ANIMA

Aviation Noise Impact Management through Novel Approaches

D2.8 – Critical review of policy and practice in other noise-affected sectors

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1 Use one of the following codes: R=Document, report (excluding the periodic and final reports)
DEM=Demonstrator, pilot, prototype, plan designs
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Executive Summary

Noise affecting citizens and communities is a growing problem that goes beyond the Aviation sector in many cases. Recent figures provided by the European Commission, actually highlight that almost 80 million people are estimated to be exposed to road noise ≥55 dB, followed by over 10 million exposed to rail noise. Hence, the importance of this analysis and report with a key focus on the noise related to non-aviation sectors affecting local communities.

The partners involved in conducting the research associated to this task (ST2.3.4) have decided that the study will focus on the following key specific non-aviation sectors:

- Transport, mainly roads and railways;
- Construction;
- Industry, mainly wind turbines/farms); and
- Domestic and leisure activities.

For each sector, the noise characteristics have been introduced, providing the reader with an overview of the different kind of noise sources, explaining briefly how they may affect the population and generate annoyance. Also, for each sector, a comparative analysis of similarities and differences between this sector and the aviation noise has been provided.

Following the description of work stated in the Grant Agreement, the report has focussed on the *means and tools* for *measuring, modelling and communicating* noise exposure in the different sectors, dedicating specific chapters for each of the above elements. Then, a review of the relevance of experience in other transport and industrial sectors affected by noise impact has been carried out, which has provided extra insight in related noise mitigation and reduction strategies.

10 case-studies across the *other sector* noise spectrum have been analysed in depth, and key messages and lessons learnt have been extracted and discussed in a dedicated section. The variety of case studies has covered a global range, from Europe, as well as internationally, since the idea was to obtain the best noise mitigation and reduction strategies, approaches or tools.

Due to the different nature of the noise sources and their characteristics, in some cases the focus has been placed on the communication and engagement process, to guarantee some sort of transferability, in other cases (e.g. the Hong-Kong case study) mitigation measures at receptors have been considered, due to the higher transferability to the aviation sector.

The wind turbine case studies provide inspiration for a novel approach to fairly share benefits with those affected by noise. Via local funds, energy discounts and community run energy co-operations, the local community can directly benefit

from the wind turbines that are created in their area. The authors suggestion is to encourage ANIMA partners to investigate the transferability of this concept to the aviation sector, considering the growth in complaints around European airports. Further suggested research is presented in the Conclusion chapter.

Introduction

Community noise is a growing problem in our fast-paced and increasingly congested world. Noise sources, especially in urban areas, are closer than ever to residential areas and other sensitive land uses. Excessive amounts of noise can cause significant annoyance and disturbance to people's daily lives.

The following document discusses non-aviation sources of noise. It considers the noise in non-aviation sectors, exploring noise monitoring and modelling techniques, how noise may impact on communities living near to sources of (non-aviation) noise and how impacts/noise exposure is communicated to those communities.

Noise mitigation and reduction strategies are also discussed with specific reference to case study examples and other relevant literature/research. Key messages from this study are also presented and discussed, along with suggested noise mitigation/reduction strategies that may be transferable to the aviation sector.

The key (non-aviation) sectors affecting local communities, and which have been discussed at consortium level and agreed at the beginning of this study, are:

- Transport (specifically roads and railways);
- Construction;
- Industry (specifically wind turbines/farms); and
- Domestic and leisure activities.

Other than aviation, these are considered to be the main sources of noise that impact on communities across Europe (and the rest of the developed world). By way of example, Figure 1 shows for the 33 member countries of the European Environment Agency (EEA-33) the estimated number of people exposed to average noise levels => 55 dB (expressed as the Lden[3]). Those numbers are based on the most recent country submissions and redeliveries of the 2017 round of noise reporting.

Both inside and outside of urban areas, roads are the dominant source of noise affecting communities, followed by railways and, to a much lesser extent, airports and industry. In the urban environment, almost 80 million people in the EEA-33 are estimated to be exposed to road noise ≥55 dB (Lden).

[3]Lden (day-evening-night) noise level. It is a descriptor of noise level based on energy equivalent noise level (Leq) over a whole day with a penalty of 10 dB(A) for night time noise (22.00-7.00) and an additional penalty of 5 dB(A) for evening noise (i.e. 19.00-23.00).

Domestic and leisure sources of noise have also been included in this study as their presence can affect the sensitivity and perception of other noise sources, but also under certain circumstances, domestic and leisure noise can dominate noise from the other outdoor sources (Transport, Industry or Construction activities).

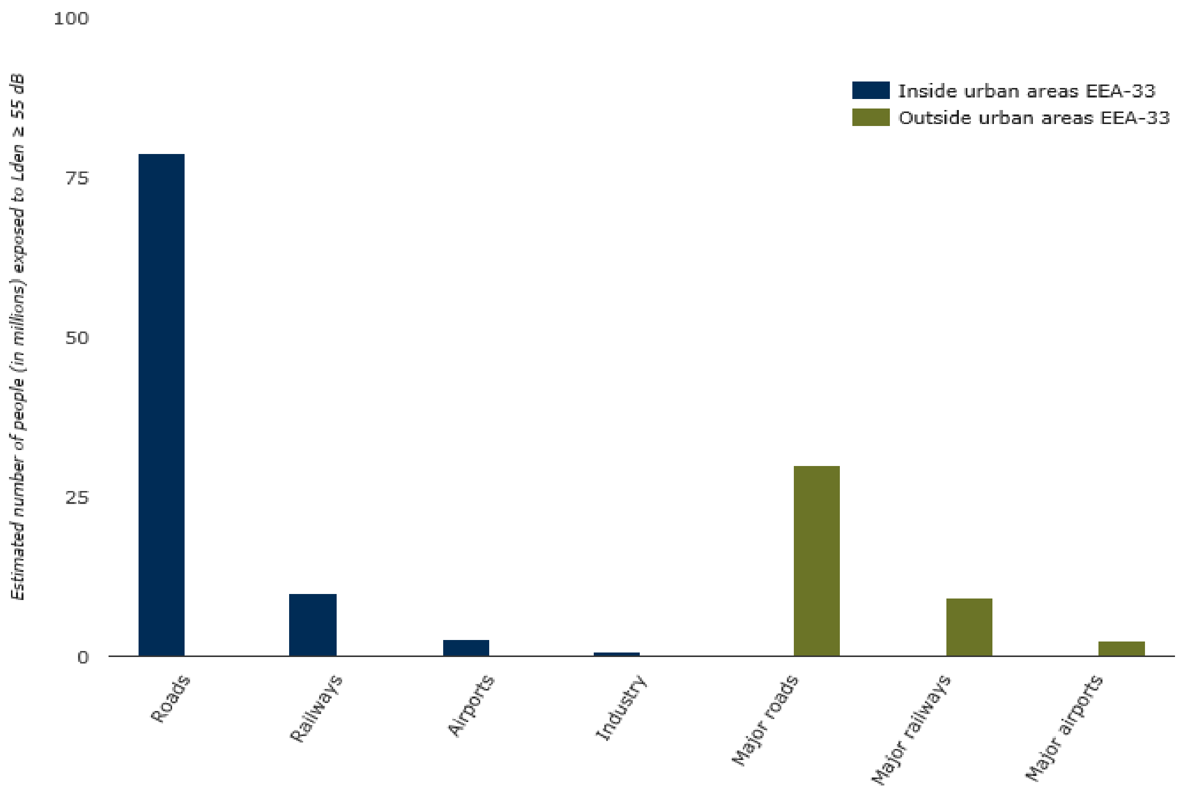

Figure 1: EEA-33 — Number of people exposed to average day-evening-night noise levels (Lden) ≥ 55 dB

(Source: https://www.eea.europa.eu/data-and-maps/indicators/exposure-to-and-annoyance-by-2/assessment-3)

Interestingly, when comparing major infrastructure with overall sector, major railways account for 93% of the population exposed to Lden≥ 55dB. This is similar to the case of major airports which account for 78% of the population assessed to be exposed for the all Airport sector. Finally, for roads only 38% of the population is exposed to Lden≥ 55dB when considering major roads only, this is expected since the major roads network traditionally represents a small percentage of the total road network and are situated mainly outside urban areas and urban roads account for the majority of the residential population exposed.

However, when we focus on the annoyance, although fewer people are exposed to air traffic noise than that from road or rail as indicated in the above Figure 1, it is reported to cause greater annoyance (Guarinoni et al., 2012; ISO, 2016; Münzel et al., 2014).

In Figure 2 below, the curves were derived for adults on the basis of surveys (26 for aircraft noise, 19 for road noise, and 8 for railways noise) distributed over 11 countries (EC, 2017).

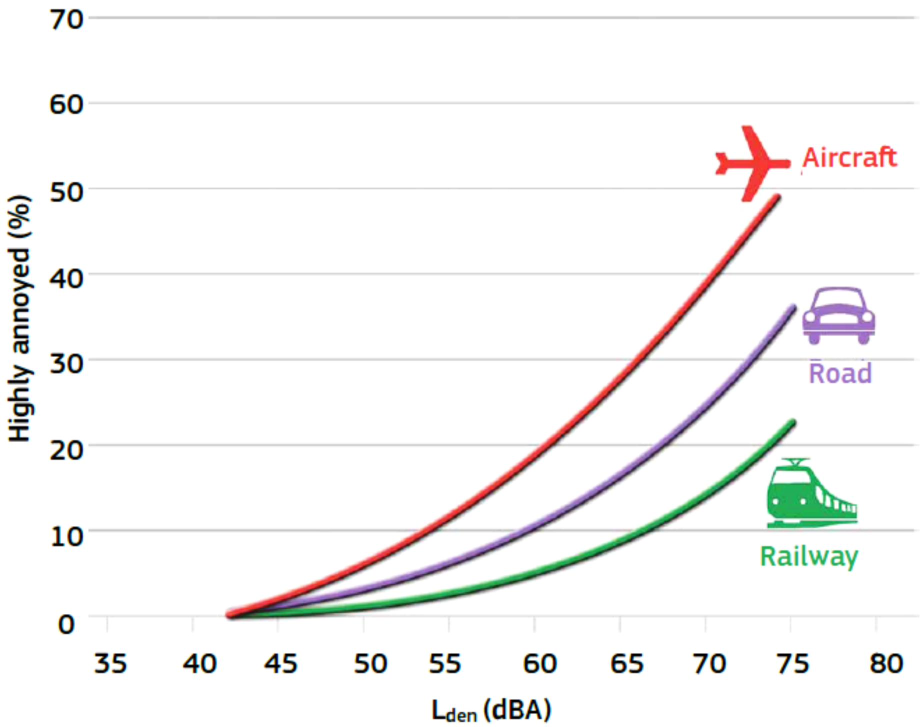

Figure 2: Percentage of people highly annoyed by aircraft, road and rail noise. (Source: adapted from Münzel et al., 2014)

Based on EU Information produced in 2002 in relation to the transportation noise (aircraft, rail and road) adding results of a Dutch study on industry noise, and wind turbine, the results are presented in the following Figure 3.

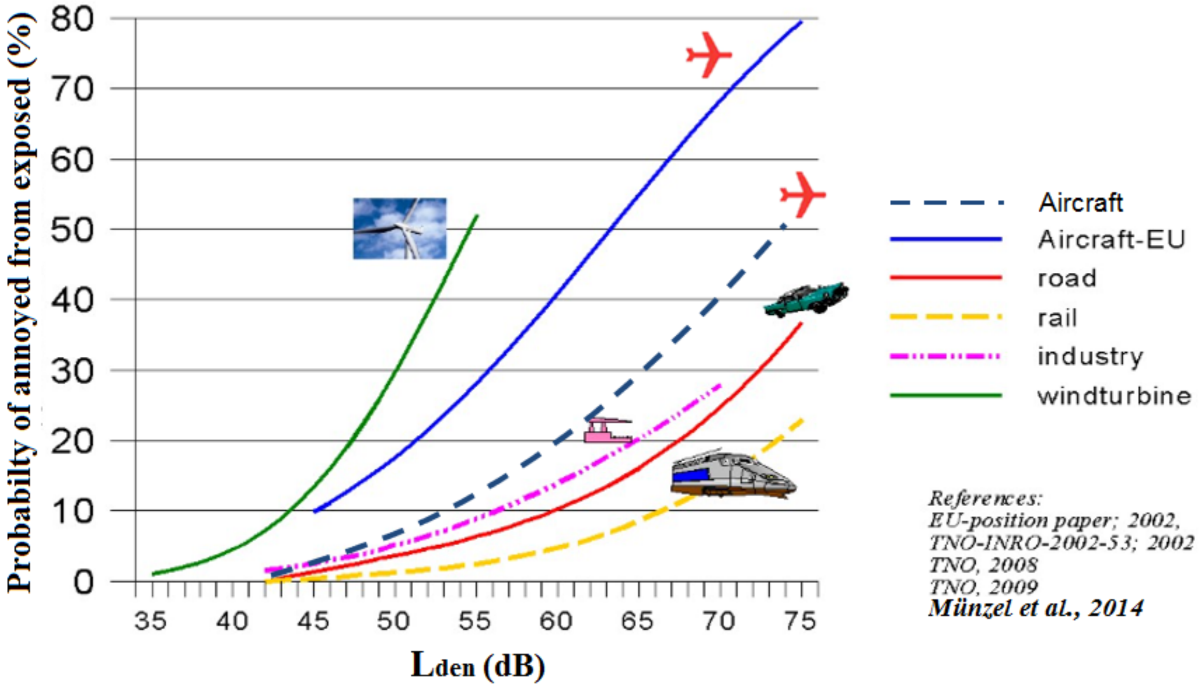

Figure 3: Percentage of people highly annoyed within the exposed group across different sectors, aircraft, road, rail, industry and wind turbine noise. (Source: http://rigolett.home.xs4all.nl/ENGELS/)

1 Methodology

In order to achieve the objective of this report, which focuses on noise mitigation and reduction strategies best practices related to non-aviation sources, three main steps have been followed.

The first was to explore and review what characterises and defines the most important non-aviation sectors, affecting local communities.

Then a review of the different noise monitoring and modelling techniques across the different non-aviation sectors has been carried out to understand if commonalities between different sectors exist and how that can help in defining the mitigation and reduction strategies.

Finally, following the successful example of the approach adopted in ST2.3.1, a number of case studies have been presented and where possible an interview protocol implemented to gather key and detailed information about the mitigation and reduction strategies, as well as the role of community engagement in each case study and how that has played a role in the success of the strategy implementation.

As a result of the different case study analyses, key messages and transferability to the Aviation sector and other work packages in ANIMA has been considered and presented in a separate section of this report.

Since ANIMA is a Research and Innovation project, a dedicated section has been included in the conclusions, focussing on future steps and gaps that have been identified in order to suggest and propose new research activities and the main focus for future research.

2 Noise characteristics for other Sectors

2.1 Transportation - Road

Road traffic noise is caused by vehicle engines, tyre-road interactions, and interactions between the vehicle and surrounding air as the vehicle is in motion. Large, heavy vehicles (e.g. Heavy Goods Vehicles, HGVs) travelling at speed are often the dominant source of road noise. Traffic flow (volume of traffic) and composition (proportions of HGVs and Light Goods Vehicles, LGVs), vehicle speeds, driving/driver behaviour and road surface composition and integrity are all factors determining the level of noise emitted from roads.

According to the European Environment Agency, when considering both inside and outside urban areas, approximately 120 million people in the EU (more than 30% of the population) are exposed to road traffic noise levels greater than 55 dB (Lden), with more than 50 million people exposed to levels above 65 dB (Lden). This can be compared with the aviation sector, where it estimated that approximately 10% of the EU population may be 'highly annoyed' by air transportation noise.

Road traffic noise is a widespread environmental nuisance which affects people in their residential dwellings and workplaces. It interferes with human ability to function optimally in daily life and is rated as the most important source of community noise. Noise affects people physiologically and psychologically: noise levels above 40 dB LAeq can influence well-being, with most people being moderately annoyed at 50 dB LAeq and seriously annoyed at 55 dB LAeq. Levels above 65 dB LAeq are detrimental to health.

Since this report focuses on the opportunity to learn from the experience of noise reduction from other sectors, below is reported an indicative list of elements of similarity and difference between the road and aviation sectors.

Similarities

- Transportation-derived noise
- Local impact
- Emotive subject
- Policies dominated by average noise (Lden, Lnight)
- Discrete events also important (night-time operations, secondary roads)

Differences

- Little community engagement
- Fewer protests
- Complaints towards State
- Multiple sources (tyres, engines)
- More constant noise (daytime, main roads)
- Community can have stake in noise source

Transferability:
Traditionally road noise characteristics are very different in relation to the aviation sector, as the basic noise characteristics are different and road noise propagates along a much shorter path and for high speed road the main noise component is rolling resistance. However, for specific circumstances, such as night traffic and low volume traffic in rural areas, the frequency of events can be considered similar to those of the aviation sector. Despite noise at night similarity the most common mitigation strategies for road (sound barriers and absorbent asphalt) are not easily transferable to the aviation noise. Instead, mitigation strategies implemented at the receptor may be transferred, as it is the case for insulation and community engagement, although specific examples of initiatives of community engagement for road noise are rare compared to the aviation sector.

2.2 Transportation - Rail

Rail transportation noise shares many of its characteristics with road traffic noise. However, all types of trains are large, heavy vehicles, that may not always travel at high speeds, i.e. a long transport train that mostly travels at 30 or 50 km/h, but due to their size and weight always produce a significant amount of noise and vibration in their environment. The most important noise sources of rail vehicles are rolling noise from the wheels on the tracks created by rough surfaces (De Vos, 2016).

Although trains can produce significant levels of noise, railway noise tends to affect less people than roads, and its impacts are mostly restricted to those individuals living very close to railway tracks and/or stations (this is especially true in large urban areas with multiple stations and rail routes). The level of noise from railways is determined by the types of train engine being used (e.g. diesel or electric), train speed and size (engine size and load/number of carriages) and the type of track and its condition. Effective maintenance of the rail infrastructure (e.g. tracks and points) is important in reducing noise emissions from railways.

Due to overall economic growth and an increase of business in the import and export branches, railway noise is expected to affect more people in the future. As traffic on existing railways increases, they will have to be more closely maintained and more railways will have to be built to meet the requirements of industry and trade.

Trains are publicly perceived as more environmentally friendly and beneficial than planes which results in a better general attitude towards them. Which may lead to the finding that train noises are perceived as 5-10 dB less than those generated by other noise sources overall, but especially less annoying at high speeds (Fields and Walker, 1982, p.191). The case for wind turbines (very environmental friendly) however can be considered an opposite extreme than the rail, as evidence and research (Figure 3) show people are more annoyed at low noise levels. Probably the main tangible advantage with wind turbines is mainly for the land owners and not the people living around. This would indicate that the beneficial reason is dominant here. In rail sector in contrast to the other noise source- except for construction noises- vibration is a crucial component of railway noise annoyance ratings. Fields and Walker (1982) estimate that due to rail tracks leading through all parts of a country and all major cities, half of all residences in a country may be affected by railway noise. Trains therefore are estimated the second biggest noise source to affect people (refer to Figure 1). In their 2018 Environmental Noise Guidelines Report the WHO recommends to set limits for railway noise during the day at 54dB $L_{den}$and 44dB L_{night}.

As done in the roads sector, below is reported an indicative list of elements of similarity and difference between the rail and the aviation noise.

<u>Similarities</u>

- Transportation noise
- Discrete events
- Predictable
- Sector expected to cause more future disturbances due to economic growth

<u>Differences</u>

- Little community engagement
- Few complaints
- Perceived as beneficial, accessible
- Complaints toward State
- Blame with operator
- Impact across large area
- Phase of technological development
- More constant noise event
- Vibrations more relevant with rail
- Opinion on environmental friendliness of transportation means
- High pitched, sudden wheel and brake squealing noise

<u>Transferability</u>:
The most important similarities of railway noise in relation to the aviation sector are to be found in the predictability and the steady growth of the sector. Accordingly, the railway and the aviation sectors have to find noise mitigation strategies and interventions that will be effective while traffic increases in the near future.
However, the basic noise characteristics are different. Railway noise propagates along a much smaller path and the most common mitigation strategy (sound barriers) is not effective for aviation noise. Also, due to the public perception of

trains to be ecologically friendly and publicly beneficial, railway noise faces a lot less community engagement than the aviation branch.

2.3 Wind turbines

Wind energy is a key component in the energy transfer from fossil fuels to renewable, sustainable energy. In order to reach climate goals for 2020, 2030 and 2050, large scale developments of on- and off-shore wind parks are planned throughout Europe. In 2018, 95% of all new power installations in the European Union were for generation of renewable energy (19.8 GW), 48% of which was wind energy (11.7 GW). Germany is the largest installer of wind energy, followed by Spain, the UK and France. Denmark has the largest relative share of wind energy (Komusanac, Fraile & Brindley, 2019).

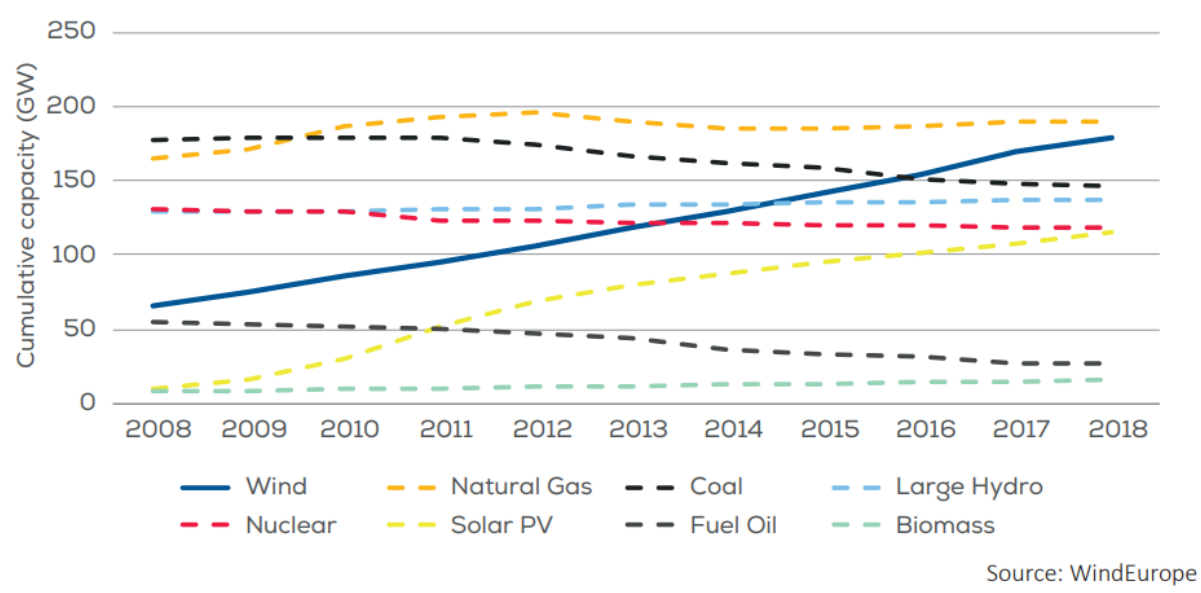

Figure 4: Total power generation capacity in the European Union (2008-18)

Currently, wind energy accounts for 9.7% of all generated electricity in the EU (EUROSTAT, 2018).

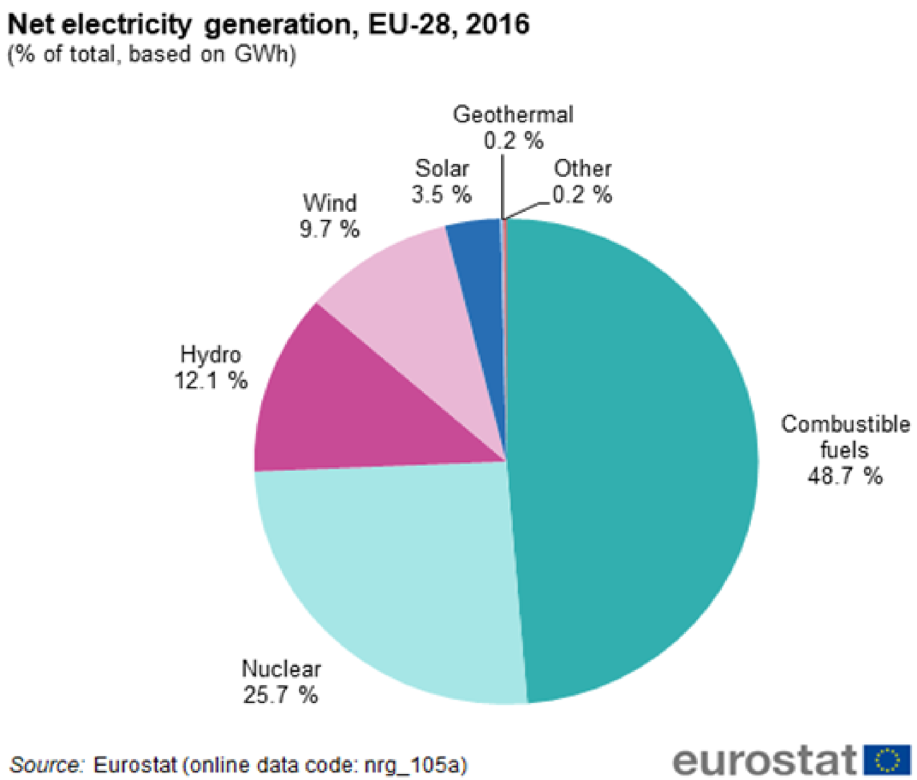

Figure 4: Electricity generation in 2016 in the European Union (EUROSTAT, 2018)

Wind turbine noise is directly linked to the production of power and therefore its generation is, to some extent, inevitable. Complex air flow phenomena occur around the blades of a wind turbine, resulting in low frequency noise, inflow turbulence noise and airfoil self-noise. In addition to aerodynamic noise, mechanical noise from wind turbines due to the motion of various mechanical parts and their dynamic response may also be important. There is research that indicates that wind farm noise can be more disturbing than 'ordinary' industrial or transportation noise (DEFRA, 2011).

When considering a large, modern wind turbine with an upwind rotor, the noise sources can be split into mechanical noise coming from the gearbox or the generator and aerodynamic noise.

These sources generate four types of sound: tonal, broadband, low frequency/infrasound, and impulsive (Tonin, 2012):

- The *tonal sound* is defined as sound at discrete frequencies. It is caused by components such as meshing gears and other, non-aerodynamic structural vibrations. Tonal sound is not usually a problem in modern turbines as evidenced by examination of numerous test certification documents from manufacturers such as Vestas, RE Power and GE.
- *Broadband sound* is characterized by a continuous distribution of sound pressure with frequencies greater than 100 Hz. It is caused by the interaction

of boundary layer turbulence with the trailing edge of the turbine blades and is also described as a characteristic "swishing" or "whooshing" sound.

- *Low frequency sound* contains frequencies in the range 20 to 100 Hz and is mostly associated with downwind rotors (turbines with the rotor on the downwind side of the tower which are no longer common). Infrasound is sound with frequencies below 20Hz and is generated by air turbulence impinging on the blade leading edge
- *Impulsive sound* is described as regular short acoustic impulses or a "thumping" sound occurring at the blade passing frequency (typically around 1 Hz). It is caused by the interaction of wind turbine blades with disturbed air flow around the tower of a downwind machine, which is no longer common.

The dominant noise source is typically the broadband aerodynamic noise from the outer part of the blades' trailing edge. This exhibits a clear swishing character that is highly directional, amplitude changes of up to 5 dB can be expected even at large distances (Oerlemans, 2011).

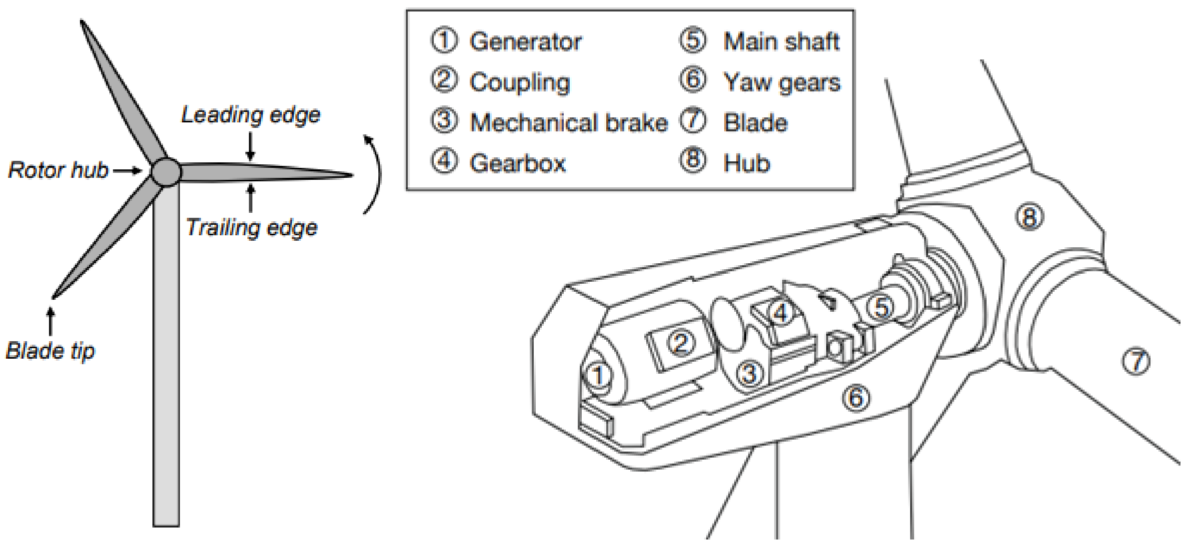

Figure 5: Wind turbine as seen from a downwind position (left – Oerlemans, 2011)**; Typical construction of a wind turbine nacelle and arrangement of blades** (right – Tonin, 2012)

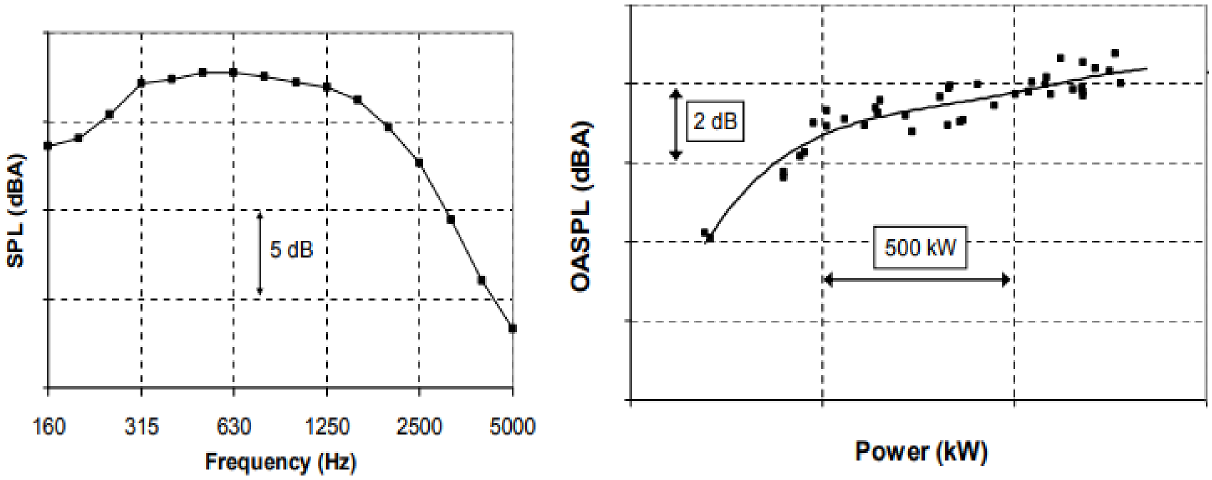

Figure 6: Wind turbine noise spectrum (left); Wind speed dependence of turbine noise, measured values and trend line (right)

Below is reported an indicative list of elements of similarity and difference between the Industrial: Wind Turbine and the aviation noise.

