CHAPTER

6

Industrial and Construction Type Noise

While transportation sources tend to dominate management plans for environmental noise pollution, there are many other potential sources of environmental noise. Sites of industrial activity, shipping ports, wind turbines, construction sites, landfills and mining sites are all examples of noise sources that are likely to require some form of a noise impact assessment. Noise assessments for such sources face different challenges than those for transportation noise. For transportation sources, it can be assumed that the overall noise level from all traffic movements over a complete year can be calculated by examining a standard movement of a certain class of vehicle and extrapolating the results to represent all movements over one complete year. This is not the case for sites of industrial activity where no "catch-all" classification approach exists. Industrial noise can vary from one site to the next and, in practice, each source on-site must be measured to obtain the noise emission value required to produce an accurate noise impact assessment. Industrial noise may also include particularly annoying characteristics such as intermittent noise, impulsive elements, audible tones and low-frequency noise. Any assessment that attempts to assess noise annoyance should also consider these.

Noise assessments are often performed to assess the impact a noise source might have on a local community. These assessments may include a strategic noise map, but very often these longer-term assessments are inappropriate because they tend to mask the impact of short-term noise pollution problems. For industrial noise, the sources under consideration may be transient in nature, may be quite seasonal (such as noise from farming activities) or may only exist for a short period of time (such as construction noise). Furthermore, noise from each of these sources can be quite different and assessments often follow guidelines and criteria specific to the type of noise under investigation; for example, the guidelines informing noise assessment at wind farms do not apply to the noise assessment of a landfill. Separate consideration of the source informs the appropriate assessment methodology to be utilised.

Bearing that in mind, this chapter focuses on the assessment of industrial noise, with particular emphasis on the emission of industrial sources (for noise mapping and impact assessments). The different options for obtaining emission values for different sources are explored. Subsequent to this, the chapter discusses other noise sources that are not normally considered in noise mapping studies but which may be prevalent in certain situations and are important when assessing noise impacts on a surrounding population.

6.1 A NOTE ON NOISE CRITERIA

The history of community noise annoyance assessments began in 1978 when Schultz analysed data from several social surveys from road, rail and aircraft noise (Schultz, 1978). He related the percentage of people that were highly annoyed to different sound exposure levels. His dose–response relationships were subjected to some criticism. Kryter, for example, argued that separate relationships for ground and air traffic gave a better representation of dose–response relationships (Kryter, 1982). Despite the criticisms, Schultz's work has gone on to be used widely in practice. More recently, Miedema and Vos compiled the largest dose–response relationship study to date, which was subsequently updated in 2001 (Miedema and Oudshoorn, 2001; Miedema and Vos, 1998). This led to the %HA measure which describes the percentage of people who are highly annoyed from noise and this has been widely used ever since.

These dose–response relationships are often used to set and justify noise design goals/criteria and predict the level of annoyance a community will experience. For example, in Australia, the New South Wales Environment Protection Authority aims to set noise criteria to ensure at least 90% of an exposed population are protected from being highly annoyed for at least 90% of the time (where possible) (New South Wales Environment Protection Agency, 2000).

When considering the potential noise impact in terms of the response of a population, it must be acknowledged that the response varies widely depending on the noise source. At exposure levels higher than 40 dB(A), the expected percentage of annoyed persons indoors due to wind turbine noise is higher than due to industrial noise from stationary sources at the same exposure level (Janssen et al., 2009). Table 6.1 shows the estimated percentage of highly annoyed related to threshold values of 45, 50 and 55 dB L_{den} for a variety of different sources (European Environment Agency, 2010). The level of annoyance induced by a source varies significantly but aircraft and wind turbine noise are considered to be the most

TABLE 6.1 Estimated Percentage of Highly Annoyed for Different Noise Sources

	Percentage of Highly Annoyed				
L_{den} [dB(A)]	Road (%)	Rail (%)	Aircraft (%)	Industry (%)	Wind turbine (%)
55	6	4	27	5	26
50	4	2	18	3	13
45	1	0	12	1	6

annoying sources. Because of the varying relationship between noise annoyance and the type of noise source, different noise criteria must be developed for different sources of noise.

The manner in which noise criteria are set is also worth considering. For industrial noise in Ireland, the EPA suggest a noise limit of 55 dB L_{Aeq} for the daytime (08:00 to 22:00) and 45 dB L_{Aeq} for the night-time (22:00 to 08:00) to be applied at nearby sensitive receivers. These limits might be considered a "pivot threshold", in that it serves to identify a critical dividing line between what is considered to be a significant and non-significant impact, even though there are no specific details to determine the relative degree of significance (Wood, 2008). Such thresholds have the advantage of simplicity, ease of application and arguably facilitate consistency of practice in noise appraisal. One disadvantage of using such a pivot threshold is that, when used in isolation, it could potentially underplay impact significance (Wood, 2008). One possible alternative would be to introduce a "relative noise increase criterion", which would require the adoption of both rural and urban background values (King and O'Malley, 2012). This method compares expected noise levels with existing noise levels and if the noise is expected to increase by a predefined amount, mitigation will be required.

Finally, authorities should also be aware of industrial noise "creep". Noise creep refers to the gradual increase in background noise level due to changing industrial activity. This is a particular problem in areas where industrial activity is expanding. For example, if two industrial sites in an area each meets a noise criteria of 45 dB, then the total noise level will be 48 dB. If two more compliant sites are opened, the total may then increase to 51 dB.

6.2 INDUSTRIAL NOISE

Industrial noise can be anything from the noise emitted from steel making plants, coal fired power stations, car assembly plants, furniture-making workshops, train depots or the loading and unloading of trucks at a distribution centre. Other activities can be classified as industrial activities or even their own subset of industrial activities, such as mineral extraction sites. Readers should note that the considerations contained in this section are applicable to all types of industrial activity.

6.2.1 Industrial Noise Annoyance

Dose–response curves for industrial noise have not been developed to the same extent as those for transportation noise. This is probably because industrial noise is less widespread than transportation noise, and industrial activities vary significantly from site to site which makes it more difficult to establish a stable dose–response relationship (Berry and Porter, 2004). However, we know from previous research that industrial noise is more annoying than transportation noise at equivalent noise levels (Miedema, 1992). These greater levels of annoyance may be related to the presence of annoying characteristics in (e.g. tonal components) in industrial noise sources. A single tone contributes more to the aversiveness of a noise than an equivalent amount of energy distributed over a wider range of frequencies (Berry and Porter, 2004). Because of this, a 1995 UK National Physical Laboratory (NPL) study sought to develop effective penalties for increased annoyance from tonal noise (Porter, 1995). Figure 6.1 outlines the results from subjective listening tests including the response to different levels of tonal noise, noise from a compressor and road traffic noise. The study used these to calculate "effective penalties" for industrial and tonal noise at different overall noise levels (Table 6.2); note the tonal noise source had a higher effective penalty.

