0.1 \cdot L_{AI,j}}} \right)$$

in dB (6).

where $L_{WA, funnel,j}$ is the total sound power level of each funnel outlet (j) and $L_{Wa,1,j}$ and $L_{Wa,1,j}$ are the sound power levels calculated for both separate measurement positions of each funnel outlet (j).

### Correction for residual noise

If temporary residual noise cannot be fully avoided during an individual measurement, the sound power level needs to be corrected by the factor $K = 0 \ldots 3$ dB, see equation (4) and (5). All corrections of the sound power level need to be documented (see also section 7). The magnitude of correction up to 3 dB can be chosen based on the subjective impression. Here, simplifying, a correction of $K = 0$ dB means that the measurement is not influenced by residual noise and a factor of $K = 3$ dB means that basically the residual noise and the sound from the source under test are perceived with the same loudness. The correction factor $K$ shall be chosen constant for all 1/3 octave band frequencies.

### Total sound power level

The total sound power level of the measured ship will be calculated from the calculated sound power level of all individual sound sources as shown in equation (6) for each 1/3 octave frequency band from 25 Hz to 10 kHz.

$$L_{WA} = 10 \log \left( \sum_{i=1}^{m} 10^{0.1 \cdot L_{WA,i}} \right)$$

in dB (7).

The broadband total sound power level will then be calculated by the energetic sum of the total sound power levels for all 1/3 octave frequency bands from 25 Hz to 10 kHz.

The low frequency total sound power level will then be calculated by the energetic sum of the total sound power levels for all 1/3 octave frequency bands from 25 Hz to 160 Hz.

### 6.4 Complementary measurements at a certain distance from the ship

#### 6.4.1 General remarks

Sound pressure level measurements at a certain distance from the ship should be performed only complementary, if due to not predictable circumstances (such as denied accessibility to the ship) measurements on board of the ship cannot be performed. The performance of measurements at a certain distance presupposes certain stricter requirements (e.g. low residual noise and accessibility) to the measurement environment, which are described below.

Furthermore, the sound pressure level measurements at a certain distance can also be performed in addition to the sound emission measurement on board of the ship. The measurements can indicate the presence of low frequency noise at a certain distance and can be used for comparisons with the sound emission measurements on board of the ship. During measurements the wind speed shall be below 5 m/s. From 2 m/s to 5 m/s the wind has to come within 60 degrees from source (ship) to receiver (microphone position). Residual noise

For performing measurements at a certain distance from the ship it is important that the measurements are not disturbed by residual noise (e.g. noise caused by cargo handling, noise caused by ships that are berthed nearby or passing ships). Before starting the actual measurements at a certain distance
from the ship, the residual sound pressure level (background noise level) shall be recorded at each measurement position from section 6.4.2. The recording time shall be at least 5 minutes. The residual noise level needs to be at least 3 dB below the sound pressure level caused by the ship at each measurement position to fulfill the measurement requirements. The recording of residual noise is e.g. possible at large distance from the vessel or before the arrival or after the departure of the ship. It needs to be assured, that the ambient conditions do not change significantly during measurements, e.g. by observing the surrounding and monitoring the background noise at a larger, but representative distance.

6.4.2 Measuring instructions
The measurements at a certain distance from the ship shall be performed at least at three measurement positions (MP). The measurement positions shall be chosen sideways from the ship, so that the most dominant sound sources of the ship will be captured with the measurement. If one side of the ship is subjectively much noisier than the other side (e.g. due to the presence of ventilation openings only at one side of the ship), both sides shall be measured if possible. However, in most cases measurements at one side of the ship will be representative for the overall sound radiation from the ship.

It is recommended to choose the following three measurement positions sideways from the ship:
- **MP 1:** one position sideways from the funnel outlet of the auxiliary engine,
- **MP 2:** one position midway between the ship bow and the centre of the ship,
- **MP 3:** one position sideways from the stern or behind the stern of the ship. It is important that there is a clear view from the microphone position to the ventilation openings at the deckhouse or at the stern of the ship.

If due to the location of the funnel the measurement position MP 1 lies within less than 10 m to MP 2 or MP 3, another representative measurement position needs to be chosen for the concerning MP 2 or MP 3 (e.g. centre of the ship). In at least one measurement position there shall be a clear line of sight between microphone and exhaust pipe outlet to avoid acoustic screening by structures like bridge wings.