Similarities

- Predominantly aerodynamic noise
- Established community engagement process
- Vocal and organized opposition
- Uncertainty about future noise impact
- Emotional debate
- Local impact
- Governed by average noise loads (L_{DEN})
- Night time disturbance is relevant

Differences

- (semi-) constant noise source
- Difference in annoyance with respect to sound character
- Strong visual component (in addition to noise)
- Public is generally favourable towards wind energy, yet against nearby wind turbines (Not In My Back Yard, NIMBY)
- Community can have stake in noise source

Transferability:
The most important similarities of Industrial: Wind Turbine noise in relation to the aviation sector are the aerodynamic noise sources and the well organised opposition. The aviation sector can take note of how some wind energy projects involve the local community and let them profit from 'their' wind turbines.

2.4 Construction

Construction sites can generate significant, but often relatively short-term, levels of noise that can disturb residents in their homes and other noise sensitive receptors (e.g. office workers). Construction works include the demolition, alteration, maintenance, repair, erection and construction of buildings, roads or other transport infrastructure. Construction sites are inherently noisy, and often involve unavoidable activities such as piling, demolition and the use of pneumatic equipment, all of which can lead to excessive levels of noise on site. A balancing act between the needs of the developer to carry out necessary works and the rights of neighbours to enjoy their properties (or place of work) is required.

Construction noise can be managed by using a combination of control measures at source (focussed on how construction equipment/plant is operated and maintained) and how the site is managed (such as the scheduling of activities and the delivery of materials, working hours and site layout). Specific control measures may be adopted for particularly noisy plant or operations such as piling and demolition works.

Below is reported an indicative list of elements of similarity and difference between the construction and aviation sectors.

Similarities

- Discrete events
- Community engagement process
- Local impact
- Emotional debate
- Governed by average noise (Lden)

Differences

- Shorter duration (known end)
- Non-transportation noise
- Strong visual component
- Complaints toward builder/contractor

Transferability:
The character and frequency of construction noise is different to that of aviation noise. Some construction activities, such as piling, can result in repetitive, impulsive noise. Other (more distributed) activities, such as saw-cutting or flattening, tend to result in more uniform noise emissions/levels. The transferability of noise mitigation measures from the construction sector to the aviation sector is therefore limited. However, methods of monitoring and communicating noise impacts in the construction sector may be applicable in the aviation sector.

In Figure 7 two different construction noise exposure-response relationships (from China and the UK) have been integrated and compared with a traffic noise exposure-response curve from Vietnam, China (Hanoi and Tianjin cities) and European average. Construction measurements were conducted in the Chinese city of Hangzhou and around the Midlands, Manchester and north-west of England respectively (Koziel et al., 2011), showing close alignment of the exposure-response relationships in shape and with a slight offset of 3-4 dB.

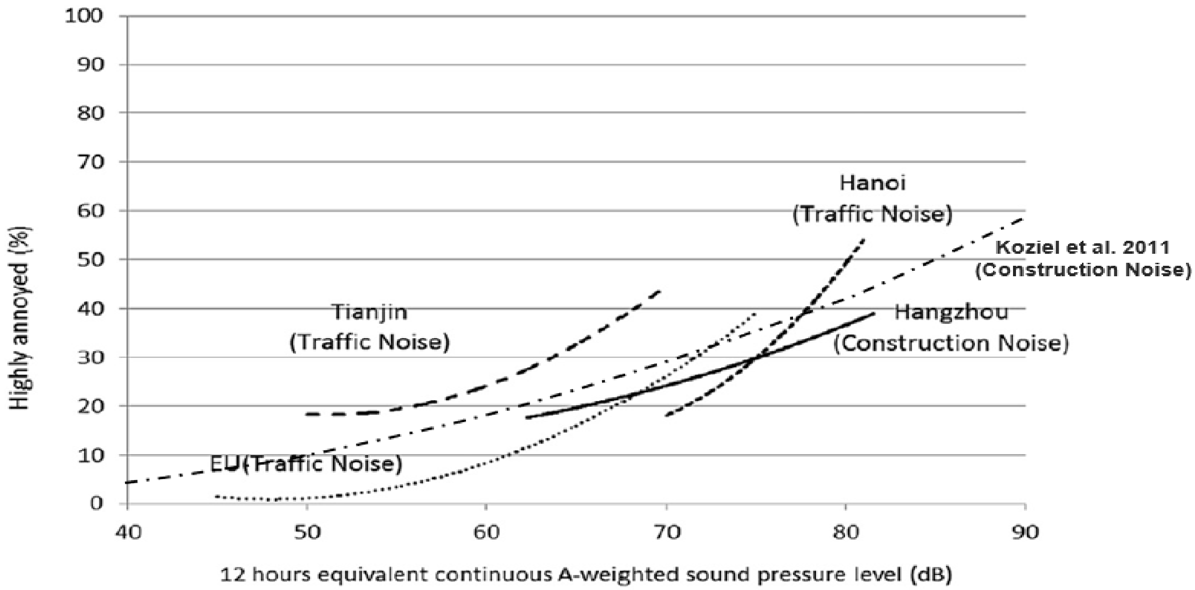

Figure 7: Exposure-response relationship for Traffic and Construction Noise (sources: Phan et al. 2010; Koziel et al. 2011)

2.5 Domestic and Leisure Activities

Domestic noise can be produced by mechanical devices such as heat pumps and ventilation systems or by activities performed by household members. Noise from household activities such as vacuuming, lawn mowing, barking dogs and listening to music can be disturbing to neighbours. Such activities are even more problematic in multifamily dwellings.

Leisure activities such as motor racing and water skiing can also produce disruptive noise. Often these activities are done in normally quiet areas, drastically increasing the 'baseline' acoustic environment, albeit for relatively short periods of time. These different sources of community noise all contribute to disturbance of community members and typically occur in people's homes, where they want to relax and recover from stress- or eventful days at work and hence increasing the potential of being perceived as annoying.

Domestic and leisure noise sources are particularly hard to come by in terms of noise regulation. Potentially, there are as many specific sources as there are inhabitants within a given area, and due to increasing population of cities and dwellings, those problems are becoming more urgent in areas that haven't had to deal with noise complaints in the past. In the 2018 noise guidelines the WHO recommends a yearly average of 70 dB $L_{Aeq,24h}$ of all combined sources not to be exceeded. Additionally, it is recommended to strictly reduce the number and time exposed to impulse noises to prevent hearing loss, a number in dB or a number of maximum events in a given time however is not provided.

Similarities:

- Occurs suddenly

Differences

- Noise is often generated by sources or individuals personally known to the receiver
- Noises often carry information (i.e. spoken word, music with lyrics etc.)
- Occurrence in closest spatial proximity to the receiver
- High potential to cause controversies in a community
- No community engagement
- Legal consequences can result immediately

Transferability:

Other than the sudden occurrence of many community noise events, that can equal a plane overflying a specific region there aren't many similarities to be found. Also, the differences are rather large. While noise around a community is produced by receiver-familiar sources, noise complaints are mostly done in person, from receiver to producer and therefore there is no proper complaint log. In cases where conflicts cannot be resolved, which is mostly relevant at night, legal steps can quickly be initiated which will stop ongoing noise immediately.

3 Monitoring

The direct measurement (or monitoring) of noise at (usually noise sensitive) locations is a key aspect of environmental noise assessment, and is usually the first step in establishing 'baseline' conditions before further detailed assessment/modelling of the potential noise impact of new infrastructure (e.g. wind turbine/farm) is undertaken.

Noise measurement/monitoring can also be used to assess, either in-situ or under controlled/research conditions, the efficacy of physical noise mitigation measures, such as acoustic balconies or barriers to protect residents from, for example, road and rail noise in built-up urban environments.

Noise measurement/monitoring is also often used to assess the impact of **construction** noise, and specifically to assess compliance with specified noise limits applicable at the site boundary or at noise sensitive receptors (e.g. residential dwellings) near the construction site. 'Live' measurement data feeds can be used by site operatives to modify or stop certain activities if noise limits are near to, or are, being breeched.

Noise measurement/monitoring can be used by relevant local authorities to investigate and help resolve noise complaints from individuals or communities affected by **domestic and leisure sources** (such as noisy residential dwellings, bars, restaurants, night clubs etc.).

Leisure noises are measured at different locations, which gives immediate noise control and gives a more realistic overview of noise propagation for single events. For example, at concerts or music intense events, there will be a measurement at close noise sensitive receivers (NSRs) like a dwelling, office building or hospital and one additional measurement inside the venues to prevent hearing loss. The advantage of this is that exceedances of the maximum levels can be prevented right away by the sound engineers.

However, there is an experimental approach to monitoring larger areas with an Internet-of-Things approach. As part of the Horizon 2020 program MONICA, it was tested to monitor the noise levels of parts of the city by building a network of low-cost smartphones equipped with an application ("OpeNoise") (Gallo et al., 2018).

First tests have shown that these solutions may be adequate for a long-term environmental noise assessment.

In terms of **railway** noise and its propagation throughout an area, many situational factors have to be taken into consideration. The most decisive levels of analysis for railway are:

- Kind of train
- Composition of the train (what locomotive is pulling what sort of wagons and how many wagons does it pull)

- Kind of wheels
- Physical condition of the tracks ("rail roughness")
- Kind and condition of the brakes
- Speed at what it travels at a given time and place
- Geographical composition of the area through which it travels

Given this variety of different requirements, railway noise is mostly calculated. This means, the relevant parameters are assessed and fed into a calculation program that is able to give an estimate about the sound propagation along a track. The EU (EC, 2014) has given out Limit pass by noises at 7.5 meters from the middle of the track and in 1.2 meters height for different rolling-stock-subsystems that are not be exceeded (see Table 1).

Table 1: Maximum noise levels for different railway components. APL = the number of axles divided by the length between the buffers (per m).

Limit values for pass by noise (dB)		
Category of rolling stock subsystem	**LpAeq,T[unit] at 80km/h**	**LpAeq,T[unit] at 250km/h**
Electric locomotives and OTMs with electric traction	84	99
Diesel locomotives and OTM's with diesel traction	85	n.a.
Electric Multiple Unit (EMUs)	80	95
Diesel Multiple Unit (DMUs)	81	96
Coaches	79	-
Wagons (normalised to APL = 0.225)	83	-

LpAeq,T[unit]: A-weighted equivalent continuous sound pressure level of the unit

Noise measurement/monitoring can be carried out using a range of different instruments depending on the time over which the measurements need to be made. If the measurements are to be made over a short period (such as boundary monitoring around a **construction** site which is a subject to short-term, intense periods of noise generation), a handheld sound level meter may be suitable. If the measurements need to be made over a longer period (for example to assess the long-term noise exposure of a residential dwelling subject to wind turbine/farm noise), an outdoor environmental measurement system may be needed.

Modern noise monitoring equipment varies significantly in cost, based on the robustness and sophistication of the measurement device and its post-processing capabilities (e.g. the range of metrics the device can calculate - LAeq, Lden, LAmax etc.). Most environmental noise monitoring systems, especially those that are designed to be left in-situ for substantial periods of time (days/weeks/months), include continuous data loggers that are accessible through telemetry or include the functionality to be able to host/share data on a website/server that can be interrogated by stakeholders.

Figure 8: Example of a handheld sound level meter.

The device in Figure 8 represents an example of a handheld sound level meter, which can be used for both **indoor** and environmental noise measurement. These devices have GPS location and remote data download functionality using 3G/GPRS. Tonal analysis and audio recording are also possible, and the device can be used outdoors for short-term boundary or impact assessment survey purposes.

Figure 9: Example of weatherproof environmental noise monitoring system

The device in Figure 9 is an example of an Environmental Monitoring System, which can be used for unattended **outdoor** noise measurements, and can therefore be used in remote locations, at construction sites and at wind farms, for example. Noise measurements can be made in all weather conditions because the sound level meter and the microphone have additional protection. The device can be powered internally (via a battery pack) or externally, has continuous data logging functionality and has the ability to share data and set trigger levels.

Technical committee 88 of the International Electrotechnical Commission (IEC) prepares standards that deal with, among others, measurement techniques for wind turbines. IEC norm 61400-11 details appropriate noise measurement techniques, including hardware, procedures, data requirements and reporting requirements. One of the requirements is the measurement between wind speeds of 6 m/s and 10 m/s.

4 Modelling and Mapping

This section provides an overview of noise modelling and mapping process, indicating different approaches to designing noise maps, from transport sector or other noise sources (industry, construction, etc.), aiming at identifying examples to be taken on board by aviation sector.

4.1 Noise Mapping

A Noise Map is a map of an area which is 'coloured' according to the noise levels in the area. Sometimes the noise levels may be shown by contour lines which show the boundaries between different noise levels in an area. Several datasets and tools are involved designing noise maps.

As part of the review process a good example of noise mapping guidance has been identified, in one proposed by the Environmental Protection Agency of Ireland who produced guidance on strategic noise mapping to support requirements detailed in the Environmental Noise Regulations 2006[4]. This provides a simple and useful representation as a step-by-step process. The guidance assists designated Noise Mapping Bodies (NMBs) in carrying out their duties under the 2006 Regulations, including making and approving strategic noise maps for agglomerations, roads, railways, major industrial sites and aircraft using airports. The guidance also covers the reporting of strategic noise maps and how they are presented to the public.

The main structure of the guidance is to present a staged approach to deliver strategic noise mapping. The approach set out may be summarised as a seven-stage process, as shown in Figure 10 below.

[4] https://www.epa.ie/pubs/advice/noisemapping/EPA%20Guidance%20Note%20for%20Strategic%20Noise%20Mapping%20(version%202).pdf

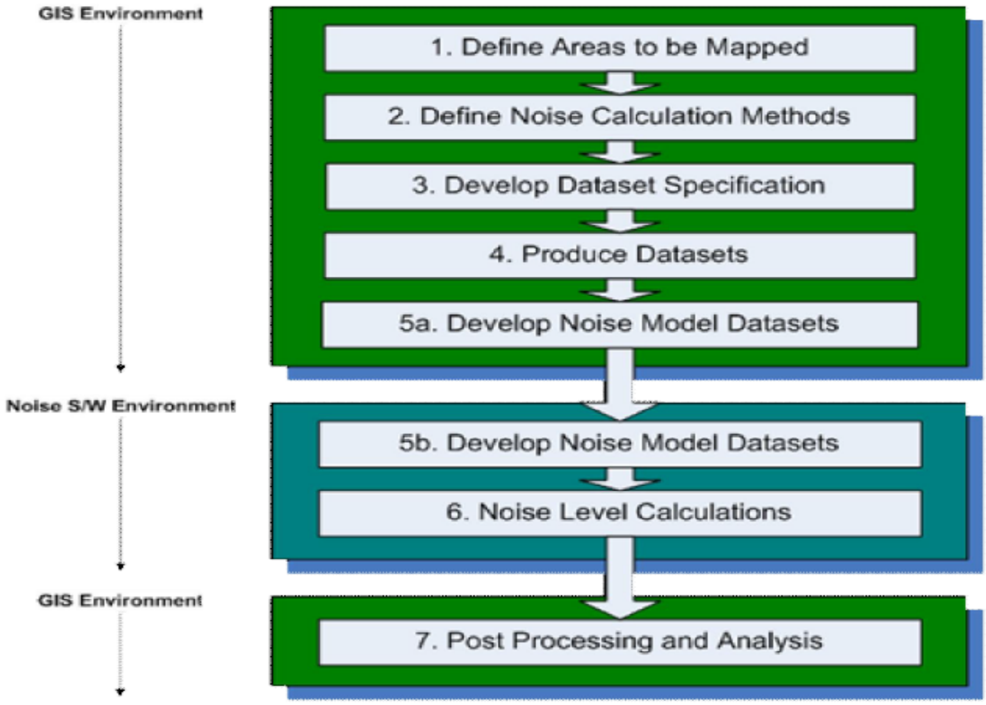

Figure 10: Overview of noise mapping process

Each stage of the process is defined by preceding stages, such that requirements and specifications are captured ahead of the datasets. These datasets are then processed and concatenated to develop the model datasets, which are checked and tested prior to the final assessment of noise levels.

It is recommended that the data processing is commenced within a Geographic Information System (GIS) environment, then passed to the specialist noise mapping software environment for final sign-off and the assessment of noise levels. The results of this assessment are then passed back to the GIS environment for post processing, analysis and mapping. Step 5 "Develop Noise Model Datasets" starts within the GIS environment, and is completed within the noise mapping software.

Chapter 7 of the guidance document covers the modelling of the various sources, including an outline of the modelling process, the definition of the three-dimensional model environment and the use of supporting data captured during field surveys (i.e. noise monitoring data).

In relation to building the three-dimensional model environment, accurate vector and boundary mapping data are noted as being important, along with, where available, high resolution orthophotography and LiDAR data. As noise mapping calculations involve the assessment/characterisation of source-to-receptor propagation paths, digital terrain model (DTM) data are important, along with information on building locations and dimensions, barriers and bridges etc. Meteorological data (wind direction and frequency, temperature and relative humidity) are also highlighted as being key to the noise mapping process.

The guidance document goes on to discuss the required input model parameters for each source (road, rail, industry, aircraft). For road noise, reference is made to the UK Calculation of Road Traffic Noise guidance (CRTN) methodology (discussed in section 4.2). Where model input data are missing to the point that it would have a significant adverse impact on the uncertainty of the modelling/mapping assessment process, the guidance recommends that detailed site surveys (monitoring) are undertaken. Regardless, the use of site-specific field data is likely to result in a lower level of uncertainty than using default model input parameters.

The strategic noise mapping process includes two key inputs:

- Base model definition (including digital ground model, buildings, topography and barriers); and
- Source model/parameter definition (for road, rail, industry, aircraft).

Once the base model and source model/parameters are defined, noise modelling is undertaken, with careful consideration given to the overall model uncertainty and the user defined calculation settings adopted for the model. The importance of pre- and post-modelling data checks is emphasised. Post-processing of the model outputs in terms of the spatial resolution/receptor resolution (area, population, dwelling) is discussed in the guidance, along with how the modelling/mapping process and results should be presented to the regulator and the wider public.

In 2004, AEA Technology Rail BV published a 'state of the art' technical document on noise mapping in support of the European IMAGINE (Improved Methods for the Assessment of the Generic Impact of Noise in the Environment) project (IMAGINE (2004)[5]. In relation to noise modelling/computation methods, different methodologies are discussed and compared for road, rail, air and industrial sources.

In relation to the computation of road noise, models from six European nations are presented and discussed in the 'state of the art' document:

- Austrian RVS 3.02;
- French NMPB;
- German RLS-90;
- Dutch RMV II;
- Nordic Nord 2000; and
- UK CRTN.

The RVS 3.02, NMPB, RLS-90 and RMV II models all calculate the LAeq metric, albeit using different calculation methodologies (segmentation of roads or the

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5 http://doutoramento.schiu.com/referencias/outras/Improved%20Methods%20for%20the%20Assessment%20of%20the%20Generic%20Impact%20of%20Noise%20in%20the%20Environment%20(IMAGINE)%20-%20State%20of%20the%20Art.pdf

decomposition of line sources into equivalent point sources). The Nord 2000 model calculates LAeq and LAmax metrics by dividing the road into uniform line sources. The UK CRTN method calculates LA10 (1 hour) and LA10 (18 hour) metrics using a road segmentation process where the contribution from each segment is combined at each receptor location. The different models cover a variety of frequency/spectral ranges, time periods (e.g. day, night, evening), source characteristics (e.g. source height and position, vehicle speed and classification) and noise pathway attenuation factors (e.g. atmospheric attenuation, ground absorption, barriers, reflections etc.).

Similar discussions and comparisons between different model types are also presented in the 'state of the art' document for rail, airport and industrial sources.

In 2006, the European Commission Working Group Assessment of Exposure to Noise (WG-AEN) published a draft 'position paper' on strategic noise mapping good practice[6]. This document discusses some of the key issues surrounding the definition of source, propagation pathway and receptor parameters for noise modelling/mapping. For example, in relation to source parameters, the spatial alignment of the road is important, as is the road gradient and the road surface type. With respect to the propagation pathway, building height and ground surface type and elevation are crucial factors. For receptor definition, the receptor location (in terms of worst-case exposure relative to the source) and setting (urban or rural) are important considerations.

4.2 Transportation - Roads

Noise modelling software and associated methodologies are well developed, particularly with respect to roads. The UK Department for Transport's (DfT) Calculation of Road Traffic Noise guidance (CRTN, first published in 1988) outlines a methodology for predicting noise levels at different distances from a highway based on traffic characteristics (e.g. vehicle speeds and traffic composition), intervening ground cover and road configuration etc.

The CRTN is the UK's primary noise calculation methodology for new road schemes and has been used in several studies outside of the UK context, including in the assessment of the effectiveness of acoustic barriers adjacent to roads in the Middle East. CRTN has also been implemented as an optional noise calculation method in leading proprietary noise modelling software packages such as SoundPLAN[7] and CadnaA[8], which enable the user to characterise the baseline noise environment and to then assess (based on a source-pathway-receptor basis) the noise impacts and/or the effectiveness of noise mitigation/reduction strategies for a given project (new road, new power station etc.).

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[6] http://sicaweb.cedex.es/docs/documentacion/Good-Practice-Guide-for-Strategic-Noise-Mapping.pdf
[7] https://soundplan-uk.com/
[8] https://www.datakustik.com/products/cadnaa/cadnaa/

In another example, The Transport Research Laboratory (TRL) in the UK has used a noise prediction model based on the European HARMONISE/IMAGINE road surface model[9] to assess the potential noise reductions achievable with different low-noise road surfaces. In Hong Kong, detailed noise modelling has been used to assess the effectiveness of acoustic balconies for residential apartments prior to full-scale, in-situ testing and measurement.

4.3 Transportation - Rail

Like for road traffic there is noise modelling software available for railways. However, HARMONISE doesn't offer a method for calculating railway noises, which is only available with the IMAGINE software.

According to final report summary, in the HARMONOISE / IMAGINE rail model the combined roughness of the wheels and the rails is a key parameter for rolling noise. The inclusion of the combined roughness leads to a major improvement in modelling accuracy especially because local track roughness can cause rolling noise to vary over a range of up to 20 dB. At present most national rail noise models include overall rolling noise data (i.e. vehicle and track contributions combined) that have been acquired from pass-by measurements on track that is not excessively rough or corrugated.

In the HARMONOISE / IMAGINE model, rolling noise is split into the vehicle and track contribution. In addition, the rail model takes into account all other potential noise sources, such as traction elements (exhaust, fans, and compressors), braking noise (including brake squeal), curve squeal and aerodynamic noise. The level of detail of these extra sources is significantly greater than is the case with other available mapping models.

4.4 Construction

Noise modelling has also been used successfully for large-scale construction projects, enabling the iterative calculation of noise impacts at sensitive receptors based on different site plant configurations, operating times and new and updated source noise data for key items of plant. This iterative modelling approach enables the construction contractor to demonstrate to the local authority that, despite the flexibility required in operational activities and scheduling to meet project milestones, no significant adverse impacts on local businesses and residents would occur. For example, detailed acoustic modelling was undertaken by Anderson Acoustics to support the construction phase of the Crossrail Moorgate Shaft project in central London[10].

In another example, from Addiscombe Environmental Consultants Limited[11], construction noise calculations can be undertaken using in-house modelling capabilities. It allows possible mitigation options to be assessed prior to

[9] http://www.imagine-project.org/
[10] https://andersonacoustics.co.uk/case-study/construction/going-beyond-61-compliance-at-crossrails-moorgate-shaft/
[11] http://www.aecl.co.uk/services/construction-noise

commencement of on-site activity. This approach has a positive effect, allowing the use of different plant/techniques or reprogramming to be assessed. The solutions are built on an extensive database of noise levels for various types of plant and activities, based on measurements undertaken during numerous site visits.

4.5 Industry - wind turbine

Predicting wind turbine noise is essential for the design of more quiet turbines and for assessing the noise impact around wind farms. Several approaches exist that range from 'rule-of-thumb' methods to full-on computational fluid dynamics (CFD) methods. In between are hybrid semi-empirical methods.

The rule-of-thumb methods can provide an order of magnitude assessment of noise, but fail to address the impact of design changes. CFD computations are very accurate, but are usually time intensive and thus costly for a calculating the 3D flow around a wind turbine. A hybrid approach assessing different sources separately using finite-element methods (instead of resolving the entire system) currently represent the state-of-art (Oerlemans, 2012).

4.6 Leisure & Domestic

This document focuses on the review of existing literature and although the authors have carried out a comprehensive review, an official procedure to model leisure and/or domestic noise seems not to be available. This is probably due to the fact that domestic and leisure noise is the result of a combination of two or more of the other noise sources, and only occasionally they relate to a single event (like an concert in an open environment or a big sports event for example). Those events are treated differently from other noises, as they occur only randomly and do not endure for longer periods of time or at multiple times throughout several days a week, like for examples trains or planes, that have a schedule or road traffic, that constantly flows.

From the review of different cases, of particular interest in the Leisure sector is the case study 11 which shows a noise modelling procedure for a large concert, using the software Sound Plan 7.0 and the CONCAVE propagation model and can therefore be regarded as an exemplary approach in leisure and domestic noise mapping and surveillance

5 Role of community engagement

As previously discussed, noise generated by wind turbines/farms, road, railway, construction projects, as well as from domestic and leisure sources can potentially have adverse impacts on communities located near to such sources. The specific response of individuals within a given community to noise generated by these sources can vary considerably due to non-acoustical factors[12] such as, for example, age, sex and socio-economic status (demographic factors), general noise sensitivity (attitudinal factors), and the amount of time spent at home, or the visibility of the noise source (situational factors). Numerous studies have investigated the effects of community noise and the noise exposure dose-response of individuals, highlighting generally that active engagement and ongoing and effective communication with local populations that are located near those sources of community noise, can change the attitude towards the noise perception, and are now considered to be critical in managing noise impacts/exposure. This engagement is part of the best practice approach towards community noise, the type of source being less important.

For example, in London, *good practice guidance on noise control for construction and demolition* sites has been published and recommends that a community liaison plan and a complaints procedure is developed for all construction sites, regardless of the size/complexity/noise risk of the project[13]. The same guidance also recommends, depending on the (noise) risk of the site, regular meetings with the local community and regulator, newsletters and email communications with the local community, and the development of project-specific websites to share information about the construction project, as well as any noise issues. This will enable feedback to be received from the local community. An extract from the guidance is presented below in Table 2.

Table 2: Extract from London good practice guidance on noise control for construction and demolition sites (note: *Not applicable; **Desirable; ***Highly recommended)

Mitigation for all Risk Sites
Develop a Community Liaison Plan. Develop a Complaint Procedure with timescales for responses and a nominated liaison person to engage with residents and to handle complaints. These should be agreed with the local authority.
Display contact details for the site manager and liaison officer prominently on the site hoarding.
Brief all site staff regarding the complaints procedure and mitigation

[12] Attitude towards the noise source, personal sensitivity to noise and situational factors such as background noise and current activity.
[13] https://www.cieh.org/media/1251/london-good-practice-guide-noise-vibration-control-for-demolition-and-construction.pdf

requirements and their responsibilities to register and escalate complaints received.

Mitigation Measures to be Considered	Low Risk	Medium Risk	High Risk
Send regular updates at appropriate intervals to all identified affected neighbours via newsletter and posting information on the site hoarding. Also make information available via email when requested.	*	**	***
Develop and maintain a website to provide information about the project and to receive feedback.	*	**	***
Arrange regular community liaison meetings at appropriate intervals including prior to commencement of project. Respond to issues raised and report back to attendees.	*	**	***
Arrange meetings and communicate on a regular basis with neighbouring construction sites to ensure activities are coordinated to minimise any potential cumulative issues.	*	**	***
Advise neighbours about reasons for and duration of any permitted works outside of normal working hours.	**	***	***
Arrange meetings and communicate on a regular basis with the local authority to monitor the progress of the works and to consider any concerns or complaints raised by the local community.	*	**	***

As mentioned above, modern environmental noise monitoring systems have the functionality to essentially **provide feeds of 'real time' noise measurement data to stakeholders**, including members of the local community and the relevant regulator. Such systems can be used to share measurement data with stakeholders, to check compliance with any agreed noise limits and and/or to allow site operatives to modify activities/operations if site noise thresholds are near to, or are, being breeched.

Interactive noise mapping can also be an effective means of communicating noise risks to the public. In the UK, noise maps for strategic road and rail routes in England[14] are publicly available. Average noise levels (dB) for various metrics

[14] http://extrium.co.uk/noiseviewer.html#

(including Lden, LAeq and Lnight) are presented and can be interrogated by the user via a geographical interface.