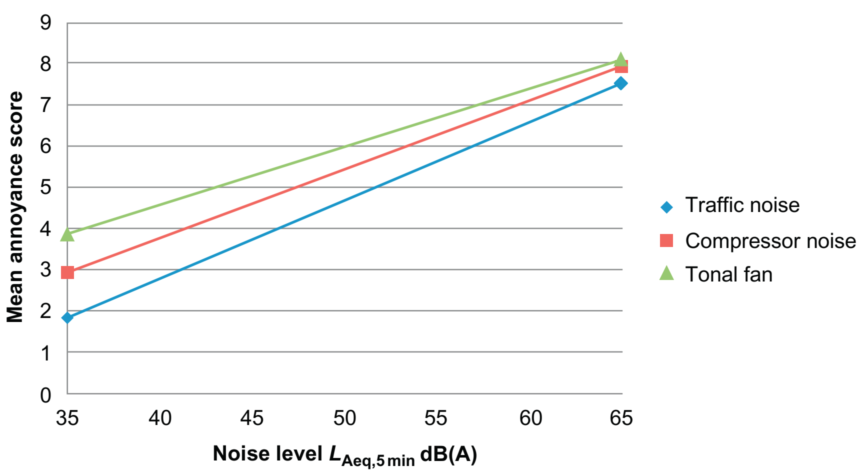


FIGURE 6.1 Example of NPL study results showing response to different levels of traffic noise, industrial noise and tonal noise, at different overall noise levels. *Adapted from Porter, (1995).*

TABLE 6.2 Calculated Effective Penalties Using Traffic Noise as a Baseline (Porter, 1995)

Noise	Penalty (Traffic Noise as a Baseline)			
	35 dB(A)	45 dB(A)	55 dB(A)	65 dB(A)
Compressor	5.8	4.5	3.3	2.1
Tonal fan	10.7	8.2	5.6	3.0

Impulsive noises are also more annoying than continuous noises, particularly at low noise levels, while the difference in annoyance is lower at higher noise levels. Results from a separate NPL study found that the level of annoyance from a pile driver at around 45 dB(A) was equal to that of road traffic noise at 60 dB(A). However, at higher noise levels (in excess of 70 dB(A)), no difference in annoyance was observed (Berry and Porter, 2004). This suggests that it is not a straightforward task of simply adding a penalty for impulsive noise as the level of annoyance is also related to the overall noise level. In fact, ISO 1996-1 notes that no mathematical descriptor exists that can define unequivocally the presence of impulsive sounds. It does however outline three different categories for types of impulsive sounds and provides examples of each (Table 6.3). Thus, if a noise source is similar to those in Table 6.3, it may be considered as having impulsive elements.

In truth, the level of annoyance from an industrial noise source can be increased by a wide variety of factors, some of which are related to the noise content (tonality, impulsiveness, intermittency, low-frequency content) while others are related to factors outside of traditional acoustic considerations. A 2003 study in the Netherlands compared noise annoyance from shunting yards (a seasonal industry) and other industries (Miedema and Vos, 2004). The study found increased annoyance for shunting yards compared to other sites; this was thought to be partly due to vibrations from shunting yards and noise from through trains. Of all sites assessed, the seasonal industry was deemed to be least annoying. It suggests that the

TABLE 6.3 Examples of Impulsive Sound Sources

Type of Sound Source	Example
Regular impulsive sound source	Examples include slamming of car door, outdoor ball games, etc.
Highly impulsive sound source	Examples include hammering on metal or wood, nail guns, pile driving, coupling impacts in rail-yard shunting operations
High energy impulsive sound source	Examples include quarry and mining explosions, sonic booms, demolition or industrial processes that use high explosives

relatively low annoyance from the seasonal industry is related to the presence of a relatively quiet period. Furthermore, aversion to the industry itself, in terms of people's perceptions of it, may increase the overall level of annoyance associated with it (Crichton et al., 2013).

6.2.2 Developing Noise Maps of Industrial Sources

The potential impact that a site of industrial activity might have on a community either now or in the future can be assessed by determining the noise emission at source and evaluating the resulting level at a nearby receiver. This can be achieved through a single point-to-point assessment (that might form part of an Environmental Impact Assessment, for example) or it may include a number of receiver positions (e.g. a grid of receivers for the development of a strategic noise map). Either way, the emission at source must be determined. Thus, the development of a strategic noise map for an industrial source will require the same source data as a single assessment.

In recent years, the development of strategic noise maps for industrial sites has been driven by the END which specifically requires these sites (including ports) to be mapped within agglomerations. However, the legislation does not explicitly define what constitutes an industrial activity so the development of maps for these sources is somewhat at the discretion of Member States (European Commission Working Group Assessment of Exposure to Noise (WG-AEN), 2006).

BOX 6.1

INDUSTRIAL NOISE AND NOISE MAPS UNDER THE END

Strategic noise maps for agglomerations must include noise from sites of industrial activity (including ports) along with road traffic, rail traffic and airports. Outside of agglomerations, the END does not require noise maps to be developed for industrial noise. The END does not explicitly define what constitutes an industrial activity; however, by way of an example, it refers to those industrial activities defined in Annex I of Directive 96/61/EC concerning integrated pollution prevention and control (IPPC). These include energy industries (such as mineral oil and gas refineries, coal gasification and liquefaction plants), the production and processing of metals, mineral industries (such as installations for the manufacture of glass), chemical industries, waste management facilities and other activities. Each site is made up of multiple activities which each represent separate noise sources. The amount and extent of these sources vary significantly across each industry.

For the first phase of noise mapping, a total of 120 agglomerations across the EU reported exposure figures for industrial noise but 25 of these reported zero exposure within the reporting threshold level (de Vos and Licitra, 2013). Austria and Ireland did not report any exposure for industrial noise; it is hard to believe that there are no industrial sites in those nations that warrant reporting under the terms of the Directive. For industrial noise, the total exposure exceeding 55 dB L_{den} across Europe amounted to 686,000 inhabitants (minimal compared to transportation sources) (van den Berg, 2009). However, the approach towards assessing industrial noise across Member States was highly variable and, therefore, only limited conclusions can be drawn from the data. In the Netherlands, industrial noise maps were based on the detailed permits that each industry is required to hold, whereas in Ireland, it was simply assumed that all industrial sites operated within the confines of their IPPC licences. This assumed that noise produced at the industrial site did not exceed 45 dB(A) beyond its boundary and therefore did not need to be mapped.