The measurements can be performed successively at the different measurement positions.

The horizontal distance \( d_h \) from the funnel outlet of the auxiliary engine in operation and the measurement position MP 1 shall preferably be chosen in such a way that the angle \( \alpha \) between the direct distance to the funnel outlet \( d_c \) and the horizontal distance \( d_h \), fulfills the relation \( 5^\circ \leq \alpha \leq 20^\circ \).

For measurement positions MP 2 and MP 3 the same horizontal distances to the ship hull as for MP 1 shall be chosen. Deviations from the suggested angle \( \alpha \) (e.g. by choosing a measurement position closer to the ship) are allowed, as long as there is a clear sight from the microphone to the funnel outlet of the ship available.

The height of the measurement position is to be chosen at least \( h_m = 6 \) m above the quay ground.

An exemplary calculation of the horizontal distance \( d_h \) from the funnel outlet to the measurement position MP 1 is shown in the Appendix.

The recording time for each measurement position shall be at least 2 minutes\(^{13} \) of extraneous noise free measurement time. Depending on the presence of residual noise, the measurement time might need to be extended.

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\(^{11}\) To make sure that wind noise is not disturbing the measurement, the signal can e.g. be checked by headphones.

\(^{12}\) To avoid noise caused by cargo handling, it could be helpful to perform the measurements at a certain distance before starting/after finishing the cargo handling on that ship or in breaks/changes of working shifts of the port staff.

\(^{13}\) Under normal conditions, the measurement time at each measurement position will most likely be between 2 and 10 minutes.
A sketch of the measurement positions is shown in Figure 6 and Figure 7.

Figure 6. Sketch of the measurement positions sideways from the axis of the ship at a certain horizontal distance $d_h$.

Figure 7. Sketch showing the relative position of the measurement position MP 1 to the funnel outlet of the auxiliary engine in operation. $h_c$ is the height of the funnel outlet above quay ground, $h_m$ is the microphone height above quay ground at the measurement position MP 1, $d_h$ is the horizontal distance from MP 1 to the funnel outlet and $d_c$ is the direct distance between the funnel outlet and MP 1.

Note: The measurement position shall preferably be chosen in such a way that no reflections or screening from surrounding objects (e.g. buildings) will disturb the measurements. If reflections and screenings from surrounding objects and/or temporary residual noise cannot fully be avoided by changing the measurement position, detailed documentation of the surroundings and the time and nature of residual noise is essential (see also section Foot Verwijzingsbron niet gevonden.). The measurement results might need to be corrected to account for the influence of reflections.

6.4.3 Acoustic data to be recorded

During measurements the following data shall be recorded for each measurement position:

- $L_{A_{eq}}$, equivalent A-weighted continuous sound pressure level at the measurement position ($k$),
- $L_{C_{eq}}$, equivalent C-weighted continuous sound pressure level at the measurement position ($k$),
- $L_{A_{95}}$, 95% percentile sound pressure level at the measurement position ($k$),
- $L_{A_{10}}$, 10% percentile sound pressure level at the measurement position ($k$),
- $L_{A_{max}}$, maximum sound pressure level during the measurement interval at the measurement position ($k$),
- Time signal preferably uncompressed in .wav format.

All data shall be recorded as 1/3 octave band level from at least 25 Hz to 10 kHz and total level including those 1/3 octave bands; the $L_{A_{max}}$ only needs to be recorded as the total level. Residual noise during measurements is to be avoided as far as possible. If temporary residual noise cannot be fully avoided, times with high residual noise need to be excluded from the measurements, if possible. If, for the evaluated measurement series, the residual sound pressure level (background noise level) is 10 dB or more below the measured sound pressure level, the results do not have to be corrected.

For cases when the residual sound pressure level is within a range of 3 dB to 10 dB below, (only) the measured equivalent continuous sound pressure level needs to be corrected according to ISO 1996-2 (6) as

$$L_{corrected} = L_{measured} - 10 \left( \frac{10^{-3} - 10^{-10}}{10^{-10}} \right)$$

in dB (8).
where
\[ L_{\text{Aeq,corr,k}} \] is the corrected equivalent sound pressure level at the measurement position (k) and \[ L_{\text{residual,k}} \] is the residual sound pressure level (background noise level) at the measurement position (k).