In relation to **domestic noise**, the New South Wales Environment Protection Agency in Australia has produced a series of leaflets/brochures aimed at the public. Subjects include dealing with barking dogs, managing noise from intruder alarms, dealing with neighbourhood noise and seeking noise abatement orders[15].

Railway companies are already proactive and make regular use of community engagement and information strategies. As case study 8 illustrates, information and involvement of the community constitutes a big part, not in mitigating the noise per se, but therefore it decreases the perceived annoyance. Other examples on community engagement are frequently found, and made public by the railway organisations. Within bigger projects, planning does regularly involve members of the concerned communities, joining dialogue forums with the responsible authorities (e.g. Deutsche Bahn [DB, German Federal Railway], 2018).

In fact, the Deutsche Bahn (2018) has provided few of rather *unconventional communicational interventions* they apply to inform the public about their efforts in noise mitigation:

- Noise protection stele/Totem (Lärmschutzstelen)

  These displays are mobile and carried around many construction sites, events and of the German Federal Railway and are supposed to give a realistic impression of different noise mitigation strategies (Figure 11). People are advised to test themselves what effect a specific noise mitigation intervention on the noise level has. This can be combined with different train types.

[15] https://www.epa.nsw.gov.au/your-environment/noise/neighbourhood-noise

Figure 11: Noise Protection Totem (Stele)

- Noise protection Info-Mobile (Infomobil Lärmschutz)

  This vehicle is a huge truck that is able to be driven around any region of interest. It carries two noise protection steles, which are exhibited in regards to noise mitigation strategies, and set of information explaining different strategies in noise mitigation approaches. It also features a stage on which announcements can be made at bigger events.

- Mobile acoustic chamber (Mobiler Akustikraum)

  It works like the noise protection steles but in a bigger scale. A whole room is prepared with the software and a green screen to provide as realistic as possible ideas of noise mitigation interventions.

- Noise Protection Information point (Infopunkt Lärmschutz)

  Additionally, the Federal German Railway has contributed technology and funding to the Infopunkt Lärmschutz which is a permanent exhibition in Berlin. In a 180° screen and 140 Speakers noise mitigation is demonstrated in the most realistic way (Figure 12).

Figure 12: Noise Protection Information point at the Fraunhofer-Institut, Berlin

Wind turbine developments apply similar engagement strategies as aviation. In addition, they have the opportunity to let local residents profit directly from the wind turbines, either by issuing shares or by offering a discount on energy.

6 Noise mitigation and reduction

This section provides an overview of the noise mitigation and reduction strategies examined and used as state of the art in the other sectors, Transport (road & rail), Construction, Industry and Leisure.

6.1 Transportation (road)

According to the European Commission[16], the biggest source of environmental noise is road traffic, exposure to which far exceeds rail and aircraft sources combined. In urban areas, road traffic is thought to account for 80% of all noise pollution.

Road traffic noise is caused by a combination of rolling noise (due to vibrations and interactions between the tyre of the vehicle and the road surface) and

16 http://ec.europa.eu/environment/integration/research/newsalert/pdf/noise_abatement_approaches_FB17_en.pdf

propulsion noise (emanating from the engine itself). *Rolling noise* dominates noise emissions when cars are travelling above approximately 30 kilometres per hour (km/h), while *propulsion noise* is the major source of noise below this speed.

In the diagram in Figure 13 below are listed the different road noise reduction/mitigation measures taken from the European Commission Science for Environment Policy, *Future Brief: Noise Abatement Approaches* (2017)[8].

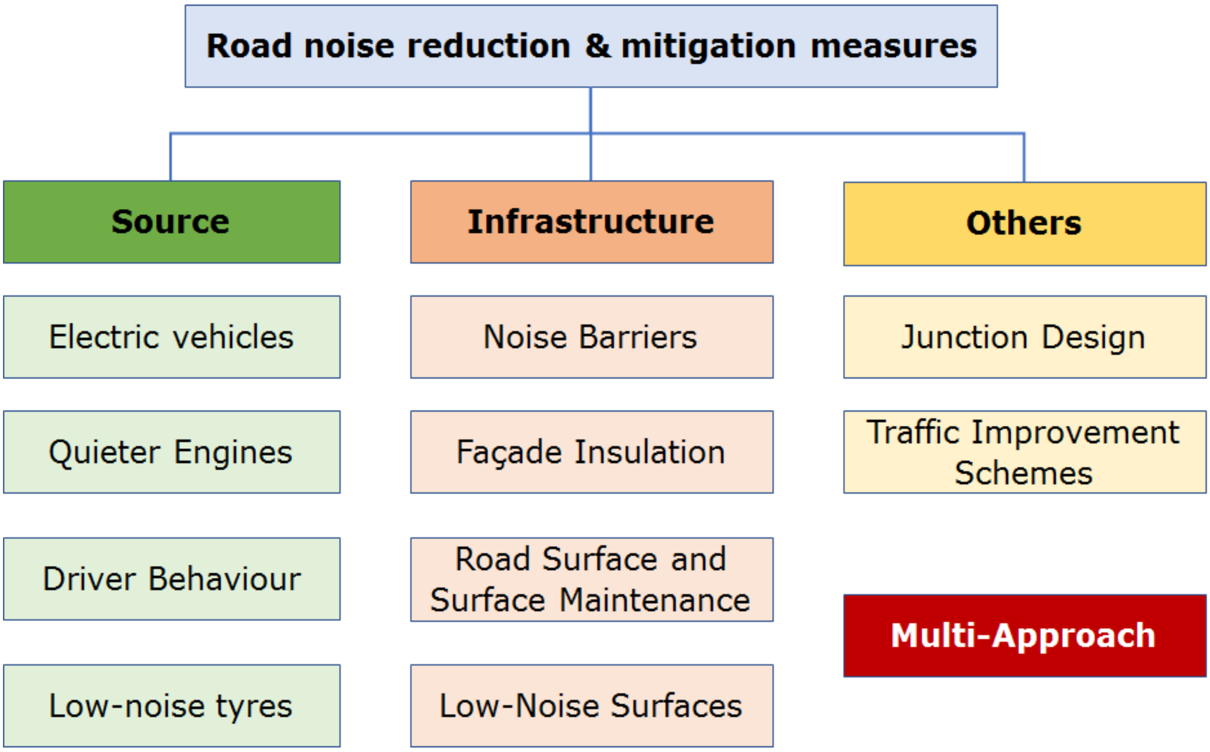

Figure 13: Road noise reduction/mitigation measures (EC, 2017)

In the following sub-sections, an overview of each of the different road noise reduction/ mitigation measures is provided.

Quieter Engines

Most road vehicles are currently powered by internal combustion engines, which generate noise when fuel is burned as well as from the exhaust, air intake, fans and auxiliary equipment. Reducing noise at source is the most effective noise abatement approach for vehicle noise. Indeed, the biggest reductions in noise emissions from cars in recent years have come from improvements to engine technology. Noise reduction technologies have been developed for internal combustion engines, which can reduce the noise level of the engine without affecting its power output. Electric and hybrid motor vehicles also offer reduced engine noise.

Low-Noise Surfaces

Road surfaces can have a significant influence on the sound produced by vehicles travelling on them. Low noise road surfaces are an optimal solution to reduce noise because they act on the source and provide an acoustical benefit to the entire population living near to the road. Important characteristics of road surfaces include their roughness, porosity and elasticity. These factors can be influenced by the amount and type of binder used (asphalt or cement concrete, for example), the mix (such as the shape and type of stones used in the mineral aggregate) and the surface treatment. The most effective road surfaces for reducing traffic noise pollution are porous and thin-layer asphalt.

Porous asphalt reduces the effect of 'air pumping' where, as the tread of the wheel hits the road, air is squeezed out as the tread is compressed. Porous asphalt can also absorb noise coming from the engine. Various European countries have shown that porous mixes can effectively reduce noise. In the Netherlands for example, where it is used on at least 60% of roads, research has shown that porous asphalt can reduce noise from passenger vehicles by 3 dB. Further results from the EU SILENCE project suggest that single-layer porous road surfaces can reduce noise on main roads by up to 4 dB (compared to conventional dense asphalt concrete), while over 6 dB reductions can be achieved using the most absorptive, open porous surfaces, although these require bi-annual cleaning.

Thin-layer road surfaces have been specifically designed to reduce noise emissions. They incorporate small aggregates (6–8 mm), an open structure to reduce noise generated by air pumping and a smooth and even surface to reduce the vibrations of the tyre. These surfaces have been applied in a Danish noise abatement programme, generating a 3dB reduction in noise from passenger cars. These surfaces are also thought to be more suitable for urban areas as porous surfaces can become obstructed with dust, reducing their ability to mitigate noise. Although they differ in composition, both types of surface have a low aggregate size, which increases the empty space (void) and aids noise absorption.

It is important to note that low-noise road surfaces are more impactful where rolling noise dominates. Where engine noise is the main source of noise pollution, low-noise road surfaces are less effective. The noise reduction effect also reduces with use; for porous asphalt road surfaces, the noise reduction effect decreases by 0.4 dB/year for light vehicles at high speeds. They can also be expensive (double-porous asphalt is almost twice as expensive per application than standard asphalt), yet relative to other noise abatement measures, such as noise barriers, the costs are relatively low.

Low-noise road surfaces also have advantages over other mitigation approaches, as they reduce noise for all buildings near to roads, as opposed to insulation for example, which only benefits the protected building.

<u>Low-noise tyres</u>

The other component of rolling noise – tyres – is also a valuable focus for noise mitigation efforts. Replacing tyres with quieter alternatives could reduce noise

emissions by around 3 dB. There are already 'quiet' tyres available in the EU labelled 66-67 dB (the average value is 70-71 dB); however, developing completely new tyres may have even more potential.
Important considerations in low noise tyre design include the tread stiffness (the texture of the rubber exterior that contacts the ground), lower levels of which can reduce excitation of tyre vibrations; mass, as tyres with higher mass generate reduced vibrations; reduced tyre width and increased external diameter; increased belt stiffness; and the volume of grooves in relation to the volume of rubber blocks in the tread, which influences air pumping. Each of these parameters can influence the rolling noise by a few decibels, but may negatively impact other tyre properties such as rolling resistance or friction. Thus, the optimisation of tyre parameters is important to obtain satisfactory noise emission levels and energy efficiency.
More radical changes to tyre design include adding a porous tread, which could reduce noise emissions by 5 dB. A more futuristic idea is that of the 'TWEEL', first envisioned by Michelin, an airless tyre that could reduce noise emissions by up to 10 dB (Figure 14).

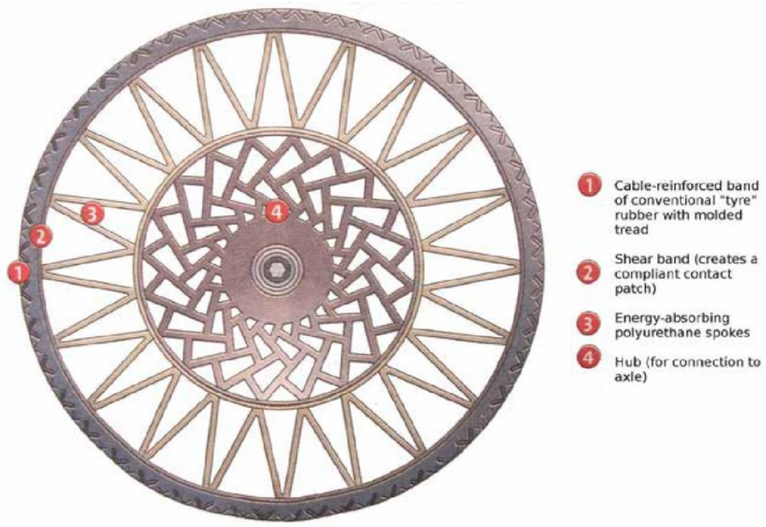

Figure 14: The Michelin TWEEL Tyre Design[17]

The benefits of low noise tyres are amplified when applied on noise-reducing road surfaces. The potential of quieter tyres could also be enhanced by the use of speed limits. It has been estimated that speed limits of 130 km/h could enhance noise reduction by an extra 2 dB. Legislation to promote low-noise tyres will be another important element.

Quieter tyres are generally no more expensive than standard tyres and perform similarly in terms of wet grip and rolling resistance. Several have been developed and are already on sale on the European market.

17 http://ec.europa.eu/environment/integration/research/newsalert/pdf/noise_abatement_approaches_FB17_en.pdf

Electric vehicles

A more transformative means of reducing traffic noise is the adoption of electric vehicles. Hybrid electric vehicles have been produced since the 1990s and more recently all-electric vehicles have been introduced, which operate using electricity at all speeds.

When in electric mode, at least at low speeds, these vehicles are quieter than traditional gasoline or diesel powered cars. This has even led to concerns that they may be dangerously quiet for cyclists or the visually impaired persons who rely on the sounds produced by vehicles as warning signals. In 2014, the European Parliament approved legislation requiring 'Acoustic Vehicle Alerting Systems' for all new electric and hybrid electric vehicles. Likewise, under US legislation, hybrid and electric vehicles are required to make audible noise when travelling at speeds up to 20 km/h. However, when vehicles run at high speed, other noises generated mainly by rolling tyres and aerodynamics prevails and studies have shown non-significant benefits.

A US source showed that, even if all cars were replaced with electric ones, the average sound level would only be reduced by 1 dB during the day, while an assessment in the Netherlands suggests that replacing the conventional car fleet with hybrid or fully electric cars could reduce noise emissions in urban areas by 3–4 dB[18]. A more recent study evaluated the effect of introducing a flow of electric vehicles into urban traffic in Spain, describing the expected effects on noise maps. The study showed that at high speeds (above 50 km/h) the benefits of electric vehicles are minimal due to the overriding contribution of rolling noise. However, when a flow of electric vehicles running at 30 km/h was studied, the authors estimated a reduction in sound levels of 2 dB. A simulated noise map showed that the substitution of internal combustion engine vehicles with electric vehicles could improve the acoustic environment for 10% of citizens.
The Scottish Government has produced guidance on possible measures to manage noise from road and rail sources[19]. Various road noise mitigation measures, taken from the guidance, are presented below, along with an example of a multi-functional mitigation approach taken from a scheme in Austria.

Noise Barriers

Noise barriers or *screens* are effective but are generally a costly measure. The location, height, length, and acoustic properties of a barrier determine its acoustic performance. Generally, to be effective, a barrier should be located close to the source, particularly, where a large area behind the barrier needs to be protected. The barrier height requirements will be determined, generally, by the height of the most exposed bedroom window of the building. To ensure the

18 http://ec.europa.eu/environment/integration/research/newsalert/pdf/noise_abatement_approaches_FB17_en.pdf
19 https://noise.environment.gov.scot/pdf/Mitigation_Guidance.pdf

performance of the barrier is not compromised, the length of the barrier should be sufficient to completely screen the traffic from view at the exposed facade. Transmission of noise through the barrier is governed by the surface mass of the screening material and the quality of construction. Any gaps or leakage should be avoided. Generally, the surface mass requirement to effectively control the transmission of noise through the barrier is met by constraints regarding wind loading.

Noise barriers can be visually intrusive. However, barriers with specially shaped top sections can be as effective in reducing noise as taller barriers. Barriers with sound absorbing material on the traffic side have a dual benefit, reduce sound transmission behind the barriers as well as the reflection of sounds to properties on the opposite side of the road. Where applicable, incorporating noise barriers within the safety fence in the central reservation of a dual carriageway (median barriers), it can improve the performance of roadside barriers, providing the median barrier is more than half the height of the roadside barrier. This method of enhancement can potentially increase performance of the roadside barrier by about 3 dB(A).

Façade Insulation

Improved facade insulation is generally regarded as a last resort if other measures of reducing noise at source, or along the propagation path fail to be sufficient. Offering grants to properties which have no sound insulation can be effective. Windows with secondary or double-glazing can achieve sound reductions of about 40 dB compared with a sound reduction of about 30 dB for single glazed windows. These performance figures are for well-sealed windows. Opening windows can reduce performance by 10 to 15 dB, however open double windows and other such designs can improve the level of sound reduction obtained via an open window. However, to maintain the acoustic benefits some form of ventilation system is likely to be required.

Streets which are flanked on both sides by multi-storey buildings can produce reverberant noise fields caused by reflections from building facades. The noise caused by reflection between facades depends on the geometry of the building layout and the sound absorption properties of both the building facades and the ground between the buildings. This reflection effect can cause an increase of 3 to 4 dB(A). Increasing the sound absorption properties of these surfaces for example by using a more porous road surface than traditional or by promoting “green wall” technology in building design would help to limit the increase in noise.

Road Surface and Surface Maintenance

The acoustic benefit gained from laying a low-noise surface is dependent firstly, on variables associated with the composition of the material such as aggregate size and void content and secondly, but equally importantly, on the current acoustic performance of the surface being replaced. An indication of the reduction in noise achieved by replacing traditional 20 mm Hot Rolled Asphalt

(HRA) surface with a low-noise surface, for example, a thin Stone Mastic Asphalt (SMA), is shown in Table 3 below.

Table 3: Typical Reduction in Noise after replacing HRA with a low-noise surface[1]

Traffic Speed (mph)	**Reduction in noise (dB(A)) and %HGVs[2]**		
	0	**10**	**20**
30	4.2	3.3	2.7
50	4.6	3.9	3.4
60	4.7	4.1	3.6

[1]Reductions based on surface conditions when relatively new; [2]HGVs = unladen weight >3.5tonnes

The table shows that, as traffic speeds increase and the percentage of HGVs in the traffic stream decrease, the acoustic benefits in noise reduction improve. The values for the typical noise reductions at the time of replacement, as shown in the table, are likely to be conservative since no allowance has been made for age-related noise deterioration of the existing surface (the above reductions are based on the average acoustic performance of these surface types when relatively new). The initial attenuation may, therefore, be higher than that shown in the Table 3.

The acoustic performance of low noise surfaces is known to deteriorate with age, and the design specification of such surfaces as SMA to maintain durability is challenging. Surface irregularities, poorly re-instated trenches, bridge joints and other such discontinuities in the surface profile can increase noise levels significantly. Typically, such surface irregularities, cause impulsive body rattle noise, particularly in the case of Heavy Goods Vehicles which can generate increases in pass-by noise levels of about 10 dB(A) when travelling over such surface profiles, causing significant disturbance to residents in the vicinity.

<u>Driver Behaviour</u>

Influencing the way vehicles are driven can have significant benefits in reducing noise impacts from road traffic. Estimates of the potential reduction in noise by adopting a less aggressive driving style range from 1 dB(A) to 5 dB(A) for cars and heavy commercial vehicles, to as much as 7 dB(A) for motorcycles. However, influencing driver behaviour to reduce noise alone is not straightforward. The most effective mechanism is through campaigns to educate the public in understanding the associated benefits in adopting a more passive style of driving. These include the economic benefits in reduced fuel consumption, the health benefits in reducing exhaust fumes and the overall improvements in traffic safety.

Encouraging companies such as freight carriers and other delivery companies to send staff on 'ecodriving' courses to promote driving styles which reduce fuel consumption could also highlight the benefits gained in reducing noise impacts in a meaningful way which can be easily understood. For example, driving in a higher gear to maintain road speed reduces fuel consumption due to lower engine speed.

Reducing engine speed by 50% will reduce engine noise by 15 dB(A). The engine noise from one vehicle at 4000 rpm is equivalent to the combined noise produced by 32 vehicles at 2000 rpm. Alternative ways of influencing driver behaviour to reduce noise impact is by using active road signs to protect nearby noise sensitive areas. This has been tried in Austria. The idea of the signs is to encourage drivers to keep to the speed limit by relying on their goodwill in responding to messages like "I want to Sleep! Please Shhh!" set alongside a photo of a sleeping baby.

Junction Design

Junction design considers factors such as traffic flow, traffic speeds, pedestrian movement, road layout and geometry. Improving a junction layout can actively promote smoother driving, and can reduce acceleration noise. Typical examples of where junction design improvements have been implemented include replacing signalised junctions with roundabouts, or non-signalised junctions with mini-roundabouts. In assessing the noise impacts from such scheme changes, the impact of changes in both noise emissions from individual vehicles (based on the maximum pass-by noise levels) and the change in overall traffic noise levels (based on longer term averaging of all vehicles emissions in the traffic stream e.g. LAeq,1h dB), need to be considered.

Compared with steady speed vehicle pass-by, noise emissions from individual vehicles decelerating, when approaching, or accelerating away from, a junction can vary by as much as ± 4 to 5 dB(A) (HARMONOISE/IMAGINE MODEL). Sites where there are large variations in vehicle noise emissions between vehicles accelerating and decelerating through a junction may benefit from improvements to the junction design. Although typically overall traffic noise levels have been found to decrease by about 2 dB(A) where roundabouts have replaced signalled junctions, the reduction in the variability of noise from individual vehicles may bring additional benefits in reducing annoyance on top of that expected from just a reduction in overall traffic noise levels.

Traffic Improvement Schemes

Traffic Improvement Schemes are introduced for a combination of reasons. These include reducing journey times and costs (thereby meeting wider objectives), improving accident statistics, and minimising environmental impacts. When such schemes are being designed, irrespective of their primary intention, appropriate care in design can result in a reduction in environmental noise at source by virtue of significant reduction in traffic flow, composition and speed.

Table 4 below indicates the logarithmic relationship between a reduction in traffic flow and noise level. Reducing flow is generally not a solely effective measure for noise reduction in most situations, as the flow reduction required for any significant effect is not realistically achievable. For example, the Table shows that a 3 dB(A) reduction in noise requires a 50% reduction in traffic volume. Such reductions are not normally possible without significant intervention elsewhere to replace the removed transport need.

Table 4: Reduction in traffic flow and noise at typical free flow speed conditions

Traffic flow reduction	**25%**	**50%**	**75%**	**90%**
Noise reduction dB(A)	1.2	3	6	10

In addition, when considering flow reduction to reduce noise, other effects should be borne in mind. For example, where achieved, a reduction in flow may lead to less congestion and promote higher traffic speeds which will offset, to some extent, the reduction in noise gained. Alternatively, a reduction in congestion, if the scheme is carefully designed, may promote smoother driving which would reduce noise emissions from accelerating vehicles. With all the above in mind, care is required in the design of traffic improvement schemes to ensure noise reduction possibilities can be maximised.

Multi-Approach Example

Figure 15 presents an example of a multi-functional noise protection project based on a scheme from Gleisdorf, Austria. The approach uses a mixture of roadside and median noise barriers, a noise reducing road surface, automated speed signs, psychological signalling and noise measurement.

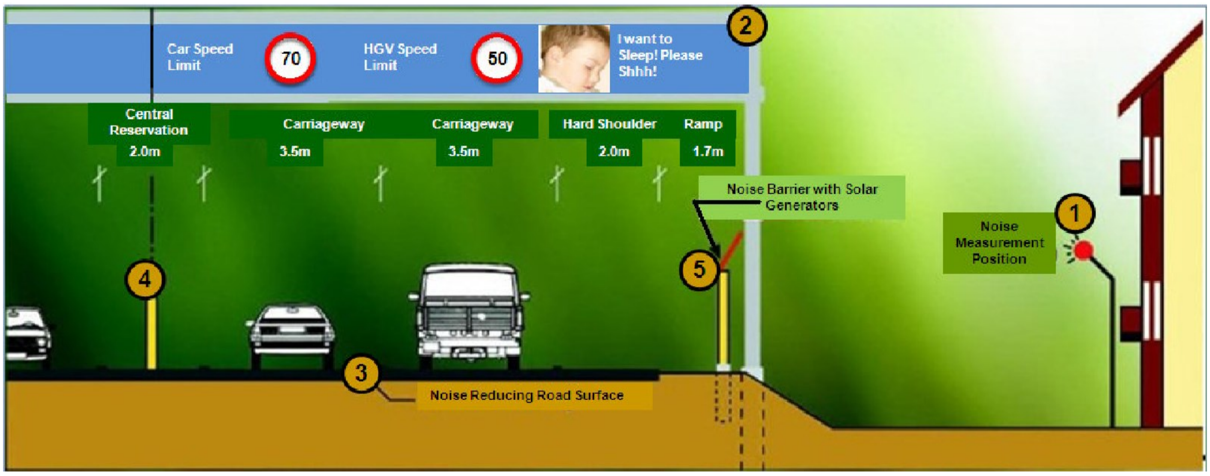

Figure 15: Multi-functional noise protection project - Gleisdorf, Austria

Key

1. Noise Measurement Facility
2. Traffic Management Device – Automatic Speed Signs with added Psychological Signs
3. Noise Reducing Road Surface
4. Median Noise Barrier
5. Noise Barrier with additional Solar Generators

6.2 Transportation (rail)

The case study 3 presented in Section 9 is taken from Hong Kong (Hong Kong Housing Authority) where, due to the high-rise and densely populated nature of the city, receptor-focussed noise mitigation options are often required in addition to more traditional measures, such as noise barriers, to protect residential areas from noise emitted from roads, railways and transport interchanges.

The installation of innovative architectural design measures, such as acoustic windows and balconies and modular apartments are estimated to result in noise reductions of between 3 dB(A) and 8 dB(A) at residential dwellings exposed to significant transport noise.

A report published by of the International Union of Railways (de Vos, 2016, pp 28-32) gives a detailed overview over the state of the art interventions in railway noise mitigation, making it a great document to see what's currently being done to control noise emission in this sector.

The classical approach to outdoor noise problems is to distinguish three options for mitigation:

- At the source (generally the most cost efficient),
- At the propagation path (by setting up barriers or by keeping distance),
- At the receiver (by installing sound proof windows).

In practice, barriers and sound proof windows are applied most frequently. Usually, when installing barriers, a cost efficiency consideration is made. For a single house at some distance from the track, a barrier would have to represent substantial length of track, and would most likely turn out to be very costly. On the other hand, for dense urban zones close to the track, barriers are often applied. Due to the visual interference, residents are often opposed to noise barriers and prefer different measures. The most relevant options are discussed below.

System approach to rolling noise

With rolling noise being the predominant source in railway noise, the control needs to be based on a system approach. The system to be looked at consists of:

- The vehicle, with the wheel, the brakes, the bogie or axle and the vehicle body, all connected by springs and dampers,
- The track, with basic elements the rail, the rail fixation with rail pads, the sleeper, the ballast and the sub-soil.

These two sub-systems meet at the contact patch between the wheel and the rail, it is the combined roughness at this location that causes the rail and the wheel to vibrate and radiate noise. Even apparently smooth surfaces have some roughness and can cause noise. In this complex system, the following options can be considered:

<u>For the vehicle</u>:

- The most important option: Reduce the wheel roughness by replacing the cast iron brake blocks (which cause rough wheels) by K- or LL-blocks or using disk brakes.
- Isolate the wheel tread from the wheel web by a resilient layer (resilient wheel); this type of wheel is hardly ever applied in heavy rail (especially for wagons with block-brake).
- Screen off the noise radiated by the wheel with wheel shrouds (disc brakes mounted on the wheel may serve as wheel shrouds) or bogie enclosures; a measure that is generally rejected by the operating companies because of the interference with visual inspection of the wheel and the axle box.
- Optimise the size and the shape of the wheel in order to reduce its vibration. This is only feasible in new vehicles and has a limited benefit.
- Some networks have monitoring stations to evaluate the success of retrofitting.

<u>For the track</u>:

- Reduce the rail roughness by regular monitoring and preventive/curative grinding; almost all networks monitor the geometric track quality as implement a regime of curative and preventive grinding. Only a few networks currently monitor the acoustic quality (“roughness”) of the track on a regular basis. Acoustic grinding is applied only occasionally. In Germany, a limited number of tracks is ground acoustically, allowing a subtraction of 2,5 to 5 dB in the calculated noise level (besonders überwachtes Gleis).
- Optimise the rail pad stiffness (softer rail pads allow the rail to vibrate more so that waves travel further from the contact point; this is called: a smaller track decay rate). In using this option, both track quality and acoustic quality need to be taken into account.
- Add a (tuned) rail damper;

Approximately 240 km of rail dampers[20] have been installed in Germany, Czech Republic and The Netherlands. In some networks the test results gave disappointing results and rail dampers have since been discarded (due to safety issues; rail wear, with negative noise effects). The reason for this difference is

[20] A rail damper is a means to limit the noise of passing trains. In this way the noise is tackled at the source. The dampers are clamped to the rails using rail fastening clips. On average rail dampers attain a noise reduction of roughly 3 dB(A).

probably the regional preference for either "hard" or "soft" rail pads. Rail dampers are expected to be more efficient the softer the rail pads.

Rail dampers are costly, although their increased application has reduced the purchase cost. The effectiveness is limited to 0 to 3 dB(A) depending on the characteristics of the wheel rail system they are applied to. Some questions remain regarding the increased maintenance cost, safety issues (occurring when rail dampers are loosening from the rail or due to excessive rail corrugation) and the impact on rail roughness growth (both positive and negative effects are reported).

Noise barriers

Noise barriers are the most commonly used mitigation measure; in only 7 networks overall more than 3,000 km of barriers with average height of 2 to 3 meters have been installed. Another 500 km are expected to be installed in the next 10 years. By comparison the use of low height noise barriers is rare, with only 10 km having been installed in Germany, the Czech Republic and the UK. In Austria legal aspects are not yet clarified (employee protection law). Noise barriers are applied in many cases, both with new rail infrastructure, significantly changed infrastructure, and as noise abatement in existing situations. As the dominant noise source (the wheel rail contact surface) is close to the track, noise barriers are highly effective as long as the receiver position is in the shadow zone (i.e. there is no direct sight from the receiver to the source). Most noise barriers near railway lines are between 1 and 4 meters high, but very high barriers (up to 10 meters) are erected in exceptional situations. The key parameter for the barrier effectiveness is the geometry, i.e. the location of the upper edge of the barrier with respect to the source location. An important effect is the reflection of sound between the barrier and the train car body, which may affect the achievable reduction. This so-called canyon effect can be avoided with a lining with high absorption coefficient of the barrier side facing the tracks. Alternatively, the barrier may be put in an inclined position, in order to direct the reflections towards the sky (barriers inclined backward) or towards the ballast (barrier inclined to the track). Well designed and located noise barriers can be effective with attenuation of 10 dB(A) or more at the façade of the receiver (when the barrier comfortably blocks line of sight between the noise source and receiver). To residents, barriers are often experienced as an intrusion to their visual quality. In planning procedures, when strict noise limits need to be adhered to, residents tend to contest the arguments leading to the barrier being built, and may demand alternative solutions. One way to solve this dilemma is to allow residents to be involved in the decision and the esthetical design of the barrier. In some types of new train design items of auxiliary equipment (even including the diesel engine) have been mounted on the roof of the coaches. This design significantly affects the efficiency of noise barriers, which would then have to be built higher to have the same effect as for more conventional rolling stock design.