Simplified approaches to the mapping of industrial sources are common because it is impractical to measure the sound power of every industrial source within an agglomeration. However, it is not best practice to assume all industrial sites are in compliance with operating permits. It is clear that some degree of consistency to the treatment of industrial sources across Europe is required. Unfortunately, there is currently no standard method to calculate industrial noise sources largely because of their variability.

The WG-AEN Good Practice Guide on Noise Mapping takes a step towards achieving some level of consistency and offers, *inter alia*, generic guidance on the typical sound power emitted from various types of industry (European Commission Working Group Assessment of Exposure to Noise (WG-AEN), 2006). Other more detailed databases describing the sound power and spectra of separate activities likely to take place in an industrial facility are being developed. Their development will undoubtedly assist authorities in the generation of strategic noise maps for industrial sources.

In practice, the most difficult aspect of a noise assessment for an industrial site is obtaining an accurate representation of noise emission. Sometimes an industrial site may be a collection of hundreds of different noise sources. To definitively develop a noise model of just one industrial site would require a tremendous amount of data gathering (including site measurements to determine source emission) and it might be considered unfeasible to produce such detailed noise models for all industrial sites in an agglomeration. Furthermore, access to industrial facilities can often be quite limited which may adversely affect the veracity of any noise measurement taken to estimate the sound power of the source. It is for these reasons that simplified approaches are often adopted.

The level of detail and the type of information required for each industrial site are dependent on the desired accuracy of the noise model, what it will be used for and what, if any, action will be taken on the basis of the modelled results. Industrial sites can be modelled as point, line or area sources. A simple assessment, using area sources to represent the emission of an industrial site, will typically require the following information (Environmental Protection Agency, 2011): the location of industrial area and the source height, a description of the industrial process, and the sound power emission level(s) (including directivity) for operations on the site. If, however, a high level of accuracy is required, more detailed information may be necessary. Unfortunately, in most cases, such information must be obtained the hard way, which includes (Santos et al., 2008) spending several weeks on-site in order to develop a full understanding of how the industry operates, close observation of all sound sources in order to measure the sound power of each, and accurately inputting the position of all sources present on-site. The CNOSSOS-EU method has produced a definitive list of all data required to represent each noise source in a site of industrial activity (Kephalopoulos et al., 2012) (Table 6.4).

6.2.2.1 Industrial Noise Emission

The key issue in developing a strategic noise map for industrial noise sources is determining the noise emission. There is no standard emission model for industrial noise; the sound power of the source(s) must be either measured or estimated. Undoubtedly, the most reliable way to capture information on the sound power of the source is through measurement. However, measurements may be time-consuming, expensive to conduct and it might not be possible to apply a consistent measurement procedure across all industrial sources within an agglomeration. An alternative is to

TABLE 6.4 Complete Set of Input Data for a Noise Source in an Industrial Site

Data Requirements
Emitted sound power level spectrum in octave bands
Working hours (day, evening, night on a yearly averaged basis)
Locations (including elevation) of the noise source
Type of source (area/line/point)
Dimensions and orientation
Operating conditions of the source
Directivity of the source

use default data contained in international databases, albeit accepting that a certain degree of accuracy may be lost in the generation of the results.

6.2.2.2 Determining Sound Power by Measurement

There are a number of international standards describing measurement methods to determine the emission of a source. Generally, the measurement methodology involves measurements being recorded at a reference distance from the source under investigation and usually at a number of positions enveloping the source. Measurement results may then be used to calculate the sound power of the source. Generally, this is based on an average of all measured results. Corrections to account for reflections and background noise may also be included in the methodology.

For the development of strategic noise maps, the END recommends ISO 9613-2: "Acoustics – Abatement of sound propagation outdoors, Part 2: General method of calculation". This method develops an engineering method for calculating the attenuation of sound during outdoor propagation at a distance from a number of point sources. The contribution of each source is combined to give the overall equivalent noise level at the position of the receiver. ISO 9613-2 does not contain any emission data on sources. However, suitable noise emission data (input data) can be obtained from measurements carried out in accordance with one of the following methods:

- ISO 8297 (1994) "Acoustics – Determination of sound power levels of multisource industrial plants for evaluation of sound pressure levels in the environment – Engineering method",
- EN ISO 3744 (1995) "Acoustics – Determination of sound power levels of noise using sound pressure – Engineering method in an essentially free field over a reflecting plane",
- EN ISO 3746 (1995) "Acoustics – Determination of sound power levels of noise sources using an enveloping measurement surface over a reflecting plane".

ISO 8297 (1994) specifies an engineering method for determining the sound power levels of large multisource industrial plants relevant to the evaluation of sound pressure levels in the environment. The method is limited to large industrial sites where most of the equipment is operating outdoors. The standard requires sound pressure level measurements on a closed path surrounding the plant with individual sources within the site treated as a single source at the geometrical centre of the plant. This requires access to all sides of industrial sites, something that is often difficult to achieve in practice (Stephenson and Postlethwaite, 2003).

In order to determine the sound power level produced by the source, EN ISO 3744 (1995) specifies a method for measuring the sound pressure levels on a measurement surface enveloping a noise source. The measurement method is suitable for use with a single source and requires unrestricted access to the source. Measurements are often conducted in controlled test environments such as a semi-anechoic room, an outdoor space and an ordinary room provided that certain conditions are met.

EN ISO 3746 (1995) is quite similar to EN ISO 3744. It is a survey-grade method based on ISO 3744, where the environmental requirements are substantially relaxed and a correction of up to 7 dB is allowed. This allows measurements to be made with machinery *in situ* within its existing working conditions (Payne and Simmons, 1999). Both ISO 3744 and ISO 3746 standards were updated in 2010. ISO 3744 and ISO 3746 are only suitable for determining the sound power level of individual sources of limited dimensions (small) and are not at all suitable for the assessment of source groups or entire companies (Wolfel, 2003). ISO 8927 is more suited for these purposes. However, practitioners should not be restricted to using these standards. For example, alternative testing procedures have been developed in Australia to measure sound power levels of large mine haul trucks which also include dynamic testing. These are based on:

- ISO 6393:2008(E) "Earth-moving machinery – Determination of sound power level – Stationary test conditions"; and
- ISO 6395:2008(E) "Earth-moving machinery – Determination of sound power level noise emissions – Dynamic test conditions".