In case of determining \( L_{\text{Ceq,corr,k}}, L_{\text{Aeq,k}} \) from equation (8) is replaced by \( L_{\text{Ceq,k}} \).

If the residual sound pressure level is less than 3 dB below the measured sound pressure level, no corrections are allowed. In this case, the measurement uncertainty is too large. The correction can be applied for each 1/3 octave band, if the conditions are conspicuous (e.g. low-frequency noise from ships passing by).

6.4.4 Evaluation of the measurement results – sound power level \( L_{\text{WA}} \)

From sound pressure measurements at a certain distance from the ship the sound power level of the measured ship will be calculated for each measurement position (k) from the (corrected) sound pressure level as shown in equation (9) for each 1/3 octave frequency band from 25 Hz to 10 kHz.

\[
L_{\text{WA,k}} = 10 \log \left( \frac{1}{2 \pi \times \omega \times d_{c,k}} \right) \text{ in } \text{dB} \quad (9)
\]

where
\[ L_{\text{WA,k}} \] is the calculated sound power level at the measurement position (k).

Total sound power level

The total sound power level of the measured ship will be calculated from the calculated sound power level of all individual measurement positions as the quadratic (energetic) average as shown in equation (10) for each 1/3 octave frequency band from 25 Hz to 10 kHz.

\[
L_{\text{WA,total}} = 10 \log \left( \frac{1}{n} \sum_{k=1}^{n} L_{\text{WA,k}} \right) \text{ in } \text{dB} \quad (10)
\]

where
\[ n \] is the total number of measurement positions (k).

The broadband total sound power level will then be calculated by the energetic sum of the total sound power levels for all 1/3 octave frequency bands from 25 Hz to 10 kHz.

The low frequency total sound power level will then be calculated by the energetic sum of the total sound power levels for all 1/3 octave frequency bands from 25 Hz to 160 Hz.

Note: The calculations of the sound power level are based on the assumption, that the exhaust of the funnel outlet is the main noise source of the ship. If the acoustic centre of the ship is different (due to other dominant noise sources on board, e.g. the engine room ventilation), the distance term \( d_{c,k} \) needs to be adjusted to be the distance between the respect measurement position and the actual centre of noise of the ship.
7 DOCUMENTATION OF RESULTS

The report is to be written in .docx and .pdf format and need to be send to the members of the central project team of NEPTUNES.
Furthermore, the results need to be filled in the Excel-spreadsheet which also needs to be sent to the members of the central project team of NEPTUNES. The Excel-spreadsheet can be downloaded from the NEPTUNES homepage. All measured data (raw time data); evaluated data and sound propagation models must be kept available for further assessments and will be made available to the project board of NEPTUNES on request.

In the following sections, the contents of the report will be described in detail. All contents shall be stated as far as the information is accessible. If some data is not available, this shall be marked with “N/A” in the report.

7.1 Formal details in the report

Front page
The front page is to contain at least the following information:
- Ship type and name of ship including registration number
- Company name (performing the measurements)
- Address of the company
- Report date
- Date of the measurements
- Position of the measurements (name of the port and berth)
- Names of the persons involved (author(s) and measurement personal)
- Information on the report’s total number of pages, including appendices
- (optional) quality procedure items

Constant information on the following pages
All pages following the front page must contain the following information:
- Company name
- Date
- Numbering

Signatures
Generally, the report is to be signed by its author (optional: and the quality reviewer).

7.2 Content to be documented in the report

General information
a) Day, time and place (port name and berth name) of the measurements;
b) Meteorological conditions during measurements (including wind speed, wind direction, temperature, barometric pressure, humidity). This information shall preferably be requested from the ship owners/crew (measurement data from the ship itself);

general information on the ship
c) Ship type
d) Name of ship including IMO registration number
e) Year of built of the ship
f) Dead weight tonnage
gh) Length and width of the ship
h) (Simplified) sketch of the ship’s contour, indicating relevant sound sources, the position of the funnel outlet(s), bow and stern of the ship;

technical information on the ship
i) Number of auxiliary engines (including number and type of different auxiliary engine systems; number of funnel outlets)
j) The existence of a silencer in the exhaust system of the auxiliary engines
k) Maximum possible load of each auxiliary engine in kW
l) Rotational speed of the auxiliary engine(s) in maximum possible load
m) Maximum combined electric load of all pumps/heaters/ lights etc. installed that could be used while moored in kW
n) Number of each sound source on board (e.g. number of openings from the different ventilation inlets and outlets, number of cooling containers/reefers on board)
o) Total container capacity in TEU
p) Maximum possible number of plugged in reefers
q) Typical average number of reefers at berth
r) Maximum combined electric load of all pumps/heaters/ lights/reefers etc. installed that could be used while moored
s Average electric load that normally occurs while moored