Façade insulation

Sound proof glazing and ventilation is often the chosen solution in cases where barriers are not cost efficient or not sufficiently effective. Depending on the legal limits the façade insulation must be improved from a standard glazing (typically 15 dB for single glazing to 20 dB for thermal double glazing) to a sound proof glazing with up to 33 dB insulation. Ventilation is provided either by a forced airflow through silencers or a natural airflow through special sound proof devices. Sound proofing has limited interference with the normal housing design in climate zones with severe winters (Scandinavia) but can have a higher interference in warmer climates and houses without air-conditioning.

Other common noise sources

In railway traffic, there are many sources other than rolling noise. Most of these occur in special situations only and therefore have less relevance than rolling noise. The most important sources are:

- Aerodynamic noise

Relevant only at speeds of 300 km/h or more, aerodynamic noise is controlled by an optimized design of the high speed vehicle. Noise barriers screen off the aerodynamic noise from the bogie region, but the noise from the higher pantograph can't be screened efficiently unless the barrier is very high. The doses response relation for aerodynamic noise is a source of ongoing discussion, particularly in countries still maintaining a railway "bonus" in the legal limits. Some parties argue that the limits would need to be lower than for a conventional speed train.

- Curve squeal

Curve squeal occurs in narrow curves where wheels fixed to the axle and locked in bogie pairs slip on the rail head. Curve squeal can be controlled with friction modifiers, including water spraying. The effect on residents is very local but often provokes complaint. Mitigation is usually on a voluntary basis as the curve squeal is not part of the legal prediction methods.

- Brake screech

Brake screech occurs mainly in disk brakes. Solutions are not obvious and therefore are still subject of research.

- Depots

In depots, rolling stock is parked and services. Depots are often located close to stations and therefore in town centers. Noise sources are stationary equipment such as air compressors, transformers and ventilation, stationary noise from diesel engines, starting noise and impulse noise in joints and switches. Specific measures are applied in cases where residential areas are located close to the depot site. In some countries, from a legal point of view, depots are considered industrial sites and have to comply with limits lower than usual for rail traffic

- Shunting yards

In shunting yards, depending on the type of yard, both locomotive noise, rail brakes and buffer noise as well as rolling noise through joints and switches is present. Rail brakes have become more sophisticated and are found to produce less noise.

- Steel bridges

A steel bridge is vibrating when the train runs over it, particularly when the rail is directly fixed on to the steel construction. The bridge is likely to produce a rumble like noise, which can be noticed by residents even at greater distance. The combined noise of train and bridge can be substantially louder than the train running on a normal track. Careful design of new bridges may control this effect. For existing bridges, measures consist of sandwich panels on large steel plates of the bridge (that is if the bridge can carry the weight), or else screens, optimized rail fixation and rail dampers

- Ground borne vibrations

Passing trains may generate vibrations in the ground. These are generally low frequency vibrations between 10 and 50 Hz. In adjacent dwellings they may be notices as either re-radiated noise, low frequency noise, rattling (for example of pottery), and sensible vibrations. Both prediction and mitigation can be extremely difficult & expensive. Other than the above sources, *rolling noise* is the most common source of railway noise. In the following sections, rolling noise is addressed

6.3 Construction

In the UK, British Standard BS 5228-1:2009 *Code of practice for noise and vibration control on construction and open sites – Part 1: Noise*[21], provides a good starting point for considering the noise mitigation and reduction strategies available to construction sites.

In BS 5228-1:2009, mitigation options are categorised into two main groups:

- Mitigation options designed to control noise at source; and,
- Mitigation options designed to control the propagation of noise.

In terms of controlling noise at source, there are many general measures that can be applied at all construction sites, such as:

[21] http://www.barbicanliving.co.uk/wp-content/uploads/2016/04/BS-5228-Part-1-Noise.pdf

- Avoiding unnecessary revving of engines and switching off equipment when not required;
- Keeping internal haul routes well maintained and avoiding steep gradients;
- Use of rubber linings in, for example, chutes and dumpers to reduce impact noise;
- Minimising the drop height of materials; and,
- Starting plant and vehicle engines sequentially, rather than all together.

Further, more specific, mitigation measures for controlling noise at source are presented below.

Controlling Noise at Source

Where a construction site is within a noise-sensitive area, the plant and activities to be employed on that site should be reviewed to ensure that they are the quietest available for the required purpose; this is in accordance with Best Practicable Means (BPM). Noise from existing plant and equipment can often be reduced by modification or by the application of improved sound reduction methods, but this should only be carried out after consultation with the manufacturer. Suppliers of plant will often have ready-made kits available and will often have experience of reducing noise from their plant.

Since ANIMA project does not focus on noise generated at sources by aircraft, this section provides more a view on actions and strategies to mitigate noise generated by construction activities, which may be useful to complement other strategies especially in case of Airport expansion including terminal buildings.

Steady continuous noise, such as that caused by diesel engines, it might be possible to reduce the noise emitted by fitting a more effective exhaust silencer system or by designing an acoustic canopy to replace the normal engine cover. It might be possible in certain circumstances to substitute existing diesel engines with electric motors, with consequent reduction in noise. On-site generators supplying electricity for electric motors should be suitably enclosed and appropriately located.

Stationary or quasi-stationary plant might include, for example, support fluid preparation equipment, grout or concrete mixing and batching machinery, lighting generators, compressors, welding sets and pumps. When appropriate, screens or enclosures should be provided for such equipment. Additional mitigation might be required at night, e.g. by moving plant away from sensitive areas to minimise disturbance to occupants of nearby premises. Noise caused by resonance of body panels and cover plates can be reduced by stiffening with additional ribs or by increasing the damping effect with a surface coating of special resonance damping material.

Enclosures: As far as reasonably practicable, sources of significant noise should be enclosed. The extent to which this can be done depends on the nature of the machine or process to be enclosed and their ventilation requirements. When it is necessary to enclose a machine or process and its operator(s) in an acoustic enclosure or building, precautions should be taken to protect the operator(s) from any consequential hazard.

Use and Siting of Equipment: Machines such as cranes that might be in intermittent use should be shut down between work periods or should be throttled down to a minimum. Machines should not be left running unnecessarily, as this can be noisy and wastes energy. Plant from which the noise generated is known to be particularly directional should, wherever practicable, be orientated so that the noise is directed away from noise-sensitive areas. If compressors are used, they should have effective acoustic enclosures and be designed to operate when their access panels are closed.

When a site is in a residential environment, lorries should not arrive at, or depart from, the site at a time inconvenient to residents.

Generally speaking, and in relation to controlling noise propagation, if noisy processes can be avoided, then the amount of noise reaching noise-sensitive areas will be reduced. Increasing the distance between the noise source and noise sensitive receptor and the installation of bunds is often the most effective method of controlling noise, this might not be possible when work takes place on a restricted site or fixed structures. Screens and barriers can also modulate the propagation of noise from construction sites. For maximum benefit, screens should be close either to the source of noise (as with stationary plant) or to the receptor. Planting of shrubs or trees can have a beneficial psychological effect but will do little to reduce noise levels unless the planting covers an extensive area. Site buildings such as offices and stores can be grouped together to form a substantial barrier separating site operations and nearby receptors. Areas which have been excavated below ground level such as basements or river works can be used to position static plant such as generators, compressors and pumps. Earth bunds can be built to provide screening for major earth-moving operations and can be subsequently landscaped to become permanent features of the environment when works have been completed. The effectiveness of a noise barrier will depend upon its length, effective height, position relative to the noise source and to the noise-sensitive area, and the material from which it is constructed.

Internationally, a very good source of noise construction abatement and reduction strategies is the Hong Kong Environmental Protection Department (HKEPD) which has published a wealth of information on noise pollution and noise mitigation in the context of the densely populated, high-rise urban environment of Hong Kong[22].

In terms of construction noise, the HKEPD suggests that it is always better to consider reducing the noise at its source. Whenever possible, quieter working methods or technologies should be used.

[22] https://www.epd.gov.hk/epd/english/environmentinhk/noise/noise_maincontent.html

Certain advance and quieter technologies have enabled some construction works to be done much quieter as compared with conventional noisy equipment. For instance, some building demolition projects have adopted the more environmentally-friendly hydraulic concrete crusher instead of the conventional mounted breaker. In some projects involving the installation of underground utilities, pipe jacking is used instead of the conventional open-cut methods.

More specific noise mitigation measures for controlling noise at source, taken from the HKEPD, are listed below:

- Hand Held Breakers, fitted with mufflers can reduce exhaust noise and body-radiated noise by up to 15 dB(A) and 6 dB(A) respectively; while if fitted with a dampening layer an approximate 3 dB(A) reduction can be achieved.
- Excavator-mounted Breakers, resulting in a noise reduction of up to 10 dB(A)
- Exhaust silencers,
- Enclosures, either partial or full can result in a reduction in the overall noise level of up to 5 and 10 dB (A) respectively.

In addition to the mitigation measures discussed above, 'administrative' noise control measures can further reduce the noise impact from construction sites. Discussion on the wider 'administrative' noise control options for construction sites, taken from the HKEPD, is presented below:

- Providing adequate planning with contingency to ensure that lengthy operations (e.g. concrete pours) can be completed in enough time and within permitted hours;
- Scheduling construction works carefully to maximise any required noisy works during less sensitive hours (e.g. lunch time, outside school hours and avoiding examination periods). For unavoidable night works, carefully schedule any noisy works at locations close to any sensitive receiver to minimise sleep disturbance;
- Minimising the concurrent operation of noisy activities to reduce excessive cumulative noise;
- Keeping nearby residents informed of what is being planned so that they can understand inevitable noise impacts, resulting in fewer complaints;
- Establishing a communication channel such as a manned hotline to address concerns from the affected neighbours, so that immediate responsive actions can be taken to reduce adverse noise impacts;
- Switching off any equipment when not in use;
- Locating noisy equipment as far away as possible from any noise sensitive receptors;
- Using the site office as an additional noise barrier whenever possible;
- Promoting good site practice through regular site supervision and training to avoid unnecessary noise disturbance created from shouting, using

loudspeakers for talking, colliding of materials or striking of steel bars due to rough handling, etc.;
- Avoiding carrying out noisy operations, including delivery of noisy/bulky equipment /material, in restricted hours or early morning, to prevent the noise affecting the nearby noise sensitive receptors;
- Monitoring noise on site regularly. In the case of an exceedance of site noise limits, further mitigation measures may be necessary;
- Maintaining a good security system, especially at the site entrance, to avoid unauthorised entry of workers during restricted hours.

Case study examples of two construction projects, one in Lincolnshire in the east of England and one in London are presented in Appendix (Section 11). Both case studies adopt many of the noise mitigation and reduction strategies already discussed.

For the construction site in Lincolnshire, which was a UK Environment Agency flood/water barrier project, a Construction and Noise and Vibration Management Plan[23] was imposed as part of the planning approval for the scheme.

The Plan states that Best Practicable Means (BPM) of noise control will be applied during construction works to minimise noise at neighbouring residential properties and other sensitive receptors arising from construction activities. General principles of noise management are outlined in the Plan, including measures for controlling noise at source and more generally across the site through administrative and legal controls, control of working hours etc. Reference to BS 5228 is also within the Plan, along with specific noise control measures for particular activities.

For the construction site in London, which was a Crossrail station/ticket hall project, the importance of the legal and regulatory framework is emphasised, again with reference to BS 5228. The use of noise modelling/prediction, compliance monitoring and of effective community liaison were also key success factors for the construction project[24].

6.4 Industry (wind turbines/farms)

Similar to aviation, wind turbine noise reduction includes the reduction of noise at the source, land use planning and operational restrictions.

Source reduction

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[23] https://consult.environment-agency.gov.uk/engagement/bostonbarriertwao/results/appendix-1---max-forni_s-proof-of-evidence--construction-noise-and-vibration-management-plan-.pdf

[24] Yuyou Liu and Y. Gao (2017). Good practice case study of managing construction noise in Central London; Conference Paper from the 24th International Congress on Sound and Vibration, London (July 2017).

Trailing edge noise usually defines the lower bound of wind turbine noise. A first obvious noise reduction technique is to lower the turbine RPM or to reduce the local angle of attack by reducing the blade pitch. Theoretically, a 20% reduction in RPM already gives a noise reduction of 5dB. Sadly, both come at a cost of the generated power. Another method is modifying the blade geometry. In a laboratory test at NLR, an optimised air foil realised a 4dB noise reduction, without a significant degradation in aerodynamic performance. Another blade modification is adding serrations to the trailing edge. The serration concept was investigated in a number of experimental studies on two-dimensional air foils and model scale rotors. Typically, overall noise reductions of up to about 4dB were achieved (Oerlemans, 2012).

Land use planning

The number of locations where wind turbines are allowed are restricted by noise constraints, third party risk and visual factors (e.g. shadow flicker).

No houses may be built within certain noise levels or noise loads. The maximum allowed values may depend on wind speed (higher wind speed increases the background noise) and location (rural, residential and sensitive areas), and the time of day. Methodology and limit values vary wildly throughout Europe ranging from 35db(A) (residential night limit in Germany) to 47dB(A) (Lden, The Netherlands) (Nieuwenhuizen, 2015).

In addition, third party risk due to blade separation within 200 metres limits developments near residential areas or critical infrastructure regardless of noise levels.

The final constraint has to do with shadow flicker (alternating shade caused by the moving turbine blades). In The Netherlands, no one must be exposed to shadow flicker for more than 21 minutes per day, for more than 17 days per year.

Operational restrictions

If shadow flicker cannot be prevented with the placement of the turbine, a so-called shadow flicker protection system can be installed. This system monitors the light conditions and position of the sun and can automatically shut down the turbine if shadow flicker might occur at nearby buildings (DNV.GL, N.D.).

6.5 Domestic and Leisure Activities

There are no dose-response relationship curves for domestic and leisure noises. Accordingly, there are also no guidelines or directives as there are for industry, road, rail and construction noises. The WHO regional office Europe published the noise guidelines for environmental noise, in late 2018. It seems, this is the first time leisure (and related) noises have been brought up for a consideration like that. However even after excessive skimming of existent literature by multiple researchers there are no evidences to be found in regard to the typically reported health outcomes. Across all the noise sources examined so far, domestic and leisure borne noises are by far the most scientifically unnoticed. So far there has only randomly been solid scientific findings at all, it is a topic that is just starting to raise interest throughout the scientific community and the authorities, mainly due to the evidence of noise impact on health. Throughout the search for literature for this review there have only very, very few examples been found that deal in general with the sound sources in question. Mostly it is regarded as a local problem, which mostly occurs between neighbours and it is to deal with by consulting the local authorities when problems occur seldomly or a lawyer to deal with constant specific noise disturbances.

Findings for health effects from exposure to leisure noise (WHO, 2018) confirm that very little information are available for any of the noise derived health parameters reported for other branches (namely cardiovascular diseases, annoyance, cognitive impairment. Only a study on Hearing impairment and tinnitus has been carried out showing however very low quality of evidence. The WHO review encourages research in leisure and domestic noise health implications to sharpen its recommendations and gain insight into the impact on human health, perception and response.

A report from Austria estimates 13% of Wien's population to be disturbed by noise generated within their neighbourhoods (Leitgeb-Zach and Pfefferkorn, 2000). Even in an urban environment like Wien this is a much smaller percentage than is estimated for road traffic noise (see chapter Transportation, roads).

Due to the diverse sources, noise characters and lack of scientific findings, it is hard to identify clearly declared neighbourhood and leisure noise mitigation approaches. However, there are some findings that relate to the overall problem of neighbourhood noise annoyance. While mostly they aren't related directly or explicitly to noises being produced by sources in the direct neighbourhood like noise from alarms, noisy equipment, parties and barking dogs, there are related practices and intervention that promise to decrease exposure while people reside at home and would therefore be affected by all possible sorts of neighbourhood and/ or leisure noise.

Active and Passive Noise Cancellation:

In this paragraph, we will take a look at acoustical noise mitigation strategies that work on the receiver side. In recent years active noise cancellation/control [ANC] has become a matter of greater interest (Manuel, 2005). While it was first mostly related to headphones to decrease influence of disturbances while listening to music on-the-go, active noise cancellation has now become more elaborated and is available as a system that sound proofs a whole car (e.g. Elliot & Nelson, 1990), or an entire section of a flat, house or company (US 005699437 A, 1995), depending on the room size. ANC is "used to describe the process through which noise is reduced by introducing a sound wave that is inverse, or a mirror-image of the unwanted noise (Mitchell, 2001, p. 16)."

While this might not be solely aimed to neighbourhood noise, it is an approach that is available while at home and therefore - depending on where individuals live - significantly reduces noise being generated in proximity to their homes. As a result, an active sound cancelling device, being installed at home will naturally decrease neighbourhood and leisure noise.

The principle is rather simple: an ingoing sound is being recorded with a microphone which is directed towards a potential noise source while another microphone produces "a digital anti-noise signal configured to attenuate noise sensed by the first microphone" (US 8,750,531 B2, 2009) (compare Figure 16). Therefore ANC-systems fall into the category of sound masking devices.

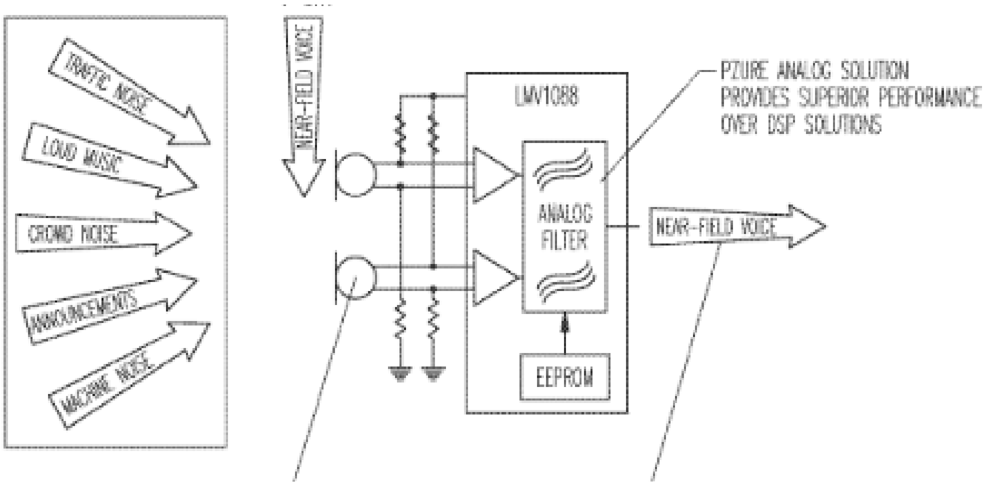


Figure 16: Sketch of active-noise-cancelling device by Delano and Waldstein in Patent US 8,750,531 B2, 2009

Lately efforts have been made that can be described as the next generation of noise cancelling, which enables devices to not only block out unwanted noises, but to also amplify desirable ones, like for example conversations being held at the same time an annoying noise is being produced. In literature those techniques and algorithms have been described as spectro-temporal detection–reconstruction [STDR] (Lee & Theunissen, 2015; Theunissen & Lee, 2013). These newly developed algorithms rely "[…] on an artificial neural network trained to detect, extract and reconstruct the spectro-temporal features found in speech" (p.1). Related features are already working in modern hearing aids (Brons, Houben, & Dreschler, 2014).

While ANC systems have become increasingly popular due to technical developments, like the further development of algorithms and dropping costs for soft- and hardware, there are other alternatives present that are "passive", i.e. they don't need an external energy supply and work all the time, without being configured, switched on or calibrated.

An example is the "Hafencity-Fenster" [Harbour-City Window] that has been invented to block out noises in flats, built in close proximity to Hamburg's harbour in northern Germany. Figure 17 shows the most elaborate version of it.

While there might be nothing new to the approach of soundproofing house construction elements, this window goes beyond the usual efforts, a double or triple-layer glass construction and is explicitly designed to reduce noises while partly open.

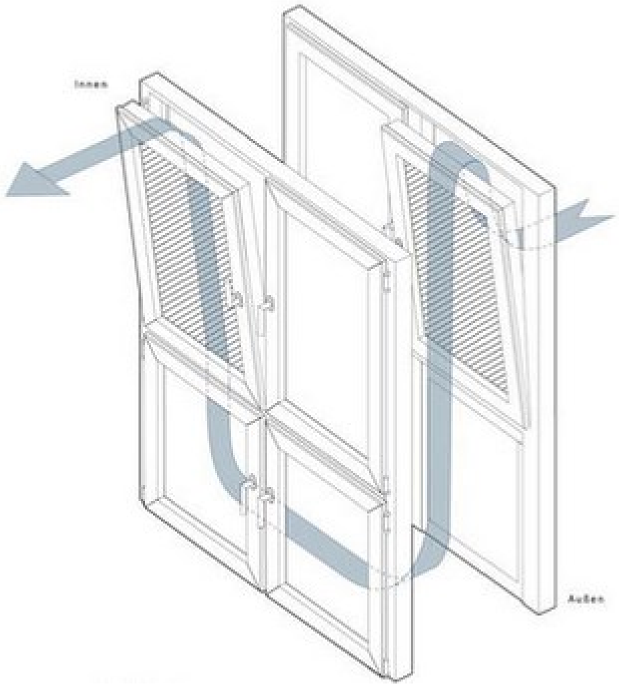


Figure 17: Sketch of the Hafencity-Fenster with redirected airflow. Retrieved from https://www.hafencity-fenster.de/, (Eilenburger Fenstertechnik GmbH & Co. KG, 2017), figure copied with permission of the CEO Gerold Schwarzer on the 28th Novembre 2018

The main idea behind the windows is re-directing the airflow through high absorbing materials and a two-layer construction. Even with a cracked window this construction enables a noise reduction between 35 and 46 dB, while still exchanging between 70m³ and 120m³ of air at 10 Pa. Closed windows enable more than 50 dB of total noise reduction. The development of the window has also received funding from the European Union's Horizon 2020 programme under the grant agreement no. 783717 (Sound-absorbing HAFENCITY windows), which makes it particularly worthy to be mentioned in this context.

Mitigation of Non-acoustical Neighbourhood and Leisure Noise-Annoyance

There are several communicational efforts to reduce noise by non-acoustical measures. The New South Wales Environment Authority [NSWEPA] for example has handed out a variety of brochures that delineate a bunch of solutions for mitigating all sorts of neighbourhood noises, each of which is dedicated to a different topic, like “Dealing with barking dogs”, or “Dealing with Neighbourhood noise” (see Figure 18).

Figure 18: Brochures made to depict solutions to different noise annoyance issues in the neighbourhood (New South Wales Environment Protection Authority [NSWEPA], 2017), retrieved from https://www.epa.nsw.gov.au/your-environment/noise/neighbourhood-noise.

Recommendations in these brochures are targeted directly towards specific noise sources and are accessible from the internet, with an emphasis on letting people resolve potential conflicts on their own, before contacting the authorities. These brochures offer a variety of self-applicable actions people can perform to reduce noise impact at any given time and place. In prospect of further considerations this may be regarded as an example of a communicational effort that increases perceived control in noise management (e.g. Donnerstein & Wilson, 1976).

Additionally, a growing body of research has identified greenspaces as non-acoustical resources which are able to mediate annoyance significantly in comparison to citizens who live in areas without access to/ or don't have a direct view on greenspaces (Dzhambov et al., 2018; Li, Chau, & Tang, 2010; Riedel et al., 2018; van Renterghem et al., 2015; van Renterghem & Botteldooren, 2016). Findings of this effect do not only relate to objectively measured greenspace like the normalized vegetation difference index [NDVI] (for a description see e.g. Carlson and Ripley (1997)) by geographical information system [GIS] percentage at a given point, but also to the perceived greenspace within a 100m buffer zone (Dzhambov et al., 2018; Li et al., 2010).

Related to these findings, there are additional evidences, that water areas like seas, ponds and rivers have a similar effect. While Li et al. (2010) propose that water elements ("wetland parks", p.1) can help mediating the effect of noise by just being at sight, evidence has emerged recently that also the sound of water has a considerable effect on the perception of (traffic) noise which is perceived as 1.7 times as loud compared to the water sounds (Leung, Chau, Tang, & Xu, 2017). The scientists see potential to employ these findings in sound masking techniques.

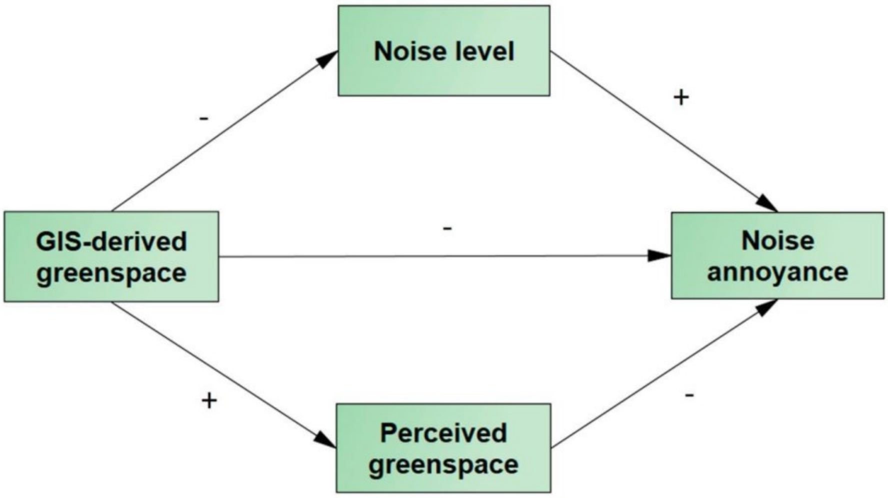


Figure 19: Conceptual diagram showing theoretically-indicated pathways linking Geographic Information System (GIS)-derived greenspace to noise annoyance. (Positive associations are marked with "+", and negative associations, with "−".) (Dzhambov et al., 2018).

7 Summary and key messages

The following sections summarise and provide key messages and lessons learnt from the cross sectorial analysis performed within this report. This includes information on background, legislation and particularly on best practices to abate or mitigate noise in non-aviation sectors identified as Road, Rail, Construction, Industry and Leisure.

For each sector a summary of key findings regarding modelling, monitoring, mitigation strategies and the role of the community engagement in addressing the noise and related annoyance issues are presented below.

7.1 Transportation - Road

Roads are the dominant sources of noise affecting communities in Western Europe. Road traffic noise is caused by vehicle engines, tyre-road interactions and vehicle-air interactions. Vehicle speed, traffic composition, driver behaviour and road surface composition and integrity are all important factors determining the level of noise emitted from roads.

Unlike in the aviation sector, where discrete noise events (such as aircraft taking off and landing) are dominant, road noise tends to be more constant in nature (especially during the day time on strategic roads).

Road noise tends to have a localised impact and can elicit an emotive response from those that live or work near to busy roads. Planned new roads or long-term traffic management schemes that redirect traffic into otherwise unaffected locations can result in a significant localised resistance/protest (often directed at the local authority/highways authority). Noise associated with new airports or significant airport extensions tends to result in national-level media coverage with associated discontent directed towards the national government/state.

Monitoring

Noise monitoring can be carried out using a range of different instruments depending on the time over which the measurements need to be made. If the measurements are to be made over a short period (such as boundary monitoring around a construction site), a handheld sound level meter may be suitable. If the measurements need to be made over a longer period (for example to assess the long-term noise exposure of a residential dwelling near a new road), an outdoor environmental measurement system may be needed.

Modern noise monitoring equipment varies significantly in cost, based on the robustness and sophistication of the measurement device and its post-processing capabilities (e.g. the range of metrics the device can calculate - LAeq, Lden, LAmax etc.). Most environmental noise monitoring systems, especially those that are designed to be left in-situ for substantial periods of time (days/weeks/months), include continuous data loggers that are accessible through telemetry or include the functionality to be able to host/share data on a website/server that can be interrogated by stakeholders.

Modelling

Modelling software and associated calculation methodologies are well developed for road noise sources. For example, the UK's Calculation of Road Traffic Noise (CRTN) methodology enables the calculation of noise levels at different distances from a highway based on traffic characteristics, intervening ground cover and road configuration etc., and has been incorporated into leading proprietary noise modelling software packages such as SoundPLAN and CadaA.

The European HARMONISE/IMAGINE road surface model has been used to assess the potential noise reductions achievable with different low-noise road sources in different European countries. In Hong Kong, detailed noise modelling has been used to assess the effectiveness of acoustic balconies for residential apartments adjacent to busy urban roads, prior to full-scale, in-situ acoustic testing.

In relation to strategic noise mapping, various European countries, including Austria, France, Germany, The Netherlands , the Nordic region and the UK have developed noise calculation methodologies and models for the assessment of road noise, each with different model output metrics and varying source, pathway and receptor parameters.

Community Engagement

The specific response of individuals within a given community to road noise can vary considerably due to some non-acoustical factors such as, age, sex and socio-economic status (demographic factors), general noise sensitivity (attitudinal factors), and the amount of time spent at home, or the visibility of the noise source (situational factors). Numerous studies have investigated the effects of community noise and the noise exposure dose-response of individuals. Active engagement and ongoing and effective communication with local populations that are near to sources of community noise is now considered to be critical (and indeed best practice) in managing noise impacts/exposure.

Mitigation and Reduction Strategies

Numerous noise mitigation/reduction techniques for road sources are detailed in the literature. These measures can generally be categorised as those that can be applied at source, those that can modify/disrupt the noise propagation pathway, and those that can be applied at the receptor. These measures can be applied in isolation or as part of a multi-functional noise reduction strategy/design.