BOX 6.2

MEASURING INDUSTRIAL NOISE

It is clear that the best way to determine the sound power levels of an industrial site is to perform detailed on-site assessments, identify individual sources and determine their sound power characteristics. However, performing such an assessment for a large industrial site is resource intensive and depends on each individual site being assessed. Measuring and collecting the relevant sound power data for a petrochemical plant of 25,000 m^2 might take about three person-days, whereas the assessment of a small manufacturer of wooden stairs might only require a half-day assessment (Witte, 2007). Furthermore, at some industrial sites, the location of the noise source may vary over time, such as at open cut (caste) mines and quarries.

6.2.2.3 Determining Sound Power by the Use of Default Parameters

If it is not possible to conduct measurements to determine the sound power of an industrial site, it may be possible to estimate the sound power levels from manufacturer supplied data (e.g. using CE-labels) (Witte, 2012). Alternatively, authorities may refer to a database describing the sound power levels and spectra for a large number of different industrial sources under various operating conditions. Such a database has been developed through the Imagine Project (Witte, 2007) and the company, DGMR, has developed a software tool (SourcedB) for easy access to this database.

The SourcedB database contains details of the sound power measurement methods, sound power calculation formulae (based on operating conditions like power consumption, rpm, etc.) as well as spectral information for a wide range of sources. Different types of sources are also referenced including point sources (e.g. small hand-held machines), line sources (e.g. a rotary kiln for cement works) and area sources (e.g. a shunting yard). For simplified assessments, the database also includes default values for typical sound power levels radiated by specific industrial activities per unit area (Witte, 2007). Activities such as petrochemical plants, power plants and ship yards can be described in this manner.

Figures 6.2 (a) and (b) present screenshots of the SourcedB database.

6.2.2.4 *Effect of Operating Conditions*

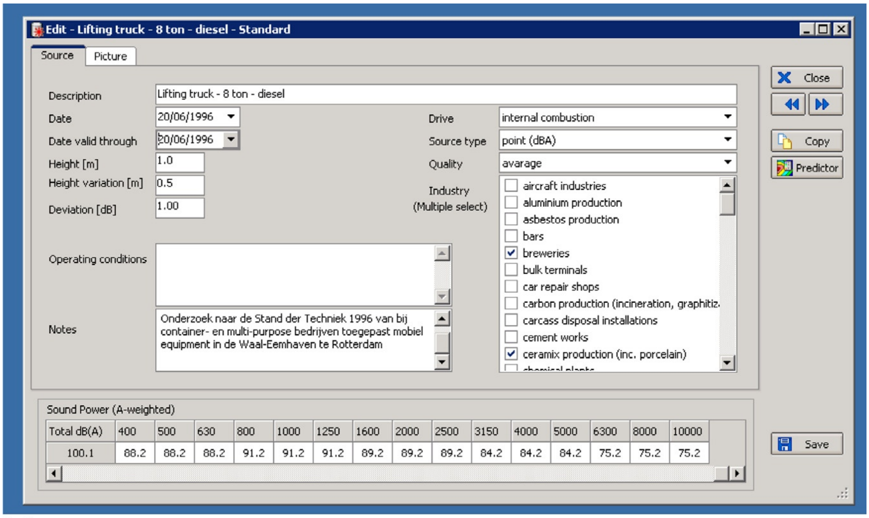
Measurements performed under the international standards identified above often report the noise emission under typical operating conditions. Noise emissions can significantly change with differing conditions of the source; differences in emission level can exist between a machine being run at full power and when idling, a lathe cutting timber or metal, or a drill cutting different material types. Features added to the source, such as silencers, limiters and screens, can also affect emission levels. All of these operating conditions must be taken into account when estimating emissions from industrial sites.

Because L_{den} and L_{night} are long-term indicators, operational times must also be considered. The forthcoming CNOSSOS-EU method includes a correction for the operational time of industrial sources. This correction, C_{w}, is added to the source sound power to determine the corrected sound power that should be used for calculations over each period. It may be calculated from Kephalopoulos et al. (2012):

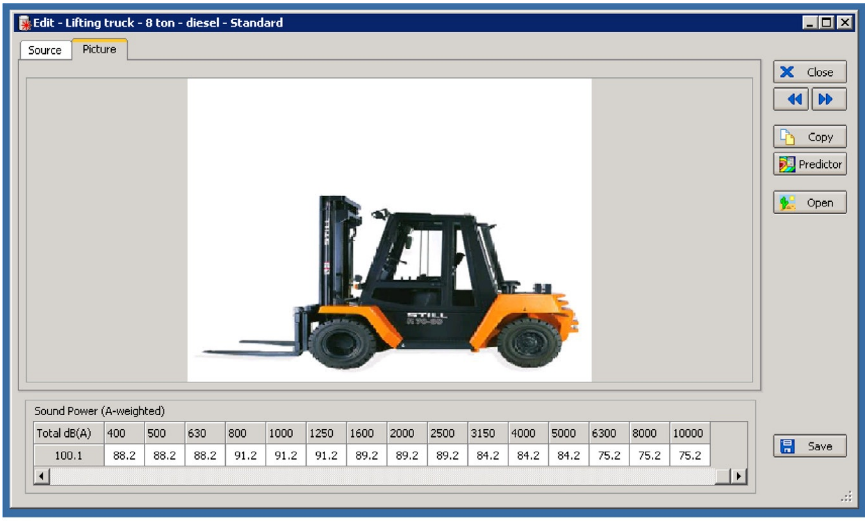
$$C_{\mathrm{w}} = 10\log_{10}\left(\frac{t}{T_0}\right)[\mathrm{dB}] \tag{6.1}$$

where t is the active source time per period based on a yearly averaged situation in hours and T_0 is the reference period of time in hours (day = 12 h, evening = 4 h and night = 8 h). Thus, for a constantly operating source ($t = T_0$), the correction will be zero, whereas a source that only operates for 50% of the day will yield a correction of approximately −3 dB.

As well as considering the operating times throughout a 24-h period, the operating days over the week, month and year should also be considered.



(a)



(b)

FIGURE 6.2 (a) Screenshot of SourcedB – data describing a lifting truck. (b) SourcedB also includes pictures of sources for clarification purposes.

A plant operating 100% of the time will not require any correction, whereas a company that works for 8 h in the day period and does not operate at weekends or holidays will result in a long-term average correction of 3.6 dB (Witte, 2012). The directivity of the source must also be considered. This will be dependent on the position of the equivalent sound source relative to nearby surfaces (Kephalopoulos et al., 2012).