General information on the measurements
t Number of each sound source on board that was in operation during the measurements
u Electrical load of each auxiliary engine during the measurements, preferably documented over time.
v Number of plugged in reefers during the measurements
w Sketch of the measurement positions at a certain distance from the ship with respect to the ship contour and orientation of the ship (bow and stern), including the position of the funnel outlet
x Height of the funnel above quay ground
y Height of the microphone at the measurement positions at a certain distance from the ship above quay ground (hm)
z Soil texture (especially percentage of absorbing and reflecting ground) between ship and measurement positions at a certain distance
aa If different from the instructions given in 6.3.2, sketch of the alternatively chosen measuring surfaces for the sound emission measurements on board including the surface area in m² for each sound source
bb If possible, a picture of each measured sound source
cc If possible, a picture of each measurement position for the measurements at a certain distance from the ship
dd Further deviations from the measuring instructions
ee Short explanation of unexpected observations (e.g. rattling sounds, pronounced tones etc.).
ff Short explanation about the presence of high sound emissions that are radiated from the ship’s hull (e.g. pumps under deck)

Acoustic information
gg Acoustic measuring equipment used during the measurements (including type, serial numbers and documentation of calibration before and after measurements)
ff All recorded time signals (.wav files) shall be sent to the central project team upon request. The title of the .wav files shall be named so that it can easily be linked to the respective measurements stated in the report. This includes e.g. the ship name, the date of measurements and the measurement position. The time signals shall at least have a sampling rate of 16 bit and a sampling frequency of 24 kHz.

ii For each measured sound source (i, j), (sound emission measurements on board of the ship, see section 0):

\[ L_{A_{eq}} \] equivalent A-weighted continuous sound pressure level
\[ L_{A_{max}} \] maximum sound pressure level during the measurement interval
\[ L_{A_{corr}} \] calculated (corrected) A-weighted sound power level; each correction needs to be documented, including the chosen correction factor K

Note: All data shall be recorded as 1/3 octave band levels from at least 25 Hz to 10 kHz (if possible from 10 Hz to 10 kHz) and broadband level including those 1/3 octave bands; the \( L_{A_{max}} \) only needs to be recorded as total level.

IV Type (and recorded level) of background noise/residual noise disturbing the measurements.

jj For each measurement position at a certain distance from the ship and each measurement position (k), (complementary measurements at a certain distance, see section 6.4.4

\[ L_{A_{eq}} \] equivalent A-weighted continuous sound pressure level
\[ L_{C_{eq}} \] equivalent C-weighted continuous sound pressure level
\[ L_{A_{95}} \] 95 % percentile sound pressure level
\[ L_{A_{10}} \] 10 % percentile sound pressure level
\[ L_{A_{max}} \] maximum sound pressure level during the measurement interval

Note: All data shall be recorded as 1/3 octave band levels from at least 25 Hz to 10 kHz (if possible from 10 Hz to 10 kHz) and broadband level including those 1/3 octave bands; the \( L_{A_{max}} \) only needs to be recorded as total level. The measurement time needs to be documented.
VI Type (and recorded level) of residual noise/background noise (e.g. what kind of sources causing residual noise were present during measurements and at which time; for example passing ships and air planes, port noise etc.).

kk The total broadband sound power level LWA,total of the ship (including all 1/3 octave frequency bands from 25 Hz to 10 kHz).

LL The low frequent sound power level LWA,total,≤160Hz of the ship (including all 1/3 octave frequency bands from 25 Hz to 160 Hz).

Additional information
Additionally, each deviation from the measurement instruction needs to be documented; if possible, including sketches.
Any comment and information that is relevant for adapting the outcome of the measurement protocol or for its reproducibility shall be documented at the end of the report. This includes any difficulties occurring during the measurements and that is of relevance for the report.
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APPENDIX

Exemplary calculation of the measurement position MP 1

In the following the horizontal distance \( d_h \) from the funnel outlet to the measurement position MP 1 is calculated for an exemplary measurement setup.