- Low-noise surfaces – porous asphalt mixes of varying composition and thickness; effective and ongoing maintenance of the road surface is important; transferable to airport apron area

- Low-noise tyres – currently available in the EU but with potential for further development (e.g. Michelin TWEEL tyre design).
- Electric/hybrid vehicles - transition away from vehicles with traditional internal combustion engines.
- Driver behaviour – public educational campaigns to promote a more passive driving style; 'eco driving' training for freight/delivery/fleet companies; active road signage to influence driving style/behaviour at night, for example.
- Junction design – improved design to enable smoother driving with less acceleration/deceleration; for example, the replacement of signalised and non-signalised junctions with roundabouts or mini roundabouts, respectively.
- Traffic improvement schemes – can result in noise reductions as a 'by-product' of changes in traffic volume, speed and composition.
- Noise barriers – location (roadside or median), height, length and acoustic performance/integrity of the barrier are key considerations.
- Façade insulation – secondary or double glazing can be effective but should be considered a last resort (i.e. after measures at source and/or along the propagation pathway are not sufficient/effective); use of 'green wall' technology to reduce reflected noise in street canyons.

<u>Case Study and lessons learnt</u>

Hong Kong is well known for its high rise, high density urban environment. It is often necessary for new housing developments, including public housing, to be built next to heavily trafficked and congested roads. Four specific receptor-based innovative noise mitigation solutions for the public housing to protect residents from road traffic/surface transport noise were considered and assessed by the Hong Kong Housing Authority – namely modular apartment design, acoustic windows, acoustic balconies and enhanced acoustic balconies. Noise reductions for the modular apartment design, acoustic windows and acoustic balconies are estimated to range between 3 dB(A) and 8 dB(A). Enhanced acoustic balconies are likely to achieve a noise reduction closer to 10 dB(A). These noise attenuation methods are important in highly constrained environments where surface transport is a key component of the noise environment.

Key lessons learnt are:

- Roads are the dominant sources of noise affecting communities in western Europe. Vehicle speed, traffic composition, driver behaviour and road surface composition and integrity are all important factors determining the level of noise emitted from roads.
- The calculation/modelling of road noise is widely undertaken in Europe. For example, the UK's CTRN methodology has been incorporated into proprietary noise modelling software packages.
- Numerous mitigation measures for controlling road noise are detailed in the literature. Measures aimed at controlling noise at source are more

effective than those aimed at modulating the propagation pathway or directly protecting the receptor.
- Case study from Hong Kong indicates that receptor-based mitigation can be effective and is important in densely populated and spatially confined environments where options for source- or pathway-based mitigation options are limited.

7.2 Transportation- Rail

With road traffic being the biggest sector for noise complaints, railways come in second regarding the noise impact on communities. Although train speeds and driver behaviour are strictly limited by regulations and schedules they run on, there are various other factors besides the speed a train drives at that affect the noise emissions, which are mostly found in geographical and track related components.

Like road traffic however, railway noise is relatively constant, except for the characteristic brake squeal and the heavy vibration that goes along with a train passing by. If the train is pulled by a diesel locomotive, there is also a high level of engine noise involved.

The railways have a much better image in terms of noise perception, the best of all of the mentioned noise sources in this report, the reason is believed to be recognised as the most environmentally friendly mode of transport. As a result, the public opposition, compared to aviation and road traffic, is considerably smaller.

<u>Monitoring</u>

Railway noise is extensively monitored and measured. There are standardized procedures for measuring railway noise, which is 1.2 meters over the centre of the track and 7.5 meters from the side of the track. A lot of different equipment is available for noise monitoring, reaching from handheld devices to installations that monitor noise emissions, at any given time and send data immediately to a control centre.

<u>Modelling</u>

There is a sophisticated noise modelling software available, like the European developed IMAGINE software, that takes into account all relevant parameters. It features detailed entries for all relevant parameters, not only for the train, but also for the surrounding area, including possible noise mitigation interventions.

<u>Community engagement</u>

Rail companies invest a lot of effort into community engagement and communication tools. It goes as far as driving a big truck through all of Germany to showcase the impact of noise mitigation interventions to the public using VR simulation. Additionally, in all major construction projects there are dialogue forums that do involve community members along with railway staff, to demonstrate openness for discussion and giving residents a chance to participate in the process.

Mitigation and Reduction Strategies

Regarding the overall noise mitigation a so-called system approach is taken that enables to take the whole system into account:

- The vehicle, with the wheel, the brakes, the bogie or axle and the vehicle body, all connected by springs and dampers,
- The track, with basic elements the rail, the rail fixation with rail pads, the sleeper, the ballast and the sub-soil.
- Noise barriers
- Facade insulation
- Train design
- Friction modifiers
- Brake technology
- Depots
- Shunting Yards
- Steel Bridges
- Vibration

Case Studies and lessons learnt

The case studies highlight the interaction between noise mitigation interventions and communication.

The approach in case study 1 was to compare a region given information to and another region that had no information, while both were treated with the same procedure of rail grinding. Although rail grinding isn't commonly applied, because it isn't as effective as the otherwise commonly applied noise barrier, it offers a considerable mitigation and is applicable where noise barriers can't be installed due to geographical reasons. As the rail grinding failed its purpose due to a broken rail grinder, the role of giving out information was clearly shown, as people who were supplied with information were considerably less annoyed after the procedure had been executed, even though most of them didn't notice any works on the rails.

Case study 2 involved VR simulation to show the effects of a new type of brakes that can be retrofitted to conventional rolling stock. The measure drastically reduces rolling noise from existing material without the need for an expensive overhaul of the braking system. The simulations created awareness and enthusiasm among rail professionals to reduce the primary source of railway noise from existing rolling stock.

The takeaway lesson here is that communication and education can help to support a holistic noise management and even have an effect on their own.

Key lessons learnt are:

- trains are perceived as publicly useful and environmentally friendly. However, they are very noisy and cause major disturbances in their closer area at both, high and low speeds
- vibration is a considerable issue with trains
- there are a lot of noise mitigation strategies that are applicable at the train, at the track or at the surrounding environment.
- railway companies focus on communication and community involvement strategies
- the case studies illustrate the success of communication efforts

7.3 Construction

Construction sites can generate significant, but often relatively short-term, levels of noise that can disturb residents in their homes and other noise sensitive receptors (e.g. offices). Construction sites are inherently noisy, and often involve unavoidable activities such as piling, demolition and the use of pneumatic equipment, all of which can lead to excessive levels of noise on site. A balancing act between the needs of the developer to carry out necessary works and the rights of neighbours to enjoy their properties (or place of work) is required.

Like in the aviation sector, construction noise tends to have a localised impact, often with a visual component, that can elicit an emotive response from those that live or work near to construction sites. Complaints regarding noise from construction sites are often directed to the local authority or the construction contractor. However, active community engagement is often a key factor in the successful management of construction noise (especially for large, complex sites which may operate for several months, even years).

Monitoring

Noise measurement/monitoring is regularly used to assess the impact of construction noise, and specifically to assess compliance with specified noise limits applicable at the site boundary or at noise sensitive receptors (e.g. residential dwellings) near the construction site. 'Live' measurement data feeds can be used by site operatives to modify or stop certain activities if noise limits are near to, or are, being breeched.

Modelling

Noise modelling has been used successfully for large-scale construction projects, enabling the iterative calculation of noise impacts at sensitive receptors based on different site plant configurations, operating times and new and updated source noise data for key items of plant. This iterative modelling approach enables the construction contractor to demonstrate to the regulator that any planned changes to the already agreed site operating 'envelope' would have no significant adverse impact on local noise sensitive receptors.

Community Engagement

Active engagement and ongoing and effective communication with local populations that are near to construction sites is now considered to be critical (and indeed best practice) in managing noise impacts/exposure. In London, good practice guidance on noise control for construction and demolition sites has been published and recommends that a community liaison plan and a complaints procedure is developed for all construction sites, regardless of the size/complexity/noise risk of the project. The same guidance also recommends, depending on the (noise) risk of the site, regular meetings with the local community and regulator, newsletters and email communications with the local community, and the development of project-specific websites to share information about the construction project and any noise issues.

Mitigation and Reduction Strategies

Construction noise can be managed by using a combination of mitigation measures designed to control noise at source (including how the site is managed and how equipment is used and maintained) and those designed to control the propagation of noise from site (for example the use of screens or bunds). In terms of controlling noise at source, there are many general measures that can be applied at all construction sites, including:

- Avoiding unnecessary revving of engines and switching off equipment when not required.
- Keeping internal haul routes well maintained and avoiding steep gradients.
- Use of rubber linings in, for example, chutes and dumpers to reduce impact noise.
- Minimising the drop height of materials.
- Starting plant and vehicle engines sequentially rather than all together.

In relation to controlling the propagation of construction noise, increasing the distance between the noise source and noise sensitive receptor(s) and the installation of bunds, screens and barriers can all help modulate the propagation of noise from construction sites.

Case Studies and lessons learnt

For a flood/water barrier construction project in Lincolnshire, UK, a Construction and Noise and Vibration Management Plan was imposed as part of the planning approval for the scheme. The Plan states that Best Practicable Means (BPM) of noise control will be applied during construction works to minimise noise at neighbouring residential properties and other sensitive receptors arising from construction activities. General principles of noise management are outlined in the Plan, including measures for controlling noise at source and more generally across the site through administrative and legal controls, control of working hours etc. Specific noise control measures for particular activities are also detailed in the Plan. For a Crossrail station/ticket hall construction project in central London, the use of noise modelling/prediction, compliance monitoring and effective community liaison were also key success factors for the construction project.

Key lessons learnt are:

- Construction sites can generate significant, but often relatively short-term, levels of noise.
- Construction noise tends to have a localised impact, with any complaints usually directed to the local authority or construction contractor.
- Balancing act between the needs of the developer to carry out necessary works and the rights of neighbours to enjoy their properties (or place of work) is required.
- Monitoring and modelling of construction noise is quite commonplace, especially for large and complex construction projects.
- Active and ongoing community engagement is important in communicating and managing noise impacts/risks of construction sites.
- Mitigation measures are well understood and range from those that are applicable at source to those that modulate the noise propagation path. There are several general mitigation measures that can be applied at all construction sites.
- Case studies from the UK emphasise the importance of the regulatory framework in securing effective mitigation. Noise modelling, monitoring and community engagement were key elements of successful construction noise management.

7.4 Industry (WindTurbine)

Wind energy is a key component in the energy transition from fossil fuels to renewable and sustainable energy sources. In order to reach climate goals for 2020, 2030 and 2050, large scale developments of on- and offshore wind parks are planned throughout Europe.

Onshore wind turbines potentially expose citizens to noise, shadow flicker, third party risk and affect the natural landscape. Therefore, plans for new wind parks can face significant opposition.

<u>Monitoring</u>

Monitoring of wind turbine noise is according to strict standards (IEC 61400-11) which details how noise should be measured, including hardware, data and reporting requirements.

<u>Modelling</u>

A hybrid approach assessing different sources separately using finite-element methods (instead of resolving the entire system) currently represent the state-of-art and can be used to assess the impact of design changes.

<u>Community Engagement</u>

While people are generally favourable towards green energy, local communities fear wind turbines due to noise, visual pollution or a negative impact on property values. Plans for new wind parks come with environmental impact assessments that quantify the impact of the wind park in terms of noise, third party risk and shadow flickering. People are then allowed to comment and oppose the plans. If the plans are within norms, the construction can commence.

Opposition to wind parks can result in protests, lawsuits and project delay. To prevent high costs, delay and political interference, developers of wind parks try to build support for their plans by proactively informing residents of the plans, addressing concerns and involving them in design changes (such as the layout of the wind park).

Mitigation and Reduction Strategies

Similar to aviation, wind turbine noise reduction relies on the reduction of noise at the source, land use planning and operational restrictions.

Adaptation of the blade geometry or addition of serrations can reduce the noise by 4 dB (each).

Noise limits are set on national level and often distinguish between the type of location (rural, urban), time of day and wind conditions. In addition to noise limits, wind parks are limited by third party risk and shadow flickering constraints. No houses are allowed within these limits.

Regarding shadow flickering, residents sometimes have the ability to (temporarily) shut down a nearby wind turbine if shadow flickering occurs.

Case Studies and lessons learnt

The case studies review the development of two wind parks in The Netherlands: One to replace an existing wind park, the other entirely new. The two studies highlight the possible differences in public reaction to wind energy. Both cases included a proactive community campaign. However, the timing of the participation process, the familiarity with wind energy and the responsibility for project coordination led to different responses. Although based on a sample size of only two, it appears that a locally coordinated engagement process initiated at the start of the project that allows community input on turbine location for residents who are already exposed to wind turbines, leads to more favourable results. What might be surprising is the potential impact of 'local history' that can fuel opposition to developments beyond reason when not addressed.

Key lessons learnt are:

- The engagement process should start as soon as possible when there are still design choices to be made.
- Local support can be increased by involving communities in the decision making process, either by asking for their input or be clearly explaining the rationale behind the design choices.

- Visual aids can help the community build an understanding of the impact of the plans on their local environment. It can be highly favourable to create and communicate a tangible benefit to those affected by the developments, e.g. participation via an energy cooperation or an energy discount.
- Finally, the local element is also important when it comes to decision making. Remote decision making might lead to alienation and distrust, especially when local history and existing tensions are ignored.

7.5 Domestic & Leisure Noise

Domestic and Leisure noises are not a category like the others treated in this report. Due to the lack of a definition, most things that intuitively fall into that category are not scientifically recognized.

Most domestic and leisure noise issues are treated as single events, that happen randomly and only over a short period of time, e.g. a neighbour moving his lawn, a dog barking, or even a concert that happens once a year, but only for a couple of hours or in some specific days. Accordingly, things in this sector are handled differently from the others. Many of the categories treated in context of this review do not apply to the issues caused by domestic and leisure noise sources, while others are a lot more relevant, like for example complaint management. Most activities performed in this branch are regulated by day and night, i.e. between 23:00 and 7:00 apply stricter rules for noise emissions than during the rest of a day.

However, these nuisances caused around where people live also have a major impact on people’s lives, as they mostly occur where people seek peace and relaxation at home, and as a result are eligible for quietness.

Monitoring

Monitoring a whole neighbourhood regarding to noise issues is almost impossible. The areas can be very wide, so an expensive system would have to be installed to permanently grant for a quiet neighbourhood.

At single events like concerts noise measurements are carried out during the event, as it offers a possibility to intervene while the nuisances occur. There are also exceptions for single events.

Modelling

Noise is modelled using calculations for special events with different sorts of software, taking into account spatial and geographical features of a region. Noise emissions are mostly set in relation to the closest *noise sensitive receivers* (NSRs), to which the sound propagation is strictly limited to a given level, depending on the proximity of the event and the characteristics of the NSR (i.e. for a hospital there are other restriction than for an office building).

Community Engagement

There are not many community engagement interventions to be found in regards to domestic and leisure noise management. For some exceptions, people are informed about particularly noisy activities that may endure over a couple of hours or days. Mostly, people are advised to act on their own when it comes to the aforementioned disturbances. There are examples of leaflets being distributed to teach residents on their own how to act in cases of noise being generated in their living environment.

Mitigation and Reduction Strategies

As stated above, domestic and leisure noise interventions are mostly complaint driven and due to their temporal character, the management mostly involves complaint management. However, there are technical solutions available that are applicable at home. Active and passive noise control devices and constructions may not be targeted towards any specific domestic or leisure noise source, but are effective in sound proofing people's living environment. The further treatment of complaints, the restriction of hours, the insulation of buildings and spaces and the immediate reaction to the infringement of community noise guidelines are the only cases of domestic and leisure noise mitigation or intervention that are steadily executed, according to the examples visited.

Case Study and lessons learnt

The presented case studies show a couple of the mentioned interventions. Most of them however do not feature an adequate noise monitoring or a report. Most methods seem to be superficial and cannot compete with the results and findings from the other sectors. A competent evaluation of noise mitigation is mostly left out and the assumption that due to a lack of complaints, residents are not annoyed is question-worthy to say the least. The case studies demonstrated illustration to decrease noise impact at places. The case study from Hong Kong showed, that basic noise insulation can be done with rudimentary tools and the case study by Marchuk and Henry (2016) illustrated, what can be done within the scope of soundproofing to realize both a pleasant nightlife and undisturbed living.

Key lessons learnt are:

- Domestic and leisure noise is the most disregarded sector by science and authorities
- There is no lobby or representation of interest
- Domestic and leisure noises are mostly being treated as a collection of the other noise sectors and are not clearly defined
- Mostly complaint management and immediate actions are applied to resolve conflicts due to noise annoyance.

8 Transferability to the aviation sector

The set of non-aviation sectors analysed and presented in this report provide a range of different noise sources and problems which, in some cases, are broadly comparable to the sources and problems apparent in the aviation sector. However, the case studies and noise mitigation strategies discussed in this report, also indicate that there are some lessons that can be learnt (from the non-aviation sectors) and some elements that are potentially transferable to the aviation sector.

Roads are the dominant sources of noise affecting communities in Western Europe. Unlike in the aviation sector, where discrete noise events (i.e. aircraft taking off and landing) are dominant, road noise tends to be more constant in nature. Like the aviation sector, road noise has a localised impact and the emotive responses of communities affected by road noise are often similar to those affected by aviation noise.

The specific response of individuals within a given community to road noise can vary considerably due to non-acoustical factors, general noise sensitivity (attitudinal factors), and the amount of time spent at home, or the visibility of the noise source (situational factors). In this regard, the main noise mitigation/reduction strategies for road sources that can be transferred to the aviation sector are those that can modify/disrupt the noise propagation pathway, and those that can be applied at the receptor. Additionally, community engagement can also be an important strategy, although better examples have been identified in other sectors.

From the analysis of the roads sector, we envisage that the most relevant and transferable case study is the one related to the Hong Kong Housing Authority (HKHA), who has developed innovative noise mitigation solutions for public housing projects. The case study indicates that receptor-based mitigation can be an effective solution for densely populated environments where options for source- or pathway-based mitigation options are limited. Noise reductions for the examples and designs provided in the case study are estimated to range between 3 dB(A) and 10 dB(A).

With road traffic being the biggest sector for noise complaints, **railways** come in second regarding noise impact on communities. Despite railway noise has similarities with the aviation sector, in terms of being discrete events and predictable frequency, the public resistance to railways/railway noise is considerably less than in the aviation and road sectors. This is most likely due to the relative positive/environmentally friendly image of this mode of transport. However, by exploring and scanning existing literature and case studies, another important factor that can definitely be used as an example for other sectors, is the fact that rail companies invest a lot of effort in community engagement and communication tools (e.g. driving a big truck to showcase the impact of noise mitigation interventions to the public, using virtual reality to give perceivable effect of a specific intervention), including the setup of dialogue forums for major projects that include community members along with railway staff. This is providing important signs of openness for discussion, facilitating a participatory role for residents throughout the process. The reported case study illustrates the success of the communication efforts.

Like in the aviation sector, **construction** noise tends to have a localised impact, often with a visual component. Likewise, complaints regarding noise from construction sites are often directed to the construction contractor or responsible authorities. However, in this sector active community engagement is often a key factor in the successful management of construction noise, especially for large projects lasting for months or years. According to the literature review, the best case study was the *good practice guidance on noise control* for construction and demolition sites for London. It recommends that a community liaison plan and a complaints procedure are developed for all construction sites, regardless of the size/complexity/noise risk of the project. Also, for certain larger sites it requires regular meetings with the local community and regulator, newsletters and email communications and the development of project-specific websites to share information about the construction project, and any noise issues. The best example of the good practice guidance was identified in the Crossrail station/ticket hall construction project in central London, where the use of noise modelling/prediction, compliance monitoring and effective community liaison were key success factors for the construction project. This gives to the aviation sector even more evidence of the importance of the regulatory framework in securing effective mitigation through effective and continuous community engagement and communication.

For the **Industrial example on wind turbine** noise, effective reduction of noise is related to mitigation at source, effective land use planning and operational restrictions, the latter being similar to the aviation sector. There is another similarity with the aviation sector as well: there is a perceived ambiguity by the public in where to locate air routes or wind turbines, as they may have less (perceived) constraints, instead traffic or railroads is accepted that must be placed between major cities with a limited number of alternative trajectories. In this sector the engagement process plays a very important role and should start as soon as possible when there are still design choices to be made. Evidence shows that local support can be increased by involving communities in the decision making process, by asking inputs or communicating effectively the rationale behind the design choices. Instead remote decision making might lead to alienation and distrust, particularly when local history and existing tensions are ignored. To prevent high costs, delay and political tensions, developers of wind farms tend to build support for their plans by proactively informing residents, addressing concerns and involving them in the design process.

From this sector, an interesting **alternative conceptual intervention** can be extracted. This is related to the fact that many infrastructures across different sectors have the common element of producing an economic benefit (from a business perspective). However, on the negative side, another common element is the impact and detriment to local communities in terms of noise which has an impact on the monetary value of land and houses, in addition to the annoyance that it causes residents. For that, an alternative conceptual intervention would be to provide to local communities, in addition to noise abatement measures, a *share of the economic benefit* generated by the infrastructure responsible for the noise impact.

Figure 20 below illustrates, conceptually, how this intervention may work, by giving part of the infrastructure generated benefit, in the form of *shares assigned to the existing properties* owned by the affected communities. In this way each property value will be topped up by the presence and economic benefit of the infrastructure and, more importantly, it will stay with the property and not with the original owner. This should mitigate the fear and perception that local affected communities are the only ones to experience a disbenefit. This approach can be considered as another form of compensation.

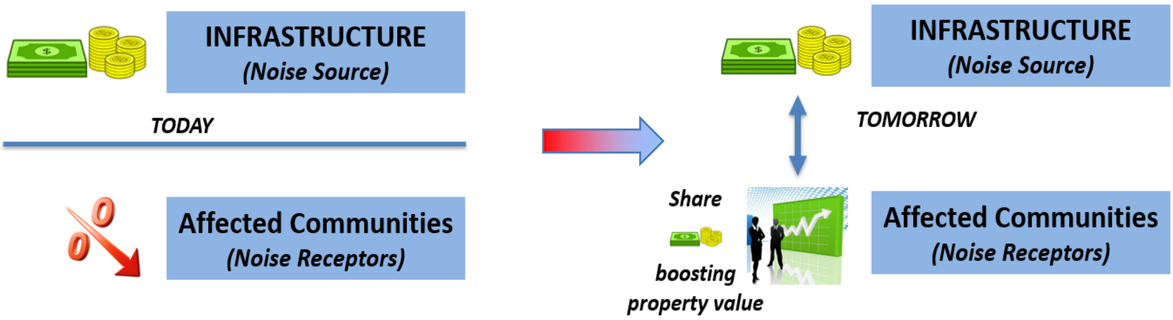


Fig. 20 Scheme of shared benefits

Finally, in the **leisure & domestic** sector, some of the technical solutions available and applicable at home (see section 6.5) are considered to be transferable to the aviation sector. Active and passive noise control devices are effective in sound proofing people's living environments. Additionally, the restriction of hours, the insulation of buildings and spaces, and the immediate reaction to the infringement of community noise guidelines are the main cases of domestic and leisure noise mitigation or intervention that can be considered for the aviation sector.

9 Conclusions

This report meets Sub-Task 2.3.4 requirements, presenting monitoring and modelling approached and several case studies proposing different strategies for the reduction of noise from other transport modes (road and rail), as well as from industry, construction and domestic and leisure activities. The main idea is to learn from other sectors how better to mitigate the noise impact in the aviation sector, to extract information for the Best Practice Portal (WP5) and identify priorities for research in WP3. The report provides a comprehensive review of the identified *other relevant sectors-as noise sources-*, and further, some case-studies are presented to be analysed for suitable transferability knowledge in the aviation sector. Additionally, where appropriate, best practice to be identified and suggested to be adopted by aviation.

The examples given from different transport sectors (road and rail), as well as those from other noise sources (wind-farm, construction, etc.) show some similarities to aviation on the steps taken to assess and manage noise impact. They all consider monitoring, and most of them modelling and mapping before selecting mitigation measures to reduce the noise impact. Some lessons learned can be shared and explored further, illustrated in the *community engagement chapter* and in several examples of case studies presented in the Appendix.

However, the important lesson aviation needs to learn is that, since population in urban areas is likely to be exposed to many and diverse noise sources, the perception of noise disturbance can be very different also, depending on which *other sector sources* are present. Hence, a holistic approach to reduce annoyance seems to be the best way forward, especially in urban areas.

Thus, a topic for future research should include *a more holistic approach* to assess noise impacts from different sectors, in an integrated and coordinated manner, since what remains essential is to reduce the annoyance and health impact due to noise, while the type of source remains important only in selecting appropriate mitigation strategies at source.

New residential developments have sprung up in towns and cities across the world, attracting people to live closer to the transport network that moves them around. This explains the importance of being proactive in using the best communication tools in engaging with communities. The example presented from the rail sector is illustrative.

There appears to be broad agreement between the professionals from different sectors that the best option in controlling the noise impact on the local community is a set of combined mitigation measures. However, all seem to agree that a proactive attitude and information on intervention(s) will have a positive feed-back with lasting results.

The noise emission levels from aircraft activity are, conventionally, determined by prediction (calculation) rather than by measurement. This is also the case with assessments of other transportation sources, such as road and rail traffic. The principal reason for this approach is that noise levels from an airfield/airport will vary considerably from day to day, both due to variations in operations, and due to the influences of weather.

The lessons learned from the examples presented in this report lead to the following suggested areas of additional research:

a) *Sharing the benefits*: proposed topics to be further developed:

- Sharing the benefits of noise improvements – new research on *noise envelopes* is suggested for WP3 on novel approaches to LUP. One method to lock-in the concept of *sharing the benefits* of airport expansion, as part of the planning process, is to set a noise envelope when developing capacity.

Noise envelopes are a concept utilised by policy-makers and airport officials to allow for capacity expansion within a noise-sustainable environment, by limiting the growth at an airport within set parameters based on noise metrics. The ANIMA project has several examples of fast-growing airports (Iasi, Cluj, Catania), where this concept can be successful tested. WP2 may also explore the concept as part of T2.5.

- Another approach that could be transferred to the aviation sector is the one highlighted in the case study of the Dutch wind farm. Infrastructures producing noise, generally have also a return of investment and profit, which today is given to shareholders. The proposition is that part of the economic benefits could be shared with existing buildings and residents in the form of "shares" linked to the properties, to reduce at least the disbenefit of depreciation. However this is a delicate territory that need further study and attention.

b) *Engaging the community:* developing communication tools to build trust

Different examples presented in Appendix emphasise the importance in building trust between relevant parties. A particular problem within densely populated communities is the perception that airports, airlines and government are focussed mainly on expanding capacity with little consideration of the detriment to the people who live nearby. The examples from the rail industry on the interaction between a noise mitigation intervention and a communicational effort, or the multi-functional mitigation approach taken from a scheme in Austria, may be worth of consideration by aviation stakeholders.

c) *Tools and methods available to incentivise industry to adopt different noise mitigation approaches:*

- additional research on noise control through *architectural acoustics* will include: interior sound reverberation reduction, inter-room noise transfer mitigation and exterior building skin augmentation.

- *Interactive noise mapping* can also be an effective means of communicating noise risks to the public

- *barriers*: more research in (computer) modelling is required to design the barrier since terrain, micrometeorology and other local specific factors make the task a very complex undertaking. The example taken from a roadway in calm or strong prevailing winds can produce a setting where atmospheric sound propagation is difficult to attenuate by any of the existing noise barrier. Noise barriers can be applicable for existing or planned surface transportation projects, including airports. They are probably the single most effective weapon in retrofitting an existing roadway, and commonly can reduce adjacent land use sound levels by up to ten decibels.

- *hazardous noise* can be controlled by reducing the noise output at source, minimising the noise as it travels along a path to the listener, and providing equipment to the listener or receiver to attenuate the noise

d) *Innovation in urban integration* – mitigating noise and vibration from city centre railways: existing innovations in track design mean nearby residents can live in harmony with the railways. Researching urban integration is suitable for city airports (Iasi a/p is located at 8 km from city centre)

II. **Exploring further, adopt and/or transfer the existing knowledge from other sectors:**

a) Publishing best-practice guidance for wind farms or construction, on *communicating noise information and impacts for local communities* and other stakeholders (Consultative Committees and other groups), can be used to better understand the impact of aviation noise and to hold airports to account.

b) Examining the use and utility of *post-code mapping tools* and deciding whether there would be benefit in developing a national airport noise post-code mapping tool in order to help people understand the impact of noise on their area (subject for research in WP3).

c) Investigate *sustainable transport schemes*, which would have the additional benefit of improving local air quality which is also damaged by airport operation.

d) Co-operative ownership / share distribution

A more radical mechanism to redistribute the benefits of additional airport capacity would be to develop a model that allows for a direct or indirect share of ownership for local people. The example from the wind farm on sharing the infrastructure benefits can be transferred to airport local communities represented by house-holds. This will allow residents to benefit from the airport's profits, while this model could also have the advantage of allowing locals to feel more involved in the operation (activity) of the airport, and develop the feeling 'I belong here'.

10 APPENDIX: Case studies

Consistently with the approach undertaken in the whole Work Package 2 on investigation of best practice and noise abatement strategies, an interview format has been set up for those case studies that had the opportunity to further investigate the case with a stakeholder involved at the time of the intervention.

It is anticipated that, the number of interviews made available are limited due, mainly, to the unavailability of people involved at the time of the intervention, or, in other cases, due to information not being available on the best contact person.

When interview was arranged at the beginning of the case study, name and information of the interviewee is reported.

Interview format

Starts with

- Goal of ANIMA
- Goal of subtask
- Goal of interview
- Structure of the interview

Discuss publication

- Case as classified annex (for internal use only)
- Publication of case description
- Publication of location / parties involved
- Publication of results
- Publication of point of contact

Please describe

Background / Overview

- Situation before intervention
- Motivation for implementation
- Stakeholders involved
- Environmental context
- Public opinion
- Conflict situation
    - *What core issues were central to any debate?*
- Hypothesis / Expected outcomes / Consequences

Intervention

- General approach
- Selected intervention

  - *What criteria underpinned the final selection of the intervention?*
  - *Was any formal provision made for wider (e.g. community) input into the decision-making process?*
  - *Were other (external) parties consulted for advice?*
  - *Were trials used to determine the impacts of a given intervention?*
  - *Were other issues (e.g. ... such as climate change, air quality, or safety) considered? How?*
- Available options
  - *What other options were available?*
  - *Why was the implemented option chosen?*
- Selection process / motivation / modelling
- Stakeholder engagement
  - *Were stakeholders presented with an opportunity to contribute to the final decision regarding the implementation option?*
- Monitoring
  - *How was the implementation and its success monitored?*
  - *Where any difficulties encountered during the implementation?*
  - *How were possible difficulties overcome?*
  - *How could these have been avoided?*
- Communication
  - *How was the intervention communicated to the public, communities or stakeholders?*
  - *Was a warning provided prior to implementation?*
- Other
  - ...