6.2.2.5 Modelling Industrial Noise Emission for Noise Mapping

For industrial noise assessments, the most dominant source of uncertainty is related to the source positioning and sound power (Witte, 2012). Thus, an accurate representation of the source is required for noise assessment as well as an accurate representation of geometric features that are likely to result in screening or reflection effects. If one considers the potential range of sources over an entire industrial site, it is easy to see how a noise assessment can become rather complex.

For noise modelling, the source of industrial noise can either be a point source, line source or area source. A point source may be taken to mean a source whose dimensions are much smaller than the distance through which propagation occurs. A line source is a source with one dimension greater than the others, and this is significant compared to the propagation distance. As the distance from the source increases, a line source will gradually evolve into a point source. Area sources tend to have large dimensions overall compared to the propagation distance; the roof or facade of a factory is a good example in this regard.

For the purposes of strategic noise mapping under the END, the Wolfel Interim Method Report recommends using global sound power levels of the entire industrial complex, thereby disregarding the actual distribution of individual sources (Wolfel, 2003). Calculations should be performed separately for each octave band. However, it is often the case that only overall A-weighted sound power levels are available. In such cases, propagation calculations should be performed assuming the attenuation terms that would be used when considering a frequency of 500 Hz.[1]

The report describes three possible sound power level formats for representing the total noise emission of an industrial site:

- Global source: an area source expressed as sound power per metre squared.
- Zonal source: sound power levels can be assigned to several distinct area sources each of which encloses a group of emitting sources.
- Point or line source: individual sources can be used when detailed information on the sound power levels and location of individual equipment exists and when the positions of buildings and potential barriers on the industrial site are known.

A toolkit to be used in the development of noise maps for industrial sources was also developed to assist EU Member States implement the END (European Commission Working Group Assessment of Exposure

[1]The level of attenuation varies with frequency. To calculate the attenuation when only A-weighted sound power levels are available, we assume the same attenuation terms that would be used in calculations at a frequency of 500 Hz.

TABLE 6.5 Default Emission Values for Different Types of Industry (European Commission Working Group Assessment of Exposure to Noise (WG-AEN), 2006)

	Default Value for L_w'' [m^2]		
Type of Industry	**Day [dB(A)]**	**Evening [dB(A)]**	**Night [dB(A)]**
Area with light industries	65	65	65
Area with commercial uses	60	60	60
Ports	60	60	45

to Noise (WG-AEN), 2006). The toolkit applies over a range of emission data availability with scenarios ranging from a full dataset spanning the day, evening and night-time periods, to scenarios where no data are available at all. Where no data are available, the recommended procedure is to consult existing databases for individual industrial sound sources with associated sound power levels. Otherwise, the default values presented in Table 6.5 are suggested.

BOX 6.3

INDUSTRIAL NOISE AND CNOSSOS-EU

The forthcoming CNOSSOS-EU method will include a methodology for the assessment of industrial noise sources. The preferred approach for CNOSSOS-EU will be to use site measurements (Kephalopoulos et al., 2012). Measurements to determine the sound power and spectra to be used to model industrial noise may be taken according to a number of international standards. In cases where site measurements are not possible, the calculation method will provide a database describing typical sound power levels for each source as well as likely working hours and directivity. This database is due to be finalised during Phase B of CNOSSOS-EU.

6.3 PORT NOISE

In the past, port activities were limited to the handling of ships and their cargos. In recent decades, these activities have evolved to include a wide range of interests including the management of individual estates which exposes port authorities to environmental regulations and concerns typical of other large industrial operations (van Breeman, 2008). Nowadays ship operations at ports, including cargo handling and related activities, often result in significant noise emissions. Thus, the END specifically requires port noise to be assessed as industrial noise within agglomerations.

To date, environmental noise from port activities has probably not received as much attention as other noise sources, most certainly in academic literature. Recently, Murphy and King (2014) monitored noise levels in the vicinity of Dublin port, Ireland, and results highlighted the extent to which port noise can be a significant environmental stressor. For guidance on the assessment of noise from ports, the EU-funded NoMEPorts project (Noise Management in European Ports) published a "Good Practice Guide for Port Area Noise Mapping and Management" (van Breeman, 2008) which outlines a common approach for the development of strategic noise maps for port area noise in the context of the END. The objective of the NoMEPorts project, which included 14 partners from 8 countries, was to reduce noise, noise-related annoyance and health problems of people living around industrial port areas.

There are a number of potential sources associated with port noise. The NoMEPorts project summarises the sources as a collection of both industrial sources and transportation sources (Table 6.6). Despite the fact that transportation noise may not necessarily be considered an industrial source, port noise assessments should take into consideration all traffic-related sources within the limits of a particular port study area (van Breeman, 2008).

Similar to a general industrial noise assessment, the key requirement of a port noise assessment is the accurate representation of the source. This requires the collection of all relevant noise source and operational data. In most cases, this will involve significant data gathering and noise measurement. Sound power levels can be obtained by either measurements taken on-site or through the use of a default database. Measurements taken

TABLE 6.6 Different Sources of Port Noise (van Breeman, 2008)

Port Noise	
Industrial Sources	**Transportation Sources**
Port services and facilities	Road traffic
Terminals (cargo handling, warehousing)	Rail traffic
Industrial areas	Air traffic
Machinery, workshop	
Vessel repair or maintenance	
Shunting yards	
Vessels when berthed (engine noise)	

on-site will provide more reliable data but this will be a time-consuming and expensive option. Default datasets can be used and the NoMEPorts project recommends that these data be accompanied by some on-site measurements. In this case, measurements act a validation exercise for modelled data rather than forming the basis of sound power assessments.

A number of lessons were identified by the NoMEPorts project for port noise mapping and are worth outlining for the reader. They include standard best practice procedures for port noise mapping:

- Collaboration between all stakeholders. This can be achieved by establishing a local working group consisting of representatives from all parties involved.
- An overview of input data requirements and the availability or otherwise of such data should be identified at the outset.
- After developing an inventory of all noise sources, screening for significance should take place to avoid unnecessary data collection.
- Gaps in the noise data can be filled by default values from international databases, for example, through the Imagine source database or by way of expert advice.