The height of the funnel will most likely be taken from ship drawings. In the following the height is assumed to be \( h_c = 66 \) m above quay ground. The microphone height will be chosen with \( h_m = 6 \) m above quay ground. The horizontal distance \( d_h \) will then be calculated by the angular function

\[
d_h = \frac{h_c - h_m}{\tan(\alpha)} \text{ in dB (11)}
\]

For the given condition \( 5^\circ \leq \alpha \leq 20^\circ \) this will result in a rounded distance of \( 165 \text{ m} \leq d_h \leq 690 \text{ m} \).

Note: The horizontal distance \( d_h \) is not similar to the horizontal distance to the ship contour. For the height of the funnel outlet \( h_c \) the distance from the quay ground is important. The distance from the ship keel to the quay therefore needs to be taken into account when taking the height \( h_c \) from ship drawings.
ANNEX III
GENERAL EXPLANATION ABOUT NOISE
Neptunes

Chapter 1
Introduction

Annex III
General explanation about noise
Noise is defined as unwanted sound at some place and at some time not fitting in a contextual environment. The indicator for sound is the decibel, abbreviated as dB. The genesis of sound is a vibration of an air particle that moves from a state of equilibrium (atmospheric pressure). This movement is due to a force which could have a mechanical, aerodynamic, thermal or hydro-dynamic nature (excitation). Due to the movement and the speed of that displacement a small pressure alteration originates. This can be measured in Pascal (Pa). The lowest number of Pascal our human ear can detect is $2 \times 10^{-5}$ Pa, called the hearing threshold. The highest pressure a human ear can withstand is $200$ Pa. At this pressure, instant hearing damage occurs. This means that the range of Pa an average human ear can observe is $107$ which is quite a huge range. Therefore, the decibel (dB) scale was introduced. This decibel scale is a logarithmic scale which compresses the $10^7$ range from 0 to $140$ dB. $0$ dB is equal to $2 \times 10^{-5}$ Pa, and $140$ dB is equal to $200$ Pa. The exponential scale is applicable to all human senses. The decibel scale represents the ‘loudness’ of the noise and is the most used characteristic in the field of the environmental noise domain. Beside the decibel, indicator for the strength of noise, there is the frequency. The frequency is the property that defines the pitch of the noise.

A young human ear can observe frequencies in the range of $20$Hz - $20$KHz. During the lifetime, this range declines. Most of the noise such as traffic-, railway and industrial noise exist from multiple frequencies; it is called random noise. Sometimes one or more frequencies are dominating in the random (broadband) noise. This implies that the noise contains one or more tonal components which are experienced as extra annoying. The human ear does not perceive a certain sound level (amount of dB’s) per frequency as equally loud. Therefore, the so-called A-weighting was introduced. Low frequencies are perceived as less noisy as middle frequencies and high frequencies, see figure beside.

An exemption is a low-frequency noise which can be very annoying and also sick making. To identify low-frequency noise by means of noise measurements, it is recommended to also use the C-filter. The C-filter does not filter out as much of the lows as the A-filter and approximates the ear at very high sound levels. By comparing the noise data measured by means of the A-filter and the C-filter, it can be observed whether a lot of low-frequency noise is included in the signal. Other filters are also available, however hardly used. In order to manage the frequencies, the octave band and third-octave band have been introduced. According to an exponential scale, the width of the frequency bands (octave bands) is defined. The octave bands are $16-31.5-63-125-250-500-1,000-2,000-4,000$, etc.) and are expressed in Hertz (Hz). Most sound level meters and sound analysers have filters that weight the noise with the so-called
A and C-filter, and have filters that determine the sound energy in the octave and/or one-third octave bands.

Legislation on ambient noise often uses the dB(A) as a quantity, which means that the noise should be measured using the A-filter. When observing sound in function of time, it appears that sound often does alter in time. Sometimes noise level displacements (amplitude) are small, sometimes large. When the alteration is repetitive, the sound is defined as intermittent (such as hammering). When the displacement is a bit (within 5-6 dB), then it is called continuous sound. When sound levels alter very steep (gunshot), noise is defined as impulsive noise. Sound propagates through air. The propagation through air depends on the frequency. Low frequencies propagate better than high frequencies. This is due to the air absorption, shielding and ground absorption. This means that at large distance from a source (industry, high way) the lower frequencies are dominant. This is also with insulation; high frequencies can be insulated better than low frequencies.