Results

- Empirical results
  - *What was the overall perception of the benefit of the intervention?*
  - *Where predictions and scenarios outcomes prove to be accurate?*
- Stakeholder response
- Lessons learned
  - *Would you have done anything differently?*
  - *What were the core challenges in moving from design through to post-implementation evaluation?*

Case Study 1: Environment Agency – Construction Noise and Vibration Management Plan for a site in Boston, Lincolnshire UK

General Requirements – Noise Control

Best Practicable Means (BPM) of noise control will be applied during construction works to minimise noise (including vibration) at neighbouring residential properties and other sensitive receptors arising from construction activities.

The general principles of noise management are given below:

- Control at source:
  - Equipment – noise emissions limits for equipment brought to site.
  - Equipment – method of directly controlling noise e.g. by retrofitting controls to plant and machinery.
  - Equipment - indirect method of controlling noise e.g. acoustic screens.
  - Equipment - indirect method of controlling noise e.g. benefits and practicality of using alternative construction methodology to achieve the objective e.g. vibratory piling techniques or hydro-demolition as opposed to more conventional but noisier techniques; selection of quieter tools/machines; application of quieter processes.

- Control across site by:
  - Administrative and legislative control,
  - Control of working hours,
  - Control of delivery areas and times,
  - Careful choice of compound location,
  - Physically screening site,
  - Control of noise via Contract specification of limits,
  - Noise Monitoring, to check compliance with noise level limits, cessation of works until alternative method is found.
  - Many of the activities which generate noise can be mitigated to some degree by careful operation of machinery and use of tools. This may best be addressed by tool box talks and site inductions.

Specific Control Measures

Without prejudice to the other requirements of this section, the Contractor shall comply with the recommendations set out in BS5228:2009 and in particular with the following requirements:

- Vehicles and mechanical plant will be maintained in a good and effective working order and operated in a manner to minimise noise emissions. The contractor will ensure that all plant complies with the relevant statutory requirements;
- HGV and site vehicles will be equipped with broadband, non-tonal reversing alarms;

- Compressor, generator and engine compartment doors will be kept closed and plant turned off when not in use;
- All pneumatic tools will be fitted with silencers/mufflers;
- Care would be taken when unloading vehicles to avoid un-necessary noise;
- The use of particularly noisy plant will be limited, i.e. avoiding use of particularly noisy plant early in the morning;
- Restrict the number of plant items in use at any one time;
- Plant maintenance operations will be undertaken at distance from noise-sensitive receptors;
- Reduce the speed of vehicle movements;
- Ensure that operations are designed to be undertaken with any directional noise emissions pointing away from noise-sensitive receptors;
- When replacing older plant, ensure that the quietest plant available is considered;
- Drop heights will be minimised when loading vehicles with rubble;
- Vehicles should be prohibited from waiting within the site with their engines running or alternatively, located in waiting areas away from sensitive receptors;
- Local hoarding, screens or barriers should be erected to shield particularly noisy activities;
- Piling will be carried out with the method that minimises both noise and the transmission of vibration to sensitive receptors;
- Temporary noise screens will be used to reduce noise from particularly noisy activities and the height of perimeter hoarding will be extended where this would assist in reducing noise disturbance at sensitive receptors;
- Hours of operation should be strictly enforced and any deviations other than those previously identified will be with the consent of the local authority;
- Occupiers of adjacent properties will be informed by the Contractor up to two weeks in advance of the works taking place, including the duration and likely noise and vibration effects;
- A regular programme of noise and vibration monitoring shall be implemented as a minimum.

Case Study 2: Central London Noise Assessment and Mitigation

Background / Overview

London is the location for some of the largest construction projects in the UK and Europe. The Thames Tideway Tunnel project, for example, involves the construction a 25-km tunnel running mostly under the tidal section of the River Thames in central London. It will provide the infrastructure for the capture, storage and conveyance of almost all of the combined raw sewage and rainwater discharges that currently over-flow into the River Thames from London. The project includes 25 construction sites, with periods of 24-hour working during the tunnelling works at some locations.

Another example is the Crossrail project, which is Europe's largest construction project. The Crossrail route runs over a distance of approximately 100 km, from Reading and Heathrow to the west of London, through new tunnels under central London, to Shenfield and Abbey Wood in the east. There are 40 Crossrail stations, including 10 new stations in central London.

Many of these large-scale construction projects have been, and continue to be, undertaken in locations near to properties that are sensitive to noise and vibration (e.g. residential dwellings and office accommodation). Urban locations such as central London therefore present a challenge in relation to the management/minimisation of noise impacts at sensitive receptors, as the effectiveness of traditional mitigation techniques, such as noise barriers, can be reduced due to the high rise and built-up nature of the inner-city environment.

The following sections describe the general legal and assessment framework for construction noise in the UK. It also discusses a construction project in central London, focussing generally and specifically on the benefits of early project planning, noise prediction/modelling and noise monitoring.

Construction Noise Assessment in the UK – Legal Framework

The main legal provisions for controlling noise from construction sites in the UK are contained in the Control of Pollution Act 1974 (CoPA). The underlying legal principle of controlling noise and vibration on site is that the activities should be undertaken in a manner which demonstrates that Best Practicable Means (BPM), as defined in Section 72 of the Act, are being adopted at all times.

The CoPA provides two mechanisms for managing construction noise and vibration on worksites. The first, under Section 60 of the Act, is a reactive mechanism that enables Local Authorities to serve a Section 60 Notice, which can include controls on working hours and methods of works to be used. The site must then be operated under the constraints of the notice (subject to appeal) which can lead to project delays and associated costs.

ANIMA
Aviation Noise Impact Management through Novel Approaches

The second mechanism, under Section 61 of the Act, is a proactive approach which enables the contractor to submit a Section 61 consent application for approval 28 days prior to the commencement of construction works. The application should detail, among other things, the construction activities, working hours and measures to be employed to demonstrate that best practicable means are being adopted at all times to minimise noise and vibration on site. If the works are undertaken in a manner compliant with a consented Section 61 application, then the local authority cannot serve a Section 60 Notice and therefore the contractor can have more certainty in the project programme.

Construction Noise Assessment in the UK – Assessment Methodology

UK construction noise is assessed following guidance set out in British Standard BS 5228:2009+A1:2014. BS5228, which has developed and improved over time since 2009, assesses construction noise differently to noise of an industrial or commercial nature (which is addressed instead by British Standard BS4142:2014).

As potential noise impacts from large-scale construction projects are (almost always) required to be assessed in an Environmental Impact Assessment (EIA), it is often necessary to consider the significance of construction noise effects on human receptors and the local environment. BS5228 introduces three example methods for assessing the significance of construction noise:

- Potential significance based on fixed noise limits:
  - This method suggests fixed noise limits for "rural, suburban and urban areas away from busy roads" (e.g. 70 dB(A) between 07:00 and 19:00) and a 5 dB(A) higher limit for "urban areas near main roads in heavy industrial areas".
- Potential significance based on noise change:
  - The ABC method:
    - Places the receptor in a category (A, B or C) depending on the baseline sound level, and from this derives the level at which a potentially significant effect could occur.
  - The 5 dB(A) change method:
    - Noise levels generated by site activities are deemed to be potentially significant if the total noise exceeds the baseline level by 5 dB(A) or more (subject to lower cut-off values) and where the duration will be for a month or more.

In addition, BS5228 also gives examples of thresholds ("trigger levels") that could be used to determine eligibility for sound insulation or temporary rehousing. To adequately assess construction noise impacts it is therefore important that a robust baseline is established and accurate predictions of construction noise are made.

<u>The Intervention</u>

This section discusses the importance of early project planning, noise prediction/modelling and noise monitoring with limited reference to a case study for a Crossrail station construction project in central London. The project is delivering a new underground station and a ticket hall, with a second integrated ticket hall. The construction site is located in the 'West End', a busy shopping area surrounded by sensitive buildings/receptors, including recording studios, theatres, schools and residential and commercial properties.

Early Planning

The management and control of noise arising from construction activities is most effective if it is considered at an early stage in the design and planning of the works. It is recommended during the design phase that the constructability of any proposal considers, among other things, the practicality of employing measures that can be incorporated to minimise noise and vibration levels. All those with responsibility for the work are encouraged to consider the steps that will be used to minimise noise and vibration from the works, including the design and formulation of contract requirements.

In many cases, simple measures can be highly effective if properly planned at the design stage. For example, the provision of electrical power on site can be used to avoid the later use of (noisy) generators. Demolishing structures in a manner which means that any structures providing screening to neighbouring properties remain in place as long as practicable, thus minimising the noise impact at that neighbouring property.

In controlling noise from construction sites, the choice of plant (i.e. controlling noise and vibration at source) and the breaking of the path of noise to the receiver through the introduction of hoardings/acoustic barriers/layout design etc., are the primary considerations which need to be planned early in the development process. The hours of work also need to be considered in order to mitigate the effects of noise and vibration on sensitive receptors.

A risk assessment approach can be adopted to enable initial identification of the overall noise and vibration risk associated with a site and proposed works, and to assist the contractor in assessing the level of noise and vibration control required. The risk assessment should be based on the locality of the proposed works (i.e. be site-specific) and include the following key elements:

- Programme duration;
- Proximity of nearest sensitive receptors;
- Ambient noise level (baseline conditions);
- Working hours; and,
- Location and duration of particularly noisy works (such as breaking and piling).

Noise Prediction/Modelling

Construction noise and vibration assessment, including noise predictions, started twelve months prior to the start of the Crossrail project construction works. BS5228 provides guidance concerning methods for predicting construction noise and assessing its impact on those exposed to it. The general approach to the prediction of site noise, taken from BS5228, is shown in Figure 21.

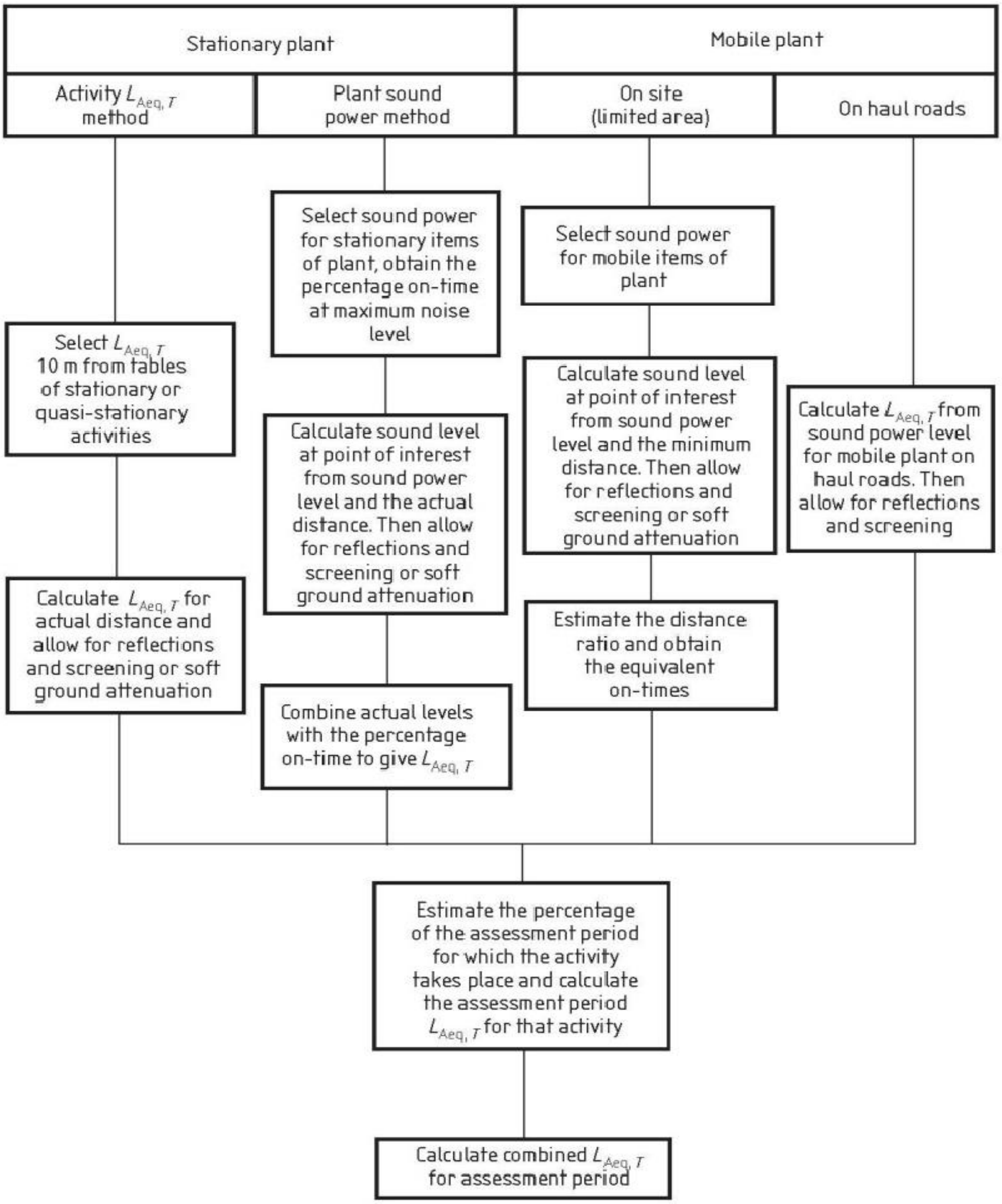


Figure 21: General Approach to Noise Prediction for Construction Sites (BS5228)

In order to calculate construction noise, the following information is required:

- LAeq or LWA of the plant;
- Operating time, Tt (as a proportion of the assessment period T);
- Distance to receptors, R or dmin;

- Traverse length (for moving plant), ltr;
- Screening, site hoarding or topography; and,
- % Soft ground (as a fraction of 1).

Noise data for the calculations can be sourced from plant manufacturer information, previous noise measurements or BS5228 (Annex C and D).

Noise Monitoring

Noise monitoring of construction activities can be undertaken for a variety of different reasons:

- Demonstrating compliance: noise monitoring is often a requirement of the Section 61 process (or other agreements) to compare actual noise levels with predictions or consented levels and to ensure legal or other compliance. Compliance monitoring can include measurements at noise-sensitive receptors, proxy locations or for the determination of plant sound power levels;
- Proactive management of noise: monitoring may be undertaken in conjunction with site visual inspections/walkovers to determine whether Best Practicable Means (BPM) are being employed on site; and,
- Complaint investigation: noise monitoring may be instigated because of a complaint, or multiple complaints, being received by the contractor of Local Authority. The type of monitoring employed is generally specifically tailored to the nature of the complaint.

Monitoring of noise from construction sites can be carried out using a range of different instruments depending on the time over which the measurements need to be made. If the measurements are to be made over a short period, a handheld sound level meter would be suitable. If the measurements need to be made over a longer period, an outdoor environmental measurement kit may be needed. Modern noise monitoring systems include continuous data loggers that are accessible through telemetry or include the functionality to be able to share data on a website/server that can be interrogated by stakeholders.

Three noise monitors and two vibration monitors were used for this Crossrail project example, at each of the ticket hall sites. Figure 22 below shows an example of in-situ construction noise monitoring.

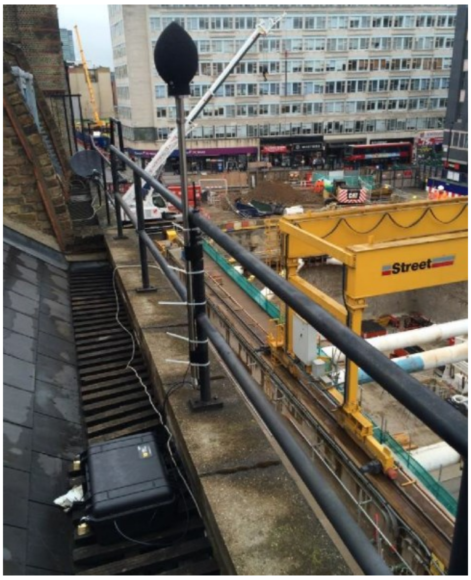


Figure 22: Example of Construction Noise Monitoring

Effective and timely reporting is essential, if monitoring is to be used to minimise noise levels and mitigate the effects of noise. There is little point in gathering reams of data if it is not regularly reviewed and reported. As noise and vibration monitors can collect noise data on a continuous basis, information can be collected and reported to interested parties at any time.

Noise and vibration reports have been used for the following:

- Verify whether all Best Practicable Means are adopted to control noise and vibration levels;
- Compare measured noise levels against predicted noise levels;
- Log any noise or vibration non-conformities including nature, status, corrective and preventive actions;
- Actions and potential for statutory intervention;
- Status on any environmental noise and vibration complaints;
- Progress/changes in programme work requirements and associated noise impacts;
- Any actions or interventions undertaken by enforcement organisations; and,
- Summaries of any noise and vibration inspections and attended monitoring results.

A variety of 'live' unattended noise monitoring systems can provide immediate alerts to site personnel if noise trigger levels are exceeded or are likely to be exceeded. This allows the rapid pro-active management of site activities and the resulting noise generation.

<u>Results, impact and lessons learned.</u>

Simple measures can be highly effective if properly planned at early design stage of a project, and optimal construction noise control can be achieved with a combination of accurate noise prediction, management of noise on site, compliance monitoring and effective community liaison.

Summary

The Control of Pollution Act 1974 sets out the legal framework for managing construction noise and vibration in the UK, and BS5228 provides guidance concerning methods of predicting and measuring noise, and assessing its impact. Simple measures can be highly effective if properly planned early in the design stage of a project, and optimal construction noise control can be achieved with a combination of accurate noise prediction, management of noise on site, compliance monitoring and effective community liaison.

Case Study 3: Hong Kong Noise Mitigation Measures for Public Housing

Background / Overview

The Hong Kong Housing Authority (HKHA) is responsible for the planning and provision of public housing in Hong Kong. Limited land resources and sustained and increasing demand for housing in the City means that it is often necessary for new public housing to be developed in close proximity to significant surface noise sources such as busy roads, railways and Public Transport Interchanges (PTIs).

For the 2016 Inter-Noise Conference held in Hamburg, Germany, the HKHA submitted a paper which summarised its own experience in developing noise reduction solutions to protect the inhabitants of public housing developments in the Hong Kong urban area. In addition to providing examples of specific receptor-focussed mitigation measures, which are discussed in more detail below, the paper also discussed more general ideas such as the source-pathway-receptor concept and the (often conflicting) requirement to protect residents from excessive noise, but to also provide sufficient lighting and ventilation.

Hong Kong is well known for its high rise, high density living environment. It is often necessary for new housing developments, including public housing, to be built next to heavily trafficked and congested roads, busy railways and PTIs. This spatial constraint along with strict environmental regulation and high demand for housing has driven the HKHA to develop innovative noise mitigation solutions for the public housing it designs and constructs in the city.

According to the HKHA, in general, mitigation of noise at source and on the sound propagation path are the most effective ways of addressing noise issues. For example, the use of noise barriers along longitudinal sources such as roads and railways are well understood and can be reasonably effective if they are situated correctly (in the line of sight between source and receptor) and are well constructed to ensure acoustic integrity. Similarly, low noise road surfaces have been used in Hong Kong (and elsewhere around the world) and have been shown to deliver noise reductions of up to 3 dB(A).

Another source-based mitigation measure that has been utilised by the HKHA to protect residents of public housing is noise covers. Noise covers have been installed on PTIs in locations where public housing is situated very close to the interchange and the use of traditional noise barriers would therefore be ineffective (line of sight protection not provided). In the situation where land is re-zoned for residential development and is then near to commercial or industrial uses, it is often necessary to install source-based mitigation measures (e.g. acoustic enclosures and louvers) to fixed plant such as chillers and cooling towers.

Figure 23: Noise cover for Public Transport Interchanges (PTI) at Hung Fuk Estate

The following noise reduction measures have been developed, tested and, where possible, deployed, by the HKHA to protect residents of public housing at the receptor location (i.e. at the property). Innovation in receptor-based mitigation has been driven by the physical constraints apparent in Hong Kong, which in many cases prevents successful deployment of source/pathway-based mitigation solutions.

<u>The Intervention</u>

Site-Specific Modular Apartments

The HKHA has used site-specific modular apartment design where source/pathway-based noise mitigation has not been possible due to physical site constraints. The modular apartment design aims to achieve a self-screening effect by the use of protruding rooms, which have fixed windows and face the noise source, and which in turn reduce the view angle of the adjacent, recessed room to the source (e.g. road). The recessed (screened) room would be for noise sensitive uses (i.e. bedroom or living room) and may have openable windows.

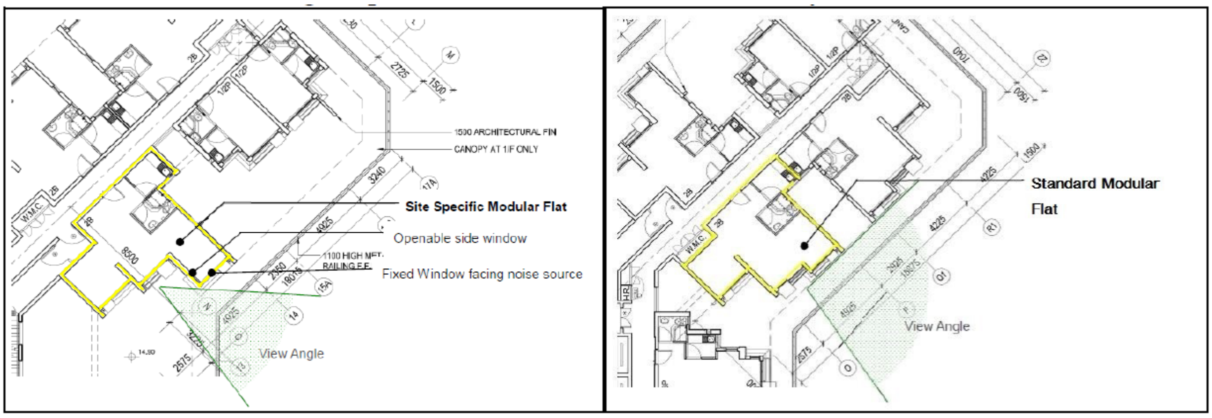


Figure 24: Site specific modular flat against Standard modular flat

Acoustic Windows

In order to provide additional noise attenuation beyond that achieved by conventional mitigation methods at a proposed public housing development adjacent to the busy and noisy Prince Edward Road East, the HKHA collaborated with the Hong Kong Environmental Protection Department (HKEPD) and the Hong Kong Polytechnic University (HKPolyU) to undertake research into the design of acoustic windows. The noise level at the boundary of the proposed development was estimated to be 85 dB(A), against a regulatory limit of 70 dB(A). Conventional mitigation measures were able to attenuate 7 dB(A) of the required 15 dB(A), leaving 8 dB(A) to be potentially addressed by acoustic windows.

Firstly, a series of laboratory tests were undertaken at the HKPolyU. Twenty different window casement designs were tested over 200 different scenarios, reflecting variations in line and point source characteristics. Next, in-situ testing was undertaken of conventional windows and the prototype acoustic windows using full scale mock-up apartment buildings. 34 microphones were installed to measure exterior and interior noise levels for 20 different window designs during peak hour traffic conditions.

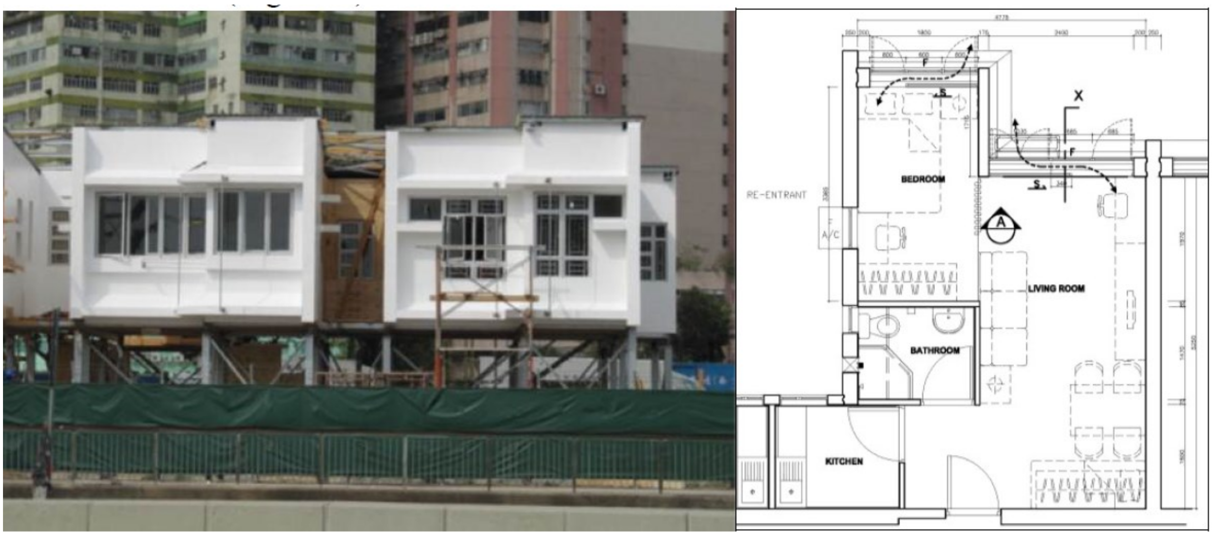


Figure 25: Mock-up Flats for comparison of the performance of conventional window and acoustic window

Acoustic Balconies

The Wing Cheong Estate is situated next to the busy and extremely noisy West Kowloon Corridor. Although a Y-Shaped block arrangement was adopted in the development's design, to reduce the view angle to the traffic corridor and to provide a degree of self-screening, initial assessments indicated that only 46% of the development would achieve regulatory noise compliance.

The site location and road configuration around it meant that conventional (source/pathway-based) mitigation measures were impractical to address the compliance issue. Consequently, the HKHA began to develop an innovative arc-screen design concept to provide shielding to the housing development's windows.

The first step in the design process comprised detailed numerical analysis to explore the effectiveness of the arc-screen design. The initial modelling results were promising, so the design team decided to undertake in-situ testing, using 3-storey full scale model prototype installations. This allowed for 'real world' noise measurements to be made (approximately 1000 acoustic samples were taken) and facilitated the testing of various arc-screen designs, materials and noise source characteristics. The results of the in-situ testing demonstrated the effectiveness of the noise attenuation provided by the arc-screen concept, which eventually evolved into the form of an acoustic balcony that was included in the design for the Wing Cheong Estate.

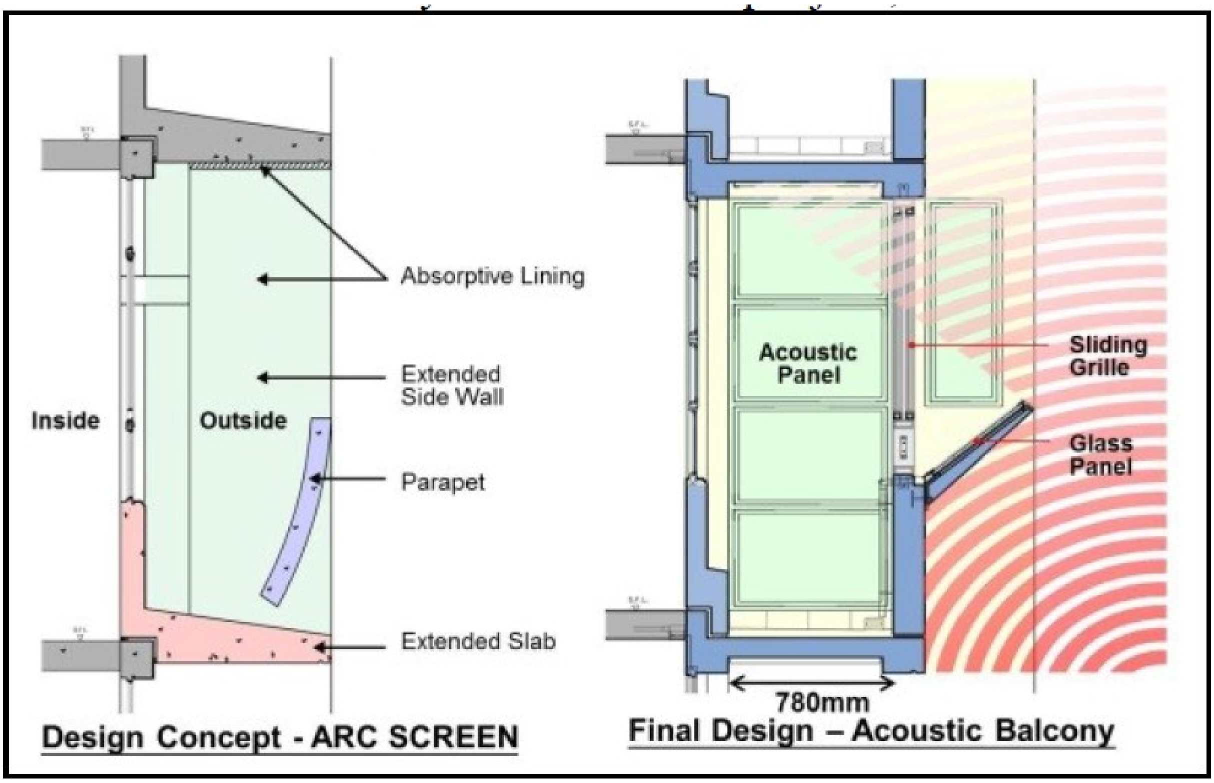


Figure 26: Initial design concept and first generation of acoustic balcony

Acoustic Balconies (Enhanced Design)

Following on from the arc-screen acoustic balcony, the HKHA, in collaboration with the HK EPD and HKPolyU, began development of an enhanced acoustic balcony design. To ameliorate the incidence of noise through the balcony door into the apartment, a sliding screen on the balcony, in front of the balcony door, was installed. Other auxiliary (optional) noise adsorptive material could be installed on the walls and ceiling of the balcony, as could an inclined panel projecting from the balcony parapet.