6.4 AIRPORTS AS INDUSTRIAL SOURCES

One of the key considerations of any noise mapping assessment is identifying where transportation noise ends and industrial noise begins. Noise mapping authorities are usually only concerned with noise sources that they are responsible for under legislation. It has been noted that railroad noise stops at the entrance of a shunting yard; once inside the site, it becomes industrial noise (Witte, 2004). The same could be said for a heavy goods vehicle delivering equipment to a factory; the moment it leaves a public road it can be considered industrial noise. Thus, if a noise mapping body is responsible for a transportation source, should they also consider cases where this source becomes industrial? This issue is quite significant in the case of aircraft noise.

There has been some debate as to whether or not noise from activities at airports that are not directly associated with aircraft movement should be considered in the development of strategic noise maps (European Commission Working Group Assessment of Exposure to Noise (WG-AEN), 2006). Such activities may include taxiing, engine testing, and the movement of plant and vehicles operating within the airport. Ultimately, the END legislation is not specific in this regard and the decision rests with the Member State or an individual national or local authority beyond the EU where no strategic mapping legislation exists. However, the WG-AEN recommends that all noise sources, particularly when their noise contribution is greater than 55 dB(A) L_{den} or 50 dB(A) L_{night}, should be mapped as industrial noise (European Commission Working Group Assessment of Exposure to Noise (WG-AEN), 2006).

The forthcoming CNOSSOS-EU model recognises that ground-based fixed sources at airports (including engine run-up) should be modelled with the same propagation methodology that is used for industrial noise (Kephalopoulos et al., 2012). The data to describe the source of these activities (engine run-up, directivity patterns, spectral information) should be contained in the international Aircraft Noise and Performance database (see Chapter 5). However, this database needs to be updated to enable any such calculations and clear guidance on how to utilise these data in conjunction with a propagation model to develop a noise map for this type of industrial site is required (Kephalopoulos et al., 2012).

6.5 WIND FARM NOISE

Wind farms (a collection of wind turbines) are being heralded as a new source of green energy and are becoming increasingly commonplace. This section describes how wind turbine noise should be modelled and assessed. It should be noted that while noise maps have not been developed for wind farms in the context of the END, noise maps are often created for such developments during the preparation of the associated Environmental Impact Statements (King et al., 2012). Indeed, noise is often reported as the most annoying aspect of wind farm developments; although degree of this annoyance may also be related to the level of visual intrusion (van den Berg et al., 2008). It may be that in locations where wind farms are perceived as having a negative impact on local scenery, the probability of noise annoyance, regardless of the A-weighted sound pressure level, is increased (Pedersen and Larsman, 2008). Furthermore, the perception of wind turbine noise may be affected negatively by the elevated position of the source.

Generally, wind turbines will generate noise that may be described as a combination of tonal, broadband, low-frequency and impulsive sounds through various phases of operation (King et al., 2012). This results in a

> **BOX 6.4**
>
> **WIND FARMS AND THE END**
>
> Noise from wind turbines is not considered when developing strategic noise maps under the END. Noise from industrial sites is only assessed within the boundaries of an agglomeration and wind turbines tend to be located in rural areas. Furthermore, wind turbine noise is usually much lower than noise from other industrial sources.

combination of mechanical and aerodynamic noise. Some authors have reported concerns associated with amplitude modulation. Amplitude modulation is a fluctuating noise (a noise level rising and falling in a regular pattern) and is related to the speed of rotating turbine blades. This fluctuating component may increase the level of annoyance associated with the turbine (Lenchine, 2009) and should be an important consideration in assessments of annoyance from wind turbines (Pedersen, 2003). Current understanding of amplitude modulation is not very well developed and more research is required to understand its nature and its association with noise annoyance. Concern also exists with issues related to low-frequency noise and infrasound. However, several studies in Australia have shown that low-frequency noise and infrasound emitted by wind turbines is at levels no different to that normally experienced in the environment (Evans et al., 2013a,b; Turnbull et al., 2012).

Wind farm developments often have a setback distance (i.e. a minimum distance to the nearest sensitive receiver), which can be for safety reasons or environmental concerns. This varies across nations and can range from 300 to 1000 m (Gamboa and Munda, 2007). Usually, the permissible limits for wind turbines are quite low, often as low as 45 dB L_{90}. Accordingly, their impact in terms of the long-term indicator L_{den} tends to be minimal (compared to other sources). However, when other factors such as low-frequency noise content and amplitude modulation are considered, supplemental indicators (which might include those outlined in Annex X of the END) should be employed to assess the noise impact of the turbines. The use of A-weighting is not appropriate when low-frequency noise is present. Some consider G-weighting, which has been designed for infrasonic assessments, may be suitable for wind farm assessments, particularly when low frequency noise may be an issue.

What makes wind turbines unique from other noise sources is that the level of noise produced at the source is dependent on the prevailing wind speed, i.e., the turbine tends to make more noise as the wind blows faster. However, this does not necessarily mean that high wind turbine speeds are directly related to increases in annoyance. As the wind blows harder, noise from environmental sources (trees, bushes, the wind itself, i.e., the background noise) also increases, and the two source types (turbine and environmental) tend to change at different rates. As such there is a wind speed where the noise from the turbine reaches a peak when it is compared against the background noise. This point is called the critical wind speed, i.e., the speed at which the noise from the turbines is at its highest level when background noise is subtracted (a worst case scenario).

Noise assessments are often conducted at this critical wind speed. Thus, before any noise modelling is undertaken, the critical wind speed must be determined by measurement. Background noise levels are measured and results are compared with typical turbine sound power curves that describe the relationship between the wind speed and sound power.

King et al. (2012) have identified errors associated with the use of a single critical wind speed for wind farm noise assessments, particularly during the night-time, and recommend that assessments be conducted over a range of wind speeds instead of the critical wind speed alone. The Institute of Acoustics (UK) recently released guidance on the assessment of wind farm noise and also recommends noise assessment over a range of speeds (Cand et al., 2013), which is consistent with the methodologies used in countries such as Australia and New Zealand.

6.5.1 Wind Farm Noise Emission

In order to model the noise from a wind farm, manufacturers generally provide sound power levels for each type of turbine. These data are usually available for a range of wind speeds and are supplied across octave bands from cut-in speed through to rated power. The data are generally referenced to a height of 10 m. Table 6.7 presents sample sound power data describing a 3 MW wind turbine, while Figure 6.3 provides an example comparing the sound power/wind speed relationship between four turbines commonly used in Ireland. When the sound power is known for all wind speeds, calculations may then be conducted for each wind speed and, together with detailed meteorological information, the long-term noise level may be established.