Sound often propagates in a spherical or hemispherical way, which means that the sound energy emitted, spreads over the surface of the sphere or hemisphere. This implies that by doubling the distance, a 6 dB reduction occurs. Example: when a noise source produces a noise level of 60 dB(A) at 100m, then at 200m the noise level amounts at least 54 dB(A).

Noise propagation depends on the temperature of the air, the higher the temperature, the higher the sound velocity. As the temperature in ambient air increases or decreases with height (stratification), it implies that the noise wave bends, depending on the gradient the noise bends towards the surface or upwards the surface. Also, the wind gradient (downwind or upwind) plays an important role in sound propagation. This is something to take into account when installing noise barriers. The noise could bend over the noise barrier! See also figure above.

The sound source is called the sound power of a source and is based on (acoustic) energy instead of pressure. Be aware, both use the same unit: dB(A)! Sound power levels can be derived from sound pressure levels. Typical sound power levels are stated in the table.
As the noise level fluctuates every second, it is hard to justify the noise. Therefore, long term averages have been defined such as $L_{Aeq(T)}$, $L_{day}$, $L_{evening}$, $L_{night}$ and $L_{DEN}$ where $T$ is a defined period of seconds, minutes or hours. Day, evening and night are often defined in legislation and can differ per country. In order to judge short-time noise, the LAMAX was introduced. LAMAX is defined as the value of the instantaneous noise such as noise from peaks or other events. Besides the levels and the pitch (frequencies) of sound, it is also possible to judge noise as function of time. As already mentioned, noise levels can differ per second. Depending on the amplitude of the noise it can be characterised as continuous when the deviation is not more than 6 dB and when more and capricious as alternating noise (like transportation noise). When noise is containing (audible) tonal components, it is defined as tonal, and if noise levels are rising very fast and steep, it is defined as impulsive noise.

When noise has a lot of audible or perceivable low-frequencies (plus minus from 20 to 125 Hz), it is called low-frequency noise. Noise with a lot of energy in low-frequencies is hard to combat by means of insulation. By roof and façade insulation the overall noise levels drop, but the remaining noise in the building comprises relatively more noise with low frequencies.

Indicators that give some insight into the dynamics of the noise levels are the $L_{95}$, $L_{50}$, $L_{10}$, $L_{5}$, $L_1$ values belonging to a certain noise signal. These statistical values are called the Ln concept. It means that a certain noise level observed is n% of the time present or exceeded. $L_{95}$ means that the noise was present or exceeded during 95% of the time observed (measured). $L_1$ means 1% of the time present or exceeded. One should be aware that these values are not noise levels!

The last indicator to explain is the SEL or Sound Exposure Level. SEL is the constant sound level that has the same amount of energy in one second as the original noise event. A-weighted sound exposure levels are denoted by the symbol $L_{AE}$.

The Environmental Noise Directive (END) has defined four categories of noise that should be mapped: industrial noise, noise from major railways, noise from major roads and noise from major airports. Major roads are roads with a traffic flow of 3 million vehicle movements annually, major railways are railways that have more than 30,000 train passages annually, and major airports are civil airports with more than 50,000 movements per year.

Note:
Due to the logarithmic scale of the decibel one should be aware that two sources producing the same noise levels at a certain distance, together produce a noise level which is three decibel higher. For example, two noise levels of 52 dB(A) result in a noise level of 55 dB(A) and not in 104 dB(A)!

<table>
<thead>
<tr>
<th>Source description</th>
<th>Sound power dB(A0))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reefer</td>
<td>90 - 94</td>
</tr>
<tr>
<td>Container ship</td>
<td>100 - 115</td>
</tr>
<tr>
<td>Placing container</td>
<td>115 - 135</td>
</tr>
<tr>
<td>Truck driving slowly</td>
<td>103 - 105</td>
</tr>
<tr>
<td>RoRo ship</td>
<td>100 - 114</td>
</tr>
</tbody>
</table>
Colophon

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