The effectiveness of this new balcony design was tested in-situ, in a vacant school, using the prototype enhanced balcony design and a conventional window unit as the base/comparative case. At least 20 microphones were installed at the test site to simultaneously measure internal and exterior noise levels under 23 different scenarios representing different inclination angles for the noise source, to in turn simulate different heights for the apartments/balconies.

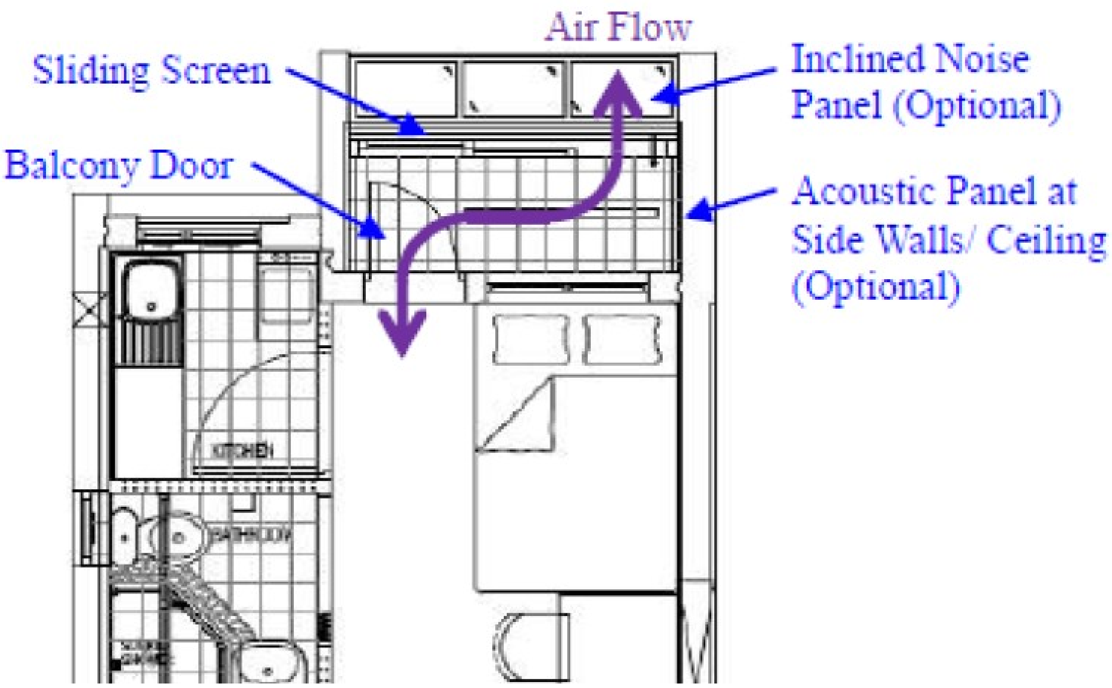


Figure 27: ***Layout of the enhanced acoustic balcony design***

<u>Results, impact and lessons learned</u>

Site-Specific Modular Apartments

Site-specific modular apartments have been used in at least two public housing developments in Hong Kong (Cheung Sha Wan Estate and Tuen Mun Area 54 Site 2), with a reduction in noise impact of up to 3 dB(A) being reported. Although modular apartment design can have beneficial impacts in terms of reducing the noise exposure to residents, other factors such as visibility/view, ventilation and lighting must also be considered in the design process.

Acoustic Windows

The testing of the acoustic windows determined that the required 8 dB(A) reduction was achievable. The HKHA will undertake noise monitoring once the development is complete to check the performance of the in-situ acoustic windows. Factors such as window cleaning, clothes hanging and the long-term maintenance of the windows were considered in the detailed design process.

Acoustic Balconies

With the application of noise absorptive linings, the arc-screen acoustic balcony is reported to achieve a noise reduction of between approximately 2 and 6 dB(A). This has since been verified by on-site noise measurements and resident surveys following completion of the housing development in the summer of 2013. The development of the arc-screen acoustic balcony enabled the Wing Cheung Estate to be built in an extremely constrained environment.

Acoustic Balconies (Enhanced Design)

The enhanced acoustic balcony, including installation of all the auxiliary/optional noise abatement measures, is reported to achieve a relative noise reduction of approximately 10 dB(A), compared to the 2 – 6 dB(A) reduction reported for the arc-screen acoustic balcony. It is considered to be an effective design for noise mitigation, and also allows more desirable air ventilation for the apartment by increasing the width of the ventilation path.

<u>Summary</u>

The high density urban setting of Hong Kong provides a great challenge to the HKHA in terms of the design and construction of public housing. However, this constrained environment has helped drive innovation in the design of noise mitigation measures, particularly receptor-based methods such as acoustic windows, balconies and modular apartment designs.

Noise reductions for four of the three specific receptor-based methods described (modular apartment design, acoustic windows and acoustic balconies) are estimated to range between 3 dB(A) and 8 dB(A). Enhanced acoustic balconies are likely to achieve a noise reduction closer to 10 dB(A). These attenuation methods are important in highly constrained environments such as the Hong Kong urban environment.

Case Study 4: Wind park 'Jaap Rodenburg II'

Interview with Erwin Lindeijer - former project manager Jaap Rodenburg II, Almere municipality

Background / Overview

A new wind park of 10 wind turbines was being developed by a joint venture of a commercial utility provider and a local energy cooperation providing power to roughly 30,000 households. The wind turbines were planned to the North-West of a major Dutch city, 1500 to 2500 m from build-up areas, near popular areas for recreational activities. The turbines would replace older turbines from the existing wind park. 2-3 turbines would be exploited via the local energy cooperation, the remaining 7-8 turbines would be exploited via the commercial utility provider.

Residents were critical to the plans due to experiences with this previous wind park. Therefore, the local municipality tasked with assessing the permit for building and exploiting the development wanted to address community concerns early on via a thorough participation process.

Figure 28: Overview of Jaap Rodenburg II site

Intervention

The municipality ran a door-to-door flyer campaign to approximately 80 households. In addition, the municipality hired NLR to create virtual reality simulations of the new wind park from 10 vantage points. The purpose of these simulations was to present the visual impact for all 10 vantage points, and the noise impact for the 4 vantage points closest to the wind farm. The locations of these vantage points were selected by the municipality to match homes of critical residents or locations in recreational areas. The simulations were presented at three town hall meetings with residents. Via an information website with a questionnaire, residents were able to state their preference for one of three possible configurations. The configurations differed in the location of the wind turbines,

By demonstrating the impact of the plans and involving residents in the design, it was expected that it would inform the residents and reduce concerns about the plans.

Afterwards, small changes were made to the design of the wind park. These changes were presented to the community using new design drawings. The drawings were communicated on the website and through a new door-to-door flyer campaign to approximately 100 households. In addition, the municipality organised a 'noise safari' which offered residents the opportunity to experience wind turbine noise at another wind park.

Results

The original plans for the wind park were well received at the town hall meetings. The information offered along with the simulations relieved convinced most residents that the plans were agreeable. However, the changes were less well received. Since they were only communicated in drawings, there was room for interpretation and fear mongering by a few outspoken critics.

One resident appealed to court, but he was turned down due to previous rulings on the validity of complaints from those living more than 1500 meters away from wind turbines. The local council concluded that the municipality had taken the proper procedures. It is expected that the permits for the development of the wind park will be signed in 2018 allowing for the building process to commence in 2020.

Case Study 5: Re-routing of rail segment

Background / Overview

The railway operator was redesigning a route segment for a cargo railway through an industrial area, but close to some villages. The new segment involved a newly designed bridge and a different trajectory, and it would also replace a noisy steel railway bridge.

Community engagement and approach

Inform the local residents of the future situation

- The noise levels for the new route segment were calculated and demonstrated in a VR simulation that was shown at town hall meetings
- In a later session, additional noise absorption measures were demonstrated as well

Result

Even where the new rail segment put trains closer to the residents and noise levels were higher than the existing situation, the sound was found to be less intrusive and annoying than earlier expected. The local community reacted positive to the additional measures that were taken to address their concerns.

Case Study 6: N33 Wind energy site

Interview with Mirjam Davidson - public relations, Innogy

<u>Background / Overview</u>

In 2000, the Province of Groningen designated an area along the N33 road as suitable for the generation of wind energy (Figure 29).

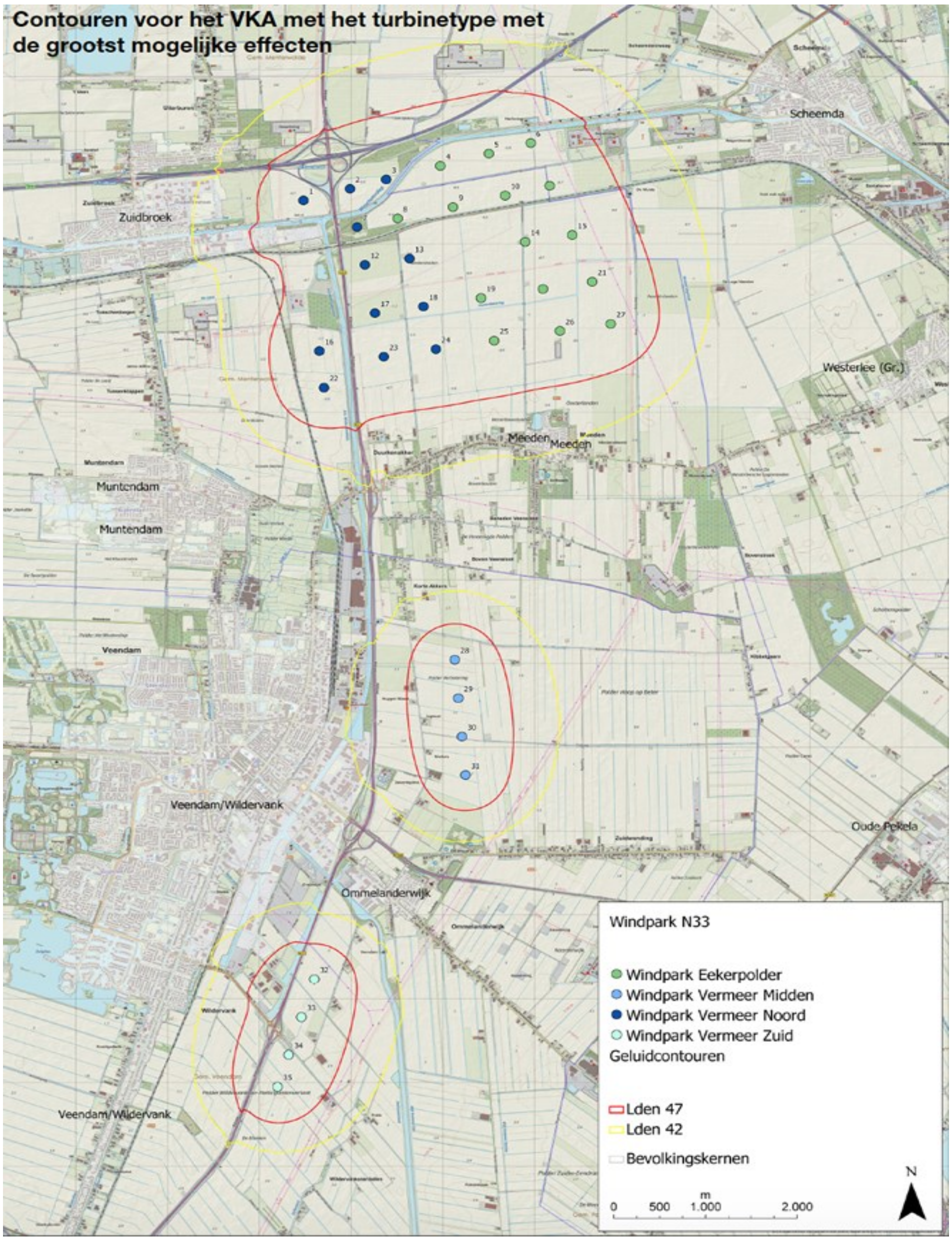


Figure 29: Noise contours 42 dB (yellow) and 47 dB (red) Lden

A joint venture of local land owners, developers of on-shore wind energy (Yard Energy) and a utility company (Innogy) started the development of the N33-project. Here 35 wind turbines should provide 120 MW of power. As the project was deemed to be of national importance under the National Coordination Act[25], the coordination of the project was delegated to the Ministry of Economic Affairs. The 35 wind turbines were to be developed in three groups along the N33 road, south of the A7 highway. Three communities are within 2 km of the wind park (Veendam, Meeden, and Ommelanderwijk). Construction of the wind park is due for the end of 2019 (Yard Energy, Innogy, N.D.).

Local communities had noise concerns and were worried by the impact on their health and the value of their property. These concerns were increased by vocal protesters who organised protests and awareness campaigns and a local history of dispute between 'workers' and 'farmers'. Some feel the workers will mainly suffer from the wind turbines, whereas the farmers who own the land on which the turbines are built will profit.

Figure 30: Protesters against wind turbines

<u>Intervention</u>

The development of the wind park required an environmental impact assessment. This assessment evaluates possible impacts introduced by the wind park in a set study area. The size of the study area depends on the severity of the expected impact, e.g. no impact larger than the threshold value is foreseen outside the study area. Among others, the impact of noise, shadow flickering, third party risk (risk to those not involved with the wind park, e.g. residents), and visual impact on the landscape were assessed.

[25] Coordination of projects related to energy infrastructure "of national importance" can be delegated to the national Ministry of Economic Affairs under the 'National Coordination Act' (*Rijkscoördinatieregeling*). For these projects, the National Government is responsible for the coordination of the project, the decision making and the participation process. The lead developer remains responsible for the project preparation. Local governments remain responsible for the local permits.

The scope of the assessment was set beforehand and presented to the public in between 14th October and 24th November 2011 at three different locations (Agentschap NL, 2011). In addition, the Ministry organised two information sessions. By law the public is allowed to comment on the scope and the results of the impact assessment.

The utility company was involved at a later stage for the exploitation of the wind. Six months before the final designs of the wind park were made public, Innogy invited residents for individual discussions in the comfort of their own home on a voluntary basis. 60 to 80 households voiced their thoughts and concerns via these talks. The concerns mainly focussed on noise, followed by shadow flickering, visual pollution of the landscape and declining property values. Most residents were not used to wind turbines and found these topics to be abstract and difficult to visualise.

To help residents to assess the impact of the plans, NLR developed Virtual Reality (VR) simulations from a number of vantage points of the future wind park. The simulations merge actual video and audio recordings with realistic simulations of the future wind turbines. To help distinguish the wind turbine noise from the background noise, the background noise could selectively be switched off. The simulations were demonstrated at a number of town hall meetings.

In addition, the project initiators founded a community fund to finance local initiatives that improve the quality of life of the residents. Residents can pitch their own ideas and projects to apply for funding.

Results

The environmental impact assessment commissioned by the Ministry of Economic Affairs and the Ministry of Infrastructure and Environment concluded that no residencies exceed the L_{DEN} norm of 47 dB_A. Also, the development stays within the norms for third party risk.

As a result of the VR simulations, the concerns shifted away from noise concerns to concerns about visual pollution of the landscape. The majority of the public has come to terms with the new wind park, a minority remain actively against the wind park.

On the 28th, 29th and 30th of January 2019 the permits were assessed in court. A ruling is expected in 12 weeks.

Case Study 7: DESTINATE, Freight trains

Interview with Rüdiger Garburg - Digitalization and Technology Board Division, Deutsche Bahn AG

Background / Overview

Rolling noise is the dominant noise source for freight trains. The noise causes large numbers of complaints by people living near the tracks. Sometimes the opposition ends up in court leading to significant planning delay. The planning cycle can last for 20 years!

The conventional cast-iron brakes that are on most train wagons are very effective for braking but in their application roughen the wheels. The rough surface leads to additional noise. Low-noise alternatives do exist. So-called K-block brake pads reduce noise by 10 dB, but due to different technical parameters cannot be easily retrofitted to older wagons with a conventional brake system. Therefore, they are only found on new wagons. Given the average service life of 20 years or more, this leads to a slow adaptation rate.

Intervention

The DESTINATE project (DESTINATE, 2018), part of the Shift2Rail European programme, a virtual reality simulation was developed by DESTINATE partner Empa from Switzerland. The simulation included auralization for the different wheel breaks. This was demonstrated at the Shift2Rail booth at the INNOTRANS exhibit in Berlin 2018. Multiple stakeholders visited the booth and experienced the simulation. 20 years of research led to the carbon fibre LL-blocks: low noise and retrofit-able to conventional wagons:

- VR simulation (video and audio) of a passing train at exhibitions
- 2 scenario's (conventional cast-iron brakes and new silent LL-blocks)

Results

Public enthusiastic about noise improvement

- Clear difference
- However, no quantitative results yet
- Scepticism against EU-wide requirement from Nordic countries: little noise concerns in remote countries, uncertain cold weather performance

Case Study 8: The impact of railway grinding on noise levels and residents' noise responses – Part I and II

Background / Overview

Although the erection of noise barriers is the most common procedure to reduce the impact of railway noise on residents alongside the track, sometimes they do not offer their usual benefit due to topographic specifics of a given region. In those cases, railway grinding, which smoothens the rail and therefore decreases train rolling noise is a common procedure to mitigate the influence of railway noise. A rough rail is able to increase rolling noise by 10-15 dB(A).

Periodical rail grinding is able to decrease noise by up to 10 dB(A), under the premise, that the corresponding train is equipped with smooth, modern wheels.

Sound measurements were performed to assess the effectiveness of rail grinding for disc braked trains compared to heavy freight trains which usually have cast iron brakes.

The study was carried out at two locally separated places in Germany: Burlafingen and Unterfahlheim (Bavaria) and Uhningen (Baden-Württemberg). The main selection criterion for the study areas was a rail condition at the beginning of the survey well below an average condition in terms of smoothness of the rail. This was determined by evaluation of the data gathered by a noise monitoring car of Deutsche Bahn (German Federal Railway).

Further selection criteria for the survey were:

- areas mainly with residential buildings
- buildings with an age of at least 5 years (no new residential areas)
- enough suitable (which means noise loaded) residential buildings (ca. 300 buildings)
- mixed population in terms of socio demographic characteristics
- no other prominent noise sources (esp. road noise or industrial noise)
- no noise barriers or sound insulation windows in the area
- no additional railbound vehicles in the near (esp. tramway)
- residential building directly neighbouring the track (distance of the first row to the track less than 50 m)

Before and after the rail grinding both acoustical measurements and interviews of the residents were done.

In order to investigate the influence of active information about the rail grinding measure, the residents have been informed only in the Baden Württemberg section.

Two hypotheses were tested:

(H1): It is assumed that in line with the decrease in noise exposure after railway grinding noise responses of residents living along a railway line are lower after railway grinding, than before the intervention.

(H2): In areas where residents receive information about railway grinding and its noise-reducing impact, the decrease in railway noise annoyance and disturbances, is stronger than in areas where residents do not receive such information.

Setup

The study was designed to investigate the *noise impact and the noise annoyance* in two geographical widely separated study areas. In these areas noise measurements and socio-acoustical surveys should be carried out before and after grinding the rails of the nearby railway line. In one of the two areas (in the Baden Württemberg section) active information about the noise abatement measure and the expected effect has been given to the residents, whereas in the other area (in the Bavarian section) the survey has been conducted as a "blind" survey without information. In Burlafingen/ Unterfahlheim information was given that this questionnaire dealt with general living conditions in the near of traffic lines. In both areas the first survey (before grinding) was conducted without any information about the rail grinding and the aim of the study. The rail grinding was done in both areas simultaneously. The pre- and post-interrogations should take place within periods of the year with similar climatic conditions in order to avoid an influence of different habitual window conditions. Therefore the pre-interrogation was planned for the autumn period and the post interrogation for the spring.

Because the effect of the rail grinding could not be described well enough by calculation only, the emission of the railway line should be measured distinguishing the different types of trains and the different noise reduction for each train type. Based on the emission measurements subject-individual noise levels had to be calculated before and after rail grinding. Accompanying measurements of the rail roughness before and after rail grinding were conducted by the Deutsche Bahn AG.

As acoustical noise levels assessment was to be determined for each participant individually, noise measurements couldn't realistically depict the propagation throughout the areas. Accordingly, to determine the noise levels and the propagation, the change in noise emission was measured and the propagation was calculated to ensure a realistic description of the noise impact on residents.

Table5: Sample Size (number of participants) for both study areas

Study area	t1: 3 month before rail grinding	t2: 1-2 month after rail grinding
With information	190	163

(Uhningen)		
Without information (Burlafingen and Unterfahlheim)	221	177
Total	411	340

Intervention

Rail grinding – The main selection criterion for the study areas was a rail condition at the beginning of the survey well below an average condition in terms of smoothness of the rail. This was determined by evaluation of the data gathered by a noise monitoring car of Deutsche Bahn (German Federal Railway). Table 6 and Table 7show the measured noise emissions in both areas.

Table6: *Noise emission values in the study area without information* (Burlafingen and Unterfahlheim)

	Train Speed (km/h)	Number of Trains						$\Delta L_{bef/aft.}$
		N_{Day}	N_{Night}	Before grinding dB(A)		After grinding db(A)		
				$L_{mE,D}$	$L_{mE,N}$	$L_{mE,D}$	$L_{mE,N}$	
ICE Train	155	33	1	57,2	45,0	49,0	36,8	-8,2
IC-Train	153	29	1	59,9	48,2	54,9	43,2	-5
IR-Train	149	15	1	57,3	48,6	50,2	41,5	-7,1
Commuter Train	122	62	10	65,3	60,3	63,4	58,4	-1,9
Freight Train	89	32	33	68,1	71,2	66,6	69,7	-1,5
Total		171	46	70,7	71,6	68,6	70,0	D:-2,1

								N:-1,6

Legend: bef/aft.: before/after (rail grinding); D: daytime; N: night-time

Table 7: Noise emission values in the study area with information (Uhingen)

	Train Speed (km/h)	Number of Trains						$\Delta L_{bef/aft.}$
		N_{Day}	N_{Night}	Before grinding dB(A)		After grinding db(A)		
				$L_{mE,D}$	$L_{mE,N}$	$L_{mE,D}$	$L_{mE,N}$	
ICE Train	135	35	2	59,4	49,9	52,0	42,5	-7,4
IC- Train	135	30	4	62,5	56,8	57,3	51,6	-5,2
IR-Train	139	26	4	62,5	57,3	55,3	50,1	-7,2
Commuter Train	83	80	17	65,8	62,1	66,2	62,5	0,4
Freight Train	89	22	41	69,6	75,5	69,0	74,7	-0,6
Total		193	68	72,4	75,7	71,2	75,0	D: -1,2
								N:-0,7

Legend: bef/aft.: before/after (rail grinding); D: daytime; N: night-time

As shown, on average the rail grinding only accounted for 2,1-1,6 dB(A) noise mitigation on the side where no information was given and even less, (1,2-0,7 dB(A)) on the side where information was given to the residents. Which is mainly to be attributed to the frequent commuter and freight train pass-bys, which were almost completely unaffected by the operation (Table 4).

Information:

As described above, in Uhingen information was handed out that explained the noise mitigating effects of the rail grinding procedure by individual letters, leaflets and local newspaper articles. Additionally, 29% of the participants in Uhingen reported to have noticed the rail grinding process whereas 63% in the Burlafingen area reported to have taken notice of ongoing rail restauration works. Although, as described above, the grinding process has hardly had any impact on the emission noise levels, which was even more relevant for the study site in Uhingen, there have been some changes in the overall reported annoyance. A comparison of the results is shown in Table5.

All measures of disturbances presented in Table 8 have been assessed before and after the rail grinding procedure using the 5 point ICBEN scale for noise annoyance: (1) not, (2) a little, (3) moderately, (4) rather, (5) very. Additionally, at t2, the change in disturbances was assessed using a three point scale (1) decreased, (2) unchanged, and (3) increased.

Table8: Means (standard deviations) of responses to railway noise before and after rail grinding

Responses to railway noise	Information about rail grinding (study area)							
	no (Burlafingen)				yes (Uhingen)			
	N	t1: before	t2: after	Sign.	N	t1: before	t2: after	Sign.
noise annoyance – railway	176	2,49 (1.23)	2.35 (1.10)	*	162	2.88 (1.05)	2.65 (0.88	**
disturbances – railway noise, overall	175	3.45 (2.73)	3.41 (2.61)		162	4.18 (2.42)	3.86 (2.40)	
disturbances – railway noise, daytime	174	1.99 (1.06)	2.05 (1.01)		160	2.52 (1.02)	2.45 (0.88)	
disturbances – railway noise, night-time	174	2.08 (1.18)	2.12 (1.13)		159	2.25 (1.02)	2.10 (0.94)	*
communication disturbances indoor	176	1.75 (1.16)	1.71 (1.06)		162	2.76 (1.16)	2.51 (1.04)	**
communication disturbances outdoor	176	2.49 (1.47)	2.64 (1.52)		160	3.75 (1.22)	3.57 (1.20)	

disturbances of recreation indoor	176	1.62 (0.96)	1.65 (1.01)		162	2.23 (1.04)	2.06 (0.98)	*
disturbances of recreation outdoor	176	2.36 (1.45)	2.40 (1.45)		162	3.06 (1.29)	3.10 (1.30)	
sleep disturbances	176	1.57 (1.05)	1.49 (0.88)		162	1.63 (0.85)	1.45 (0.77)	**
psycho-vegetative disturbances	176	1.34 (0.69)	1.31 (0.66)		162	1.54 (0.66)	1.40 (0.64)	**

Sign. (t-Test): * $p < .05$; ** $p < .01$

<u>Results</u>

Although the rail grinding has basically failed to reach its estimated effect due to a technical problem with the rail grinder, with decreasing noise levels only by about 1-2 dB(A), there's is an important finding in this example. Despite less residents even noticing the grinding process, while profiting even less from the decrease in noise emissions after rail grinding, the residents in Uhingen reported significantly lower annoyance scores. As it was ensured the conditions in both study areas were the same and the researchers even controlled for conditions like weather and air humidity, the decrease in reported annoyance scores is likely related to the information that has been spread throughout the Uhingen study area.

Although on account of the broken rail grinder H1 could not be thoroughly tested, the second hypothesis could be confirmed. Tested parameters all sank after the grinding process, despite the noise level being almost unaltered in comparison to t1.

The researchers stress that this finding shouldn't lead to the assumption that a communicational effort can replace technological solutions, but instead they can supplement each other. By handing out information about the planned abatement measures, transparency was increased, which greatly supported the otherwise failed approach in actually mitigating noise. It should therefore become common practice.

<u>Acknowledgements</u>

The study described was founded by Deutsche Bahn AG (German Federal Railway). This study has been issued in two independent proceedings of Internoise 2013, having an author of this report (**Schreckenberg, D,** from Zeus**)** member of the team:

1. Liepert, M., Möhler, U., **Schreckenberg, D.,** & Schuemer, R. (2013). The impact of rail grinding on noise levels and residents' noise responses – Part I: Study design and acoustical results. In Proceedings Of Inter-Noise 2013 (Ed.).
2. **Schreckenberg, D**., Möhler, U., Liepert, M., & Schuemer, R. (2013). The impact of railway grinding on noise levels and residents' noise responses – Part II: The role of information. In Proceedings Of Inter-Noise 2013 (Ed.).

Case Study 9: Control of noise from public entertainment activities in Hong Kong

Background / Overview

One of the very few examples out of the branch of leisure noise control is to be found in the case study by Kwok and Cheng (2014). Hong Kong is a mega city, with more than seven million residents, living and working in closest proximity to all sorts of noise sources. Naturally, in an environment as busy as that, multiple noise sources pollute the living environment at once. Where many people live and work the need for leisure activities is high.

According to the authors, there's a lack of venues for activities like the here described, which results in many of these activities being performed outside, or at open places like stadiums and promenades. While the attendants increase their pleasure in their attendance with loud music or other noisy activities, the residences suffer from their overly loud surroundings.

In this example, efforts were made to soundproof a traditional Chinese bamboo theatre, while holding an opera performance during the Chinese new year celebrations. Public entertainment activities are controlled by means of a Noise Abatement Notice (NAN) under the Noise Control Ordinance, which gives the following noise control guidelines for events like the opera (Table 9).

Table 9: ANLs applied in Hong Kong in general

Time Period	Area Sensitive Rating (ASR) in $L_{eq\ (30\ min)}$		
	Type A ASR	Type B ASR	Type C ASR
7am-11pm (Day & Evening time)	60	65	70
11pm-7am (Night time)	50	55	60

The event organizer or the person-in-charge of the venue has to ensure that the noise emanating from the entertainment event as assessed at 1 meter from the exterior facade of the nearby noise sensitive receptor (NSR, compare Chapter: Modelling) does not exceed the acceptable noise levels (ANLs) stipulated in the technical memorandum (TM).

Although these guidelines exist and are binding, due to the special characteristics of entertainment noise containing singing and music (e.g. dominant low and high frequency components), there are special, additional guidelines, imposed by the Hong Kong authorities, which have been adopted from the Code of Practice in the UK (Table 10).

Table 10: Control criteria for music noise from public entertainment activities

7am-23pm (Day & evening time)	$L_{eq\ (15\ min)}$at any NSR should not be more than 10db(A) above the prevailing background noise measured in $L_{eq\ (5\ min)}$
23pm-7am (Night time)	Not audible within any NSR

To ensure best possible outcomes, the Hong Kong Environmental Protection Department (EPD) furtherly supports a pre-emptive approach. When approached, EPD would advise the venue owner or event organizer on the control criteria of entertainment noise and possible noise mitigation measures during the event planning stage. Typical advice includes careful selection of the locations and orientation of the performance stage and loudspeakers; self-monitoring of the noise level for immediate rectification; provision of a manned hotline to deal with noise complaint; advanced notification to nearby residents; limitation on time periods for rehearsals; etc. Site specific control measures would also be recommended with due consideration of the nature of the event, the potential noise impact, frequency of occurrence, and precedent complaint history, etc.

Intervention

Due to the aforementioned lack of appropriate locations, it was proposed to use a temporarily idle construction site as the place for the Chinese opera, which according to the authors of the study "blends music, song, dance, martial arts and acrobatics into its vibrant and usually loud performance". On 10.000m² it was aimed to host 800 guests for the evening, while the area in question reached as close as 40 meters to the next housings.