BOX 6.5

WIND SHEAR

Sound power data used for predictions are generally based on measurements taken for IEC 61400-11 (IEC 61400-11, 2006). This standard requires hub height (the distance from the ground to the axis of rotation, i.e., the centre of the turbine blades) wind speeds to be standardised to a 10 m height. Wind speeds taken on-site during a background noise assessment must also be referenced to a height of 10 m. However, wind speed will vary with height above the ground level, generally increasing with increased height.

ETSU-R-97 presents a simple method to correct wind speeds to a height of 10 m using a ground roughness length (The Working Group on Noise from Wind Turbines, 1996). However, this method holds significant potential for error. Differences in the wind shear between day and night periods have been observed. Describing the wind shear in terms of only the surface roughness, and not on atmospheric stability, is not a good predictor for night-time wind profiles (van den Berg, 2004). This is precisely why new guidance on the collection of wind speed has been developed and it requires wind speed measurements at a minimum height of 10 m (Cand et al., 2013).

TABLE 6.7 Example Sound Power Levels for a 3-MW Wind Turbine, Referenced to a Height of 10 m

Wind Speed [m/s]	L_w [dB(A)]	Octave Band Levels 63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
5	100.9	82.1	86.9	91.5	93.5	95.9	94.6	90.5	79.1
6	104.2	85.7	90.9	94.0	96.5	99.1	98.2	94.3	83.7
7	106.1	89.7	93.3	96.1	98.3	100.8	100.1	96.2	85.7
8	107.0	91.8	94.0	97.3	99.6	101.8	100.5	96.7	86.7
9	106.9	92.3	94.2	96.9	99.5	101.7	100.4	96.4	86.6

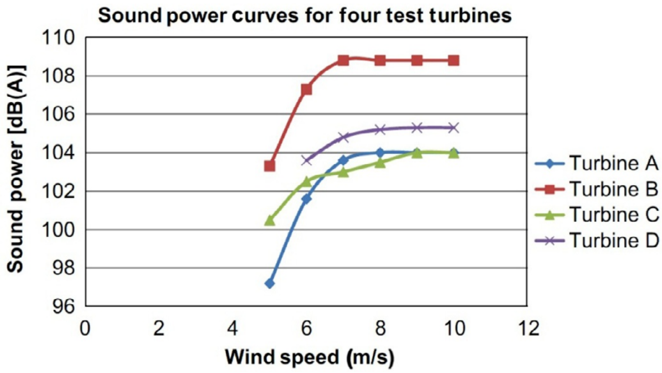


FIGURE 6.3 Different source profiles for different turbines (King et al., 2012).

6.5.2 Background Noise Assessment

Permissible noise limits for wind farms are often expressed relative to the background noise across a range of wind speeds, i.e., a relative increase criterion (e.g. 5 dB(A) above background noise). Therefore, a detailed assessment of the background noise is required prior to the development of a wind farm. This involves a background noise survey that requires at least 1 week of continuous noise monitoring. Good practice suggests at least 20–30 measurements should be taken within 2 m/s of the critical wind speed (The Working Group on Noise from Wind Turbines, 1996). Measurements recorded during periods of heavy rainfall should not be used in the analysis given that noise levels are raised by the sound of the rain itself. In Australia and New Zealand, good practice involves the acquisition of approximately 2000 valid measurements of 10 min (the equivalent of 2 weeks) and at least 500 of these points should include the worst case wind direction.

It is generally regarded that windshields will be effective up to wind speeds of 5 m/s (BS 4142, 1997). In higher wind speeds, the wind passing over the diaphragm of the microphone of the sound level metre can generate noise interference. However, in the case of background noise assessments, noise measurement in wind speeds of up to 12 m/s may frequently be required. Measurements in conditions at these high wind speeds may be influenced by the wind itself and may not be a true representation of the background noise environment (King et al., 2012). New guidance suggests that microphones should be housed within enhanced-performance windscreens to reduce the effects of flow-generated noise at the microphone (Cand et al., 2013); care must be exercised using standard wind shields only designed for low-wind velocities (usually windshields with a diameter less than 100 mm).

During noise monitoring periods, meteorological conditions (including wind speed and direction) must be monitored simultaneously with background noise measurements. Wind speed and sound pressure levels can then be plot to determine the relationship between background noise and wind speed. A third-order polynomial is usually appropriate to describe this relationship (Cand et al., 2013) although higher order polynomials have been used successfully (King et al., 2012). Figure 6.4 presents such a relationship.

6.5.3 Noise Limits for Wind Farms

Noise limits for wind farm developments are generally set relative to background noise levels at nearby noise-sensitive receivers. For example, a daytime lower fixed limit of 45 dB(A) or a maximum increase of 5 dB(A)

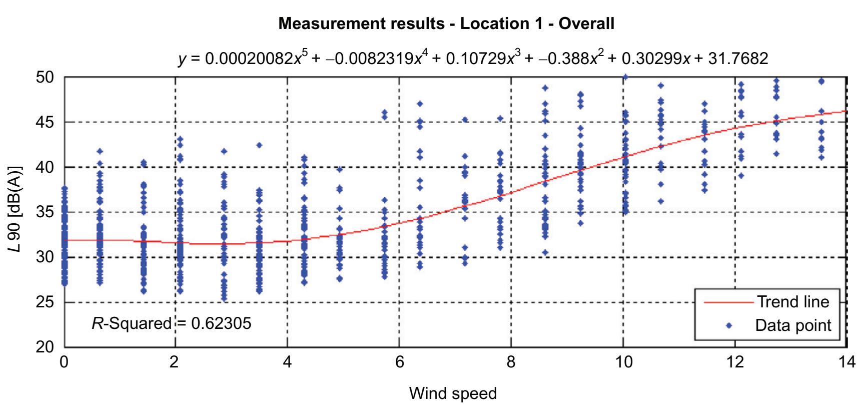


FIGURE 6.4 Example result from a background noise survey relating the background noise level with wind speed.