Two shields of a metal layer construction have been installed to the otherwise open bamboo-structure to grant for a quieter surrounding.

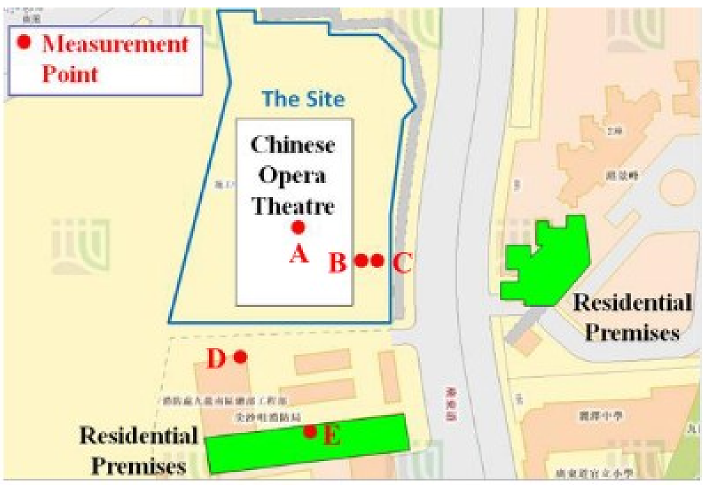


Figure 31: Noise measurement locations in, and around the theatre

Microphones at five different locations throughout the affected were installed to measure the noise impact on residential buildings (Figure 28), compared to the noise measurements that were taken inside the building. Table 11 gives an overview over the measures of each microphone position:

Table 11: Measurement results of noise impact from metal-sheeted bamboo theatre

Measurement Point (remarks)	Noise levels in dB(A) (corrected by the prevailing background noise levels)	
	Chinese Opera Music	Western Pop Music
A (inside the theatre)	87	91
B (next to the access door)	79	79
C (further away from the access door)	74	75
D (around 15m above the ground)	72	71
E (around 25m above the ground)	66	62

As there couldn't be any live measurements during the actual performance of the opera, the researches set up loudspeakers and played two different kinds of music in high volume to test the noise emissions of a noise live performance.

Results

Overall, the researchers regarded the insulation of the bamboo theatre with two layers of metal shields as successful. As there have been no measurements of sound during the actual performance, the only indicator available was the noise complaints. As there weren't any of those at the time the performance took place, the researchers assumed the intervention had served its purpose.

Furthermore, the study illustrated that temporarily occurring noisy events like the opera performance can be controlled in regards to their noise emissions by planning ahead, even if there are only rudimentary means available.

Acknowledgements

The study only hardly passes as a "best practice" example. The study design is very basic executed. There's no continuous noise modelling, or a baseline assessment. Also, assuming that due to a lack of complaints, there is no noise annoyance, this is to be regarded as an important question. People may have been annoyed, but just didn't complain.

The study is considered as an example in this deliverable, because there are only few neighbourhood and leisure noise studies to report, at present. Case Study 10: Acoustics of a Music Venue/Bar.

Background / Overview

While building a multi-purpose entertainment location in Toronto, a former Portuguese deli had to be transformed into a bar, with a live music stage and a microbrewery. Because of the non-purpose built location, measurements had to be implemented to assure a better overall acoustic experience inside and a sufficient noise control set up to protect residents from music performances (there are three rental apartments inside the same unit), as bar music is being played inside the venue. As the bar and the live music venue were to be operated simultaneously, noise separation was another aspect of interest. A detailed layout and a construction plan of the venue are shown in Figure 32.

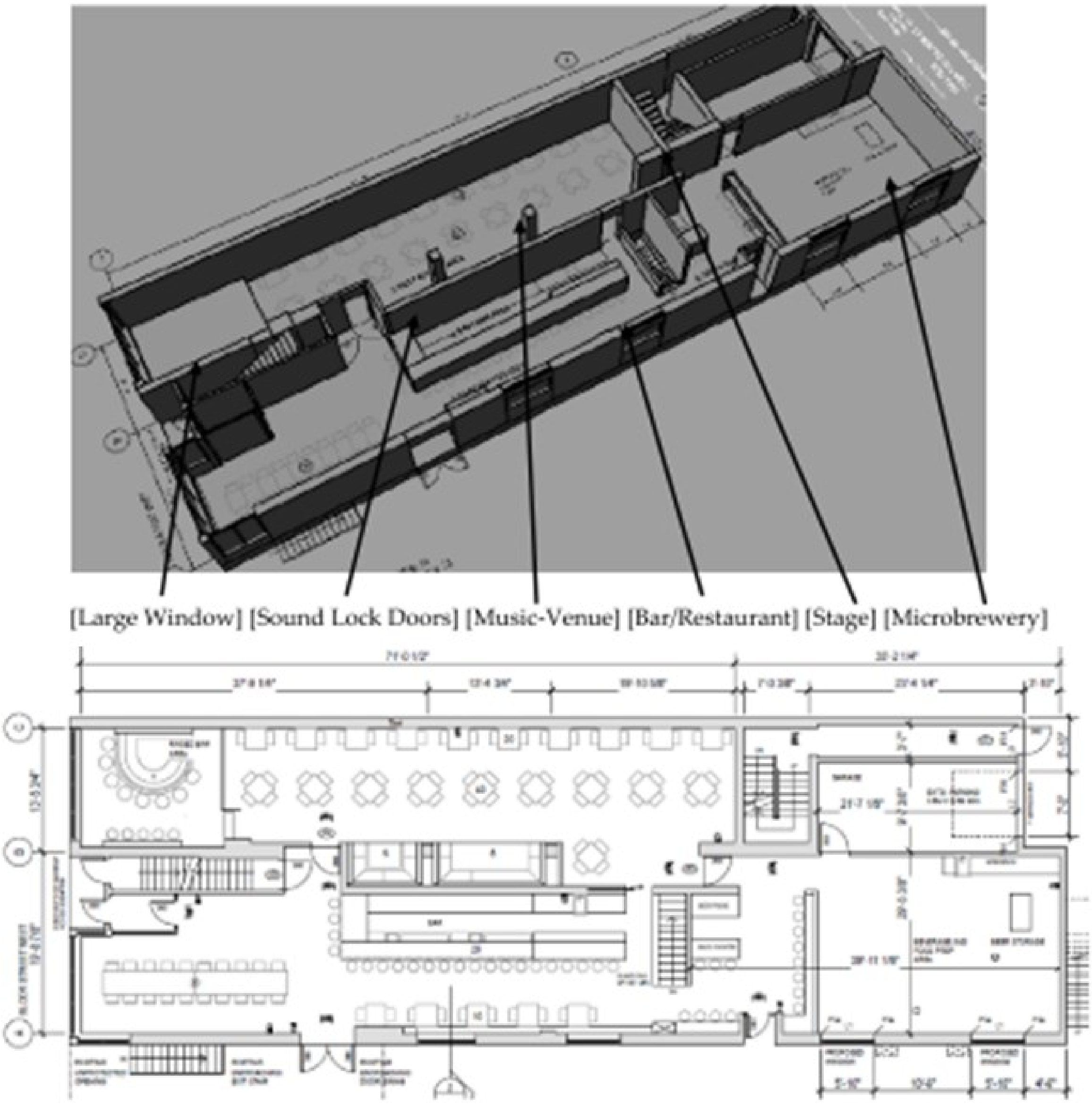


Figure 32: Layout and construction plan for the Bar/ Music Venue

The music venue is supposed to host both reinforced and unreinforced concerts, to grant for a decent sound quality; five acoustical criteria had to be met to ensure biggest possible musical enjoyment:

- adequate loudness in every part of the room
- uniform distribution of sound pressure levels
- optimum reverberation for music
- free from acoustical defects (such as echoes)
- low background noise levels and vibration.

Summing up, the redesign of the old deli had to serve multiple purposes: it was redesigned to host a bar, a small stage and a microbrewery at the same time. As each of these facilities needed to be soundproofed from the others, so every section would have its own environment which wasn't to be disturbed by the others, extensive retrofitting of sound control measures had to be undertaken.

Intervention

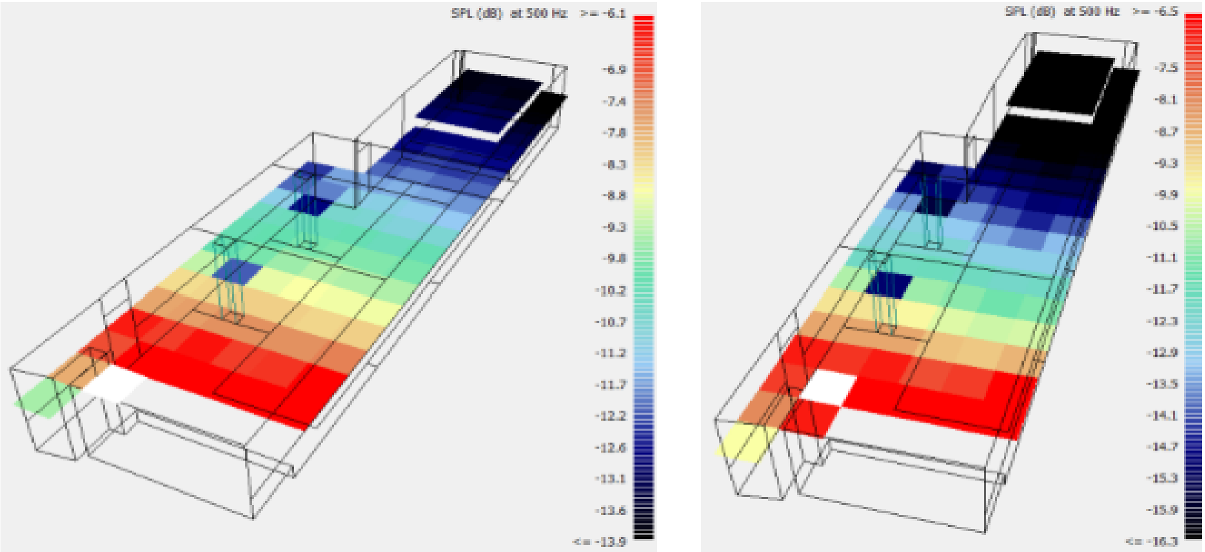
Through few tests, it was made sure that the sound inside of each part of the venues was adequately fit to their respective purposes, which is of lesser interest in regards of this write up.

To provide sufficient sound insulation to the outside, and additionally help sound quality inside, different types of diffusers (Figure 33) were used along with moveable absorbing curtains, to grant for the best possible outcomes.

Figure 33: Types of sound absorbers during the insulation in the music room

While perfectly uniform diffusion was not needed, the main objective for these diffusers was to diffuse early lateral reflections. The location of the speakerand subwoofers are very critical to control the acoustic energy delivered from speakers to room modes. In order to limit the first three orders of the axial modes (for the venue's width and height axes) to be energized, appropriate locations of the subwoofers were recommended—25% of the room width from each wall and elevated at 25% of the room height from the floor, which correspond to the null locations for the second-order standing waves. Simple room acoustic simulations were not undertaken since the main frequencies around 125 Hz were below the Schroeder cut-of frequency limit for the simulation software.
The music room was modelled in the ODEON software for both, an empty room and a full room. Here, the potential decrease in SPL is the most relevant, accordingly the other reported parameters in relation to sound quality inside the venue will not be reported.

According to Figure 34 in comparison, before the installation of the diffusors, the venue now absorbs up to 13.9 dB more than before when empty and up 16.3 dB when crowded.



(a) (b)

Figure 34: Sound pressure level variation in the redesigned music room at 500Hz (a) empty (b) fully occupied

Acoustical measurements have been carried out to assess the reduction in SPL (and more) at four locations around the venue (Figure 35).

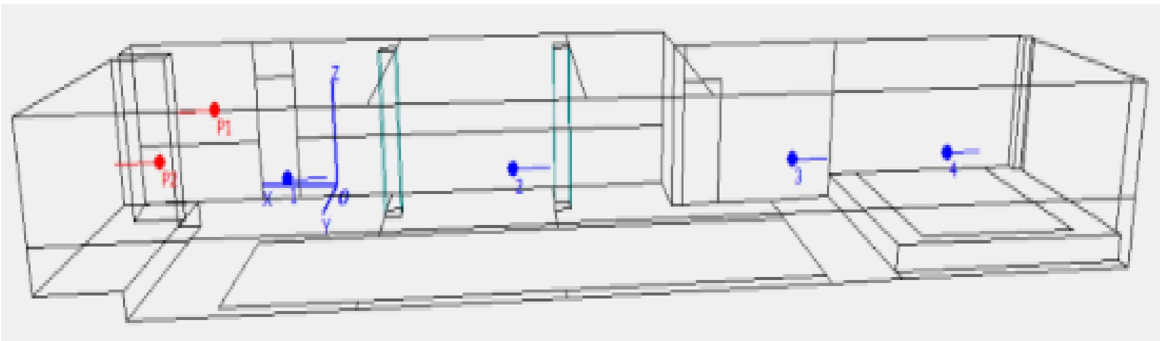


Figure 35: Measurement locations (1-4) and speaker locations (P1 and P2) in the empty music room

Table 12 additionally shows the average achieved decreases in SPL at the four check points while the room was empty.

Table 12: Average achieved decreases in SPL

	Location 1	Location 2	Location 3	Location 4
SPL, dB	-7.12	-9.54	-11.56	-12.44

<u>Results</u>

The study illustrates how to successfully grant for a sufficient acoustical sensation when visiting a bar or a concert, while effectively preventing noises to be perceived as too loud outside.

The decreases in SPL show an average reduction in SPL between 7 and more than 12 dB inside the room, which is a considerable amount in comparison to other sound reduction interventions.

Acknowledgements

This case study has been published in an architectural paper (Ramakrishnan & Dumoulin, 2016). As a result, sound insulation is only a side outcome of the article. The main aim appeared to be to separate noises being produced either in the music hall or at the bar while both had to work simultaneously. However, due to the fact that there were also some apartments above the complex, the sound pressure level had to be kept under control. The reduction of the SPL is not concludingly evaluated in the article, hence the results are purely based on what the author can extract from the case study.

Case Study 10: Regulatory Strategies for Managing Noise from Outdoor Music Concerts

Background / Overview

Brisbane authorities meet several challenges when attempting to regulate noise from outdoor music concerts. According to the study by the Brisbane City Council (2016), annoyance caused by outdoor concerts majorly depends from the following aspects:

- The nature and scale of the event.
- The location and attitude of the local community.
- How often such concerts occur at the location, their duration and finish times.
- Meteorological conditions
- Whether or not the community has been consulted or notified prior to the concert.

Further, the Council agrees that there is also a minimum noise level, that is needed to grant the expected pleasure for the audience, which they identify at around 100 dB(A) for large concerts and at around 95 dB(A) for smaller ones.

Given the fact, that both these values are rather high in comparison to the other usual noise sources, and have a very temporal character (i.e. they only endure for a couple of hours, as opposed to constant traffic noise etc.) noise management strategies mostly rely on the restriction of location, frequency, duration, and finish time. Accordingly, concert noise control falls mostly in the category of noise management, rather than the acoustical mitigation by interventions that rely on path or source control for example, the intervention of choice therefore is the minimisation of complaints, as those are immediate and directly related to the ongoing events. Additionally, the comparatively short duration of concerts requires immediate actions.

As different tolerance levels exist in almost every community in Brisbane, restrictions are aimed to reflect the needs of each local community.

The researchers summarize that for concerts there are two major requirements to be met: providing a tolerable level at the receptor and providing a practical level at the concert itself. For practical reasons, the authorities decided to control the concert levels at the mixing desk of a venue for the purpose of enforcement, which has four reasons:

- ease of self-regulation: the mixing desk operator can check him-/ herself for the noise levels achieved at the mixing desk
- ease of enforcement: measures taken at the mixing desk can easily be transferred to the noise levels at the receptors

- correlation with the receptor level: Once a venue has passed a noise modelling assessment and proven suitable for events, the mixing desk levels can then be correlated with to forecast receiver levels
- levels obtained at the mixing desk can be transmitted to the authorities to confirm noise compliance

To take into account the different characteristics of music styles there are two criterions for measuring concert noise emissions which are 110dB(C) respectively 100 dB(A). It is reasoned that bass-intense music isn't properly reflected by an A-weighted sound measurement, which takes bass and vibration a lot better into consideration than the C-weighting.

Intervention

The case reported here isn't conducted as a case study, it rather summarizes the experiences that have been made while outdoor concerts have taken place. There are fines in accordance to noise compliance at music festivals, which equals the loss of a bond, the organizers had to pay in advance. For the purpose of demonstrating the fine system, the location Brisbane Riverstage was chosen, which is separated from the nearest receivers by 400 meters, allowing levels at the concert to reach 100dB(A) and 110 dB(C).

Otherwise the venue is surrounded by high rise apartment buildings, which are exposed to noise levels above 55dB, in some cases 60 to 70 db(A) or even, as noise modelling shows (Figure Figure 36 and 37).

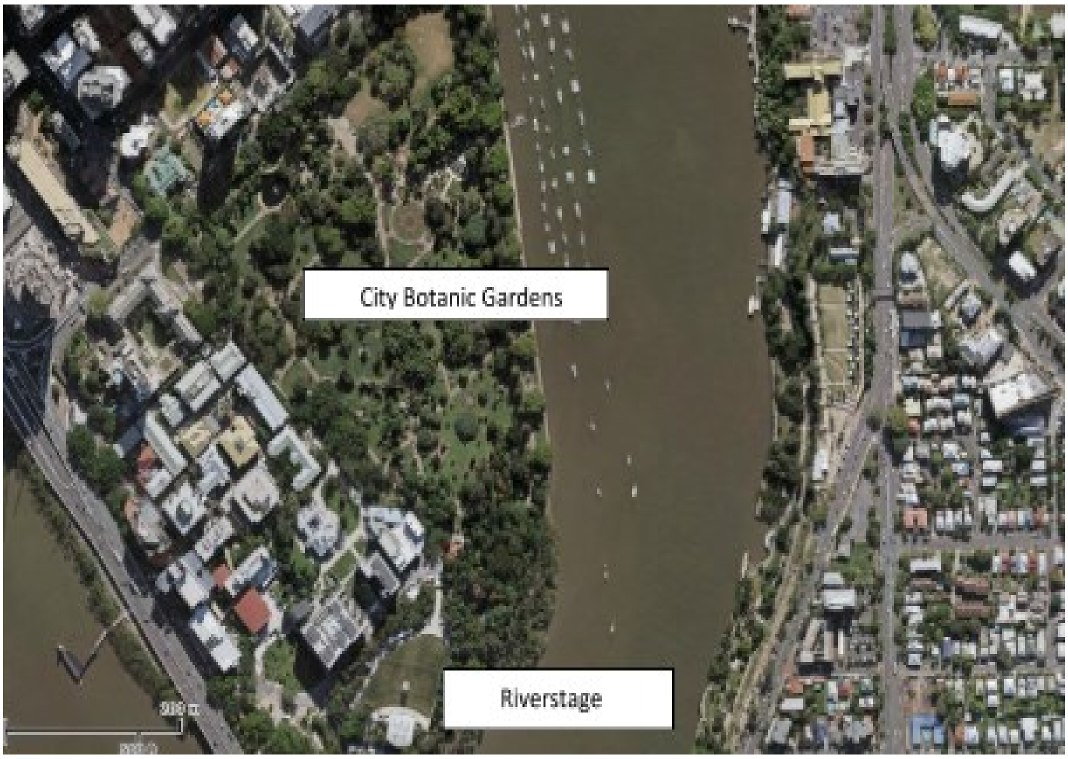


Figure 36: Brisbane River stage area and its surroundings

Further sound modelling showed that by exceedances of only three dB only increases the number of people exposed to 70 dB(A) only slightly, but drastically increases the number of people exposed to 55 dB(A). The article also illustrates the results of sound modelling that show the noise exceedance by 6 dB, which does increase people exposed to overall volumes of more than 65 dB and therefore has a very high potential to cause high amounts of complaints.

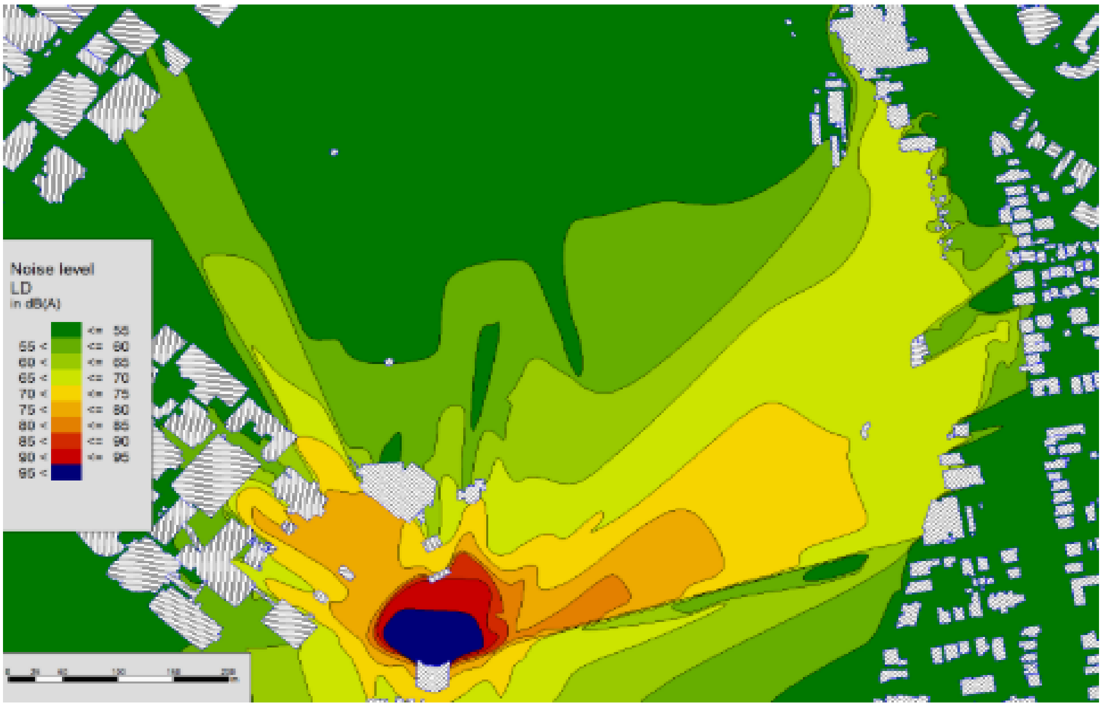


Figure 37: Noise Propagation throughout the area at 100 dB(A) at 30m from the stage (mixing desk position) and 1.5m height

While the Queensland Environmental Protection Act 1994, sets the maximum penalty for noise nuisances at 1700A$ for an individual and 8800A$ for a corporation, this isn't sufficient for a large scale event, that hosts more than 200 people, because it may represent less than 1% of the revenue.

Consequently, a performance bond was established that is scaled after the size of a festival (Table 13).

Table 13: Performance Bonds established by the Brisbane City Council, scaled by event size

Size of Event (People attendance)	Performance Bond A$
2000-5000	0-5000
2001-20000	10000
20001-300000	25000

>30000	50000

Results

The approach toward performance bond deduction in 2012 was:

- 2% deduction per exceedance of a noise condition by up to 3dB
- 4% deduction per exceedance of a noise condition by greater than 3dB.

For example, a 2012 event exceeded the 110dBC criterion for 32% of the measured 5 minute intervals. The majority of these intervals were only 1-3dB above the noise limit. There were enough small exceedances that it became known to the event operators that 100% of the bond had been lost well before the event was due to end. This can be particularly problematic where there are multiple stages with multiple small exceedances. As a result, there was no clear incentive for further compliance. The final performances resulted in numerous and significant breaches of up to 9dB.

Thus, the Council decided to use a more lenient approach that allowed for smaller exceedances as long as they were corrected immediately. The approach taken towards the deduction of the bond was now set at:

5% deduction for exceedances of 3dB for two consecutive 5 minute intervals.

One Year later (2013), the same event exceeded the criterion for 110dB(C) measured in front of the house for 19% of the time, while the worst exceedance was 4dB. This equals a big decrease in total noise level exceedances and maximum noise exceedance that was less than half the level of the year before.

The researchers conclude, that a reasonable balance has been found between enabling a enjoyable concert experience and noise protection for residents in proximity.

REFERENCES

De Vos, P. (March 2016). *Railway noise in Europe - State of the art report.* Paris, France: International Union of Railways (UIC). Retrieved from International Union Of Railways website: https://uic.org/IMG/pdf/railway_noise_in_europe_2016_final.pdf

Oerlemans, S (2011). *Wind turbine noise: primary noise sources*. Amsterdam, The Netherlands: Netherlands Aerospace Centre (NLR).

Tonin, Renzo (April 2012). *Sources of wind turbine noise and sound propagations*. Acoustics Australia - Vol. 40, No. 1.

Nieuwenhuizen, Edwin (2015). *Differences in noise regulations for wind turbines in four European countries.* EuroNoise 2015, Maastricht, The Netherlands.

https://www.researchgate.net/publication/8072125_Perception_and_annoyance_due_to_wind_turbine_noise-A_dose-Response_relationship

https://www.eea.europa.eu/data-and-maps/indicators/traffic-noise-exposure-and-annoyance/noise-term-2001

WHO guidance on Community Noise, although of the 1990' https://apps.who.int/iris/handle/10665/66217

https://www.eea.europa.eu/data-and-maps/indicators/exposure-to-and-annoyance-by-2/assessment-3

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4483667/

Fields, J. M. & Walker, J. G. (1982). The Response to Railway Noise in Great Britain. Journal of Sound and Vibration. (85), 177–255. Retrieved from https://internoise2018.org/assets/documents/11_Fields_and_Walker.pdf

DEFRA, 2011. Wind Farm Noise Statutory Nuisance Complaint Methodology. Report Prepared for Defra: Contract No. NANR 277. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69222/pb-13584-windfarm-noise-statutory-nuisance.pdf

IMAGINE (2004). Improved Methods for the Assessment of the Generic Impact of Noise in the Environment IMAGINE – State of the Art. Deliverable 2 of the IMAGINE project. AEA TECHNOLOGY RAIL BV.

EC, 2014. Commission Regulation (EU) No 1304/2014 of 26 November 2014 on the technical specification for interoperability relating to the subsystem 'rolling stock — noise'. Official Journal of the European Eunion.

EC, 2017. Future Brief: Noise abatement approaches. Science for Environmental Policy. April 2017, Issue 17. http://ec.europa.eu/environment/integration/research/newsalert/pdf/noise_abatement_approaches_FB17_en.pdf

Y. Liu, B. Xia, C. Cui, M. Skitmore. Community response to construction noise in three central cities of Zhejiang province, China. Environmental Pollution 230 (2017) pp. 1009-1017

H.Y.T. Phan, T. Yano, H.A.T. Phan, T. Nishimura, T. Sato, Y. Hashimoto. Community responses to road traffic noise in Hanoi and Ho Chi Minh City. Applied Acoustics 71 (2010) 107–114.

Z. Koziel, E. Peris, J.S. Woodcock, G. Sica, A.T. Moorhouse, D.C. Waddington. Calculation of noise in residential environments. 10th International Congress on Noise as a Public Health Problem (ICBEN) 2011, London. http://usir.salford.ac.uk/id/eprint/19136/1/ICBEN2011_ZKoziel.pdf

Gallo, E., Ciarlo, E., Santa, M., Spostaso, E., Fogola, J., Grasso, D., …., Halbwachs, Y. (2018). Analysis of leisure noise levels and assessment of policies impact in San Salvario district, Torino (Italy), by low-cost IoT noise monitoring network. Proceedings of Euronoise 2018 (pp. 699–704). Crete.

Deutsche Bahn AG. (2018). Baubeginn für zusätzlichen Lärmschutz im Mittelrheintal. Retrieved from https://www.deutschebahn.com/pr-frankfurt-de/Baubeginn-fuer-zusaetzlichen-Laermschutz-im-Mittelrheintal-3386596

Hong Kong Environmental Protection Department; Environmental Noise - Mitigation Measures: https://www.epd.gov.hk/epd/noise_education/web/ENG_EPD_HTML/m4/mitigation_2.html#g [accessed: 15.11.2018]

Hong Kong Housing Authority: https://www.housingauthority.gov.hk/en/ [accessed 15.11.2018]

John HL HO and Chimmy WM CHU, Hong Kong Housing Authority (2016). Research and Development of Noise Mitigation Measures for Public Housing Development in Hong Kong – A Case Study of Acoustic Balcony (Conference Paper submitted at Inter-Noise 2016, Hamburg, Germany).

Liepert, M., Möhler, U., Schreckenberg, D., & Schuemer, R. (2013). The impact of rail grinding on noise levels and residents' noise responses – Part I: Study design and acoustical results. In Proceedings Of Inter-Noise 2013 (Ed.).

Schreckenberg, D., Möhler, U., Liepert, M., & Schuemer, R. (2013). The impact of railway grinding on noise levels and residents' noise responses – Part II: The role of information. In Proceedings Of Inter-Noise 2013 (Ed.).

Marchuk, A., & Henry, F. (2016). Regulatory Strategies for Managing Noise from Outdoor Music Concerts. In Acoustics 2016 (Ed.), Proceedings of ACOUSTICS 2016 (pp. 1–10).

Komusanac, Ivan; Fraile, Daniel; Brindley, Guy (February, 2019). *Wind energy in Europe in 2018*. Wind Europe.

Destinate project website (2018): https://www.destinate-project.tu-berlin.de/menue/destinate/ [accessed: 26.04.2019]

DNV.GL (N.D.). *Shadow flicker protection system for wind turbines*. https://www.dnvgl.com/services/shadow-flicker-protection-system-for-wind-turbines-72275 [accessed 26.04.2019]

Website of EUROSTAT (2018). *Electricity production, consumption and market overview*. https://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_production,_consumption_and_market_overview#Electricity_generation [accessed on 26.04.2019]

Ramakrishnan, R., & Dumoulin, R. (2016). Acoustics of a Music Venue/Bar—A Case Study. Buildings, 6(1), 11. https://doi.org/10.3390/buildings6010011

Marchuk, A., & Henry, F. (2016). Regulatory Strategies for Managing Noise from Outdoor Music Concerts. In Acoustics 2016 (Ed.), Proceedings of ACOUSTICS 2016 (pp. 1–10)