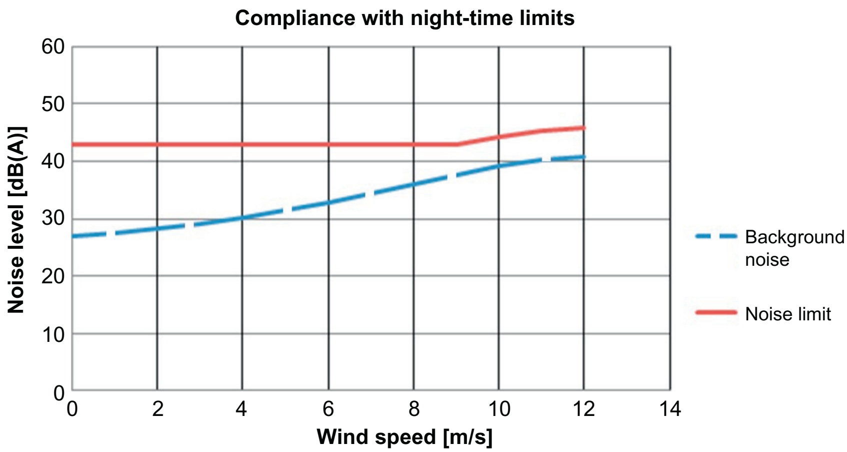


FIGURE 6.5 Night-time noise limit set relative to background noise level at different speeds.

above background noise at nearby noise-sensitive locations is common and is recommended in ETSU-R-97 (The Working Group on Noise from Wind Turbines, 1996). However, in very quiet areas, where background noise is less than 30 dB(A), the use of a margin of 5 dB(A) above background noise may unduly restrict wind energy developments which should be recognised as having wider national and global benefits (The Working Group on Noise from Wind Turbines, 1996).

Separate noise limits are generally applied for daytime and for night-time. During the night, the protection of external amenity becomes less important and the emphasis is on preventing sleep disturbance. In the UK, a lower fixed limit of 43 dB(A) external to the property has been deemed appropriate to protect sleep inside properties during the night. Figure 6.5 displays how the background noise level for a test location varies with wind speed. In this example a flat limit of 43 dB(A) during the daytime is observed, up until a wind speed of approximately 9 m/s, at which point the background level plus 5 dB(A) becomes the appropriate criterion.

6.6 CONSTRUCTION NOISE

Noise from construction can often occur very close to noise-sensitive receivers and its characteristics can change throughout the lifetime of a construction project. It can start with demolition, proceed to excavation works and highly impulsive piling works, before evolving to more continuous noise as the construction progresses. Noise levels can also vary throughout the day, and depending on the permissible limits enforced, might even continue through the night-time period. Given the nature of activities involved, it is not always possible to mitigate noise levels down to acceptable levels using the standard mitigation measures that might be appropriate for use in an industrial context. However, construction noise is generally transient and by its very nature construction noise will only be present for a finite-time period. Because of this, it is not appropriate (or indeed very useful) to develop strategic noise maps for this type of noise source. Nevertheless, it should be mitigated against as part of any serious overall environmental noise abatement strategy.

Many factors affect the impact that construction noise has on the local community: the location of the site in relation to sensitive receivers, hours of operation, the existing ambient levels in the area and the characteristics of the noise itself. Another consideration might include the level of communication between the site operator and local residents. It has been well established that people's attitude to noise can be influenced by their attitudes to the source or activity itself (BS 5228, 2009). Construction noise tends to be more readily accepted by local residents if they feel the site operator is taking all possible measures to avoid unnecessary noise. In fact, a simple rule of thumb indicates that good public relations may result in a 5 dB noise bonus, while bad relations are equivalent to a 5 dB penalty (Wassermann and Parnell, 2008).

6.6.1 Sources of Construction Noise

There are many sources of noise associated with a construction site: the movements of vehicles (usually including a high percentage of heavy vehicles), breaking up concrete, cutting steel, ground excavation, drilling, pumping, welding, etc. In the UK, BS 5228 (2009) is used for noise and vibration control on construction and open sites. BS 5228 provides a range of sound level data on construction site equipment and site activities. This data should be used for informative purposes. Some examples are presented in Table 6.8 (BS 5228, 2009).

6.6.2 Hours of Activity

Construction noise is often controlled by restricting the times during which construction can occur. Many authorities restrict construction activities to normal working hours and do not allow activities to take place over weekends or public holidays. For example, in South Australia because

TABLE 6.8 Typical Noise Levels for Various Construction Activities

Equipment	L_{Aeq} at 10 m
Breaking up concrete with pulverizer mounted on excavator	76
Breaking stud partition with lump hammer	69
Breaking windows with lump hammer	81
Clearing site with a dozer	75
Loading lorries with tracked excavator	79
Water pump (size 6 in.)	65
Precast concrete piling – hydraulic hammer	89
Small cement mixer	61
Diesel scissor lift (idling)	70
Petrol hand-held circular saw	91
Angle grinder (grinding steel)	80
Hand-held cordless nail gun	73

construction noise results in an adverse impact on amenity,[2] it is restricted from operating on a Sunday or a public holiday. For all other days, it is restricted to hours between 07:00 and 19:00.

In some exceptional circumstances, construction may need to take place outside of these hours. Examples include the delivery of oversized plant structures, emergency work, and maintenance and repair of public infrastructure where work during the standard hours might disrupt essential services. In such cases, regulators might encourage a range of work practices to minimise the construction noise impact rather than focusing on meeting stringent noise criteria.

Noise may be minimised from construction by the operator implementing best practice work methods. Some examples include:

- scheduling of particularly noisy activities during less sensitive periods of the day;
- choosing plant and equipment that is the quietest and most suitable for the project. This may include ensuring noise reduction devices are installed on plant (for example, fitting more efficient exhaust sound reduction equipment, use of machines inside acoustic enclosures);

[2]Identified as continuous noise levels exceeding 45 dB(A), or a maximum noise level exceeding 60 dB(A) (Construction Noise and Information Sheet, 2011).

- ensuring all equipment is well maintained and operating within specifications;
- making use of mitigation measures where appropriate (e.g. acoustic screens);
- employing work practices which minimise noise activities. These may include restricting waste material from being dropped at excessive heights and line chutes and dump trucks with resilient material.

BS 5228 sets out methods and criteria for assessing the significance of noise effects. One such method includes the ABC method. This method sets threshold values to determine if there will be a significant effect at dwellings for three different categories (A, B and C). The threshold values are different for each ABC category and different time periods. The ambient noise level is determined for the appropriate period and then rounded to the nearest 5 dB. This is then compared to the total noise level, including construction noise. If the total noise level exceeds the appropriate category values, a significant effect is deemed to occur.

6.7 MINING MINERAL/EXTRACTION SITES

Unlike manufacturing type facilities that can be located in appropriate industrial estates, mining and extractive industries need to be generally colocated with the resource being mined. This places significant limits on the ability of operators and responsible authorities to manage noise from these sites, particularly if they are 24 h operations. Sources of mining noise include blasting, mobile equipment such as bulldozers, haul trucks and excavators, fixed plant equipment such as conveyor belts and crushers, screens and preparation plants.

In many cases, it is neither reasonable nor feasible to mitigate to the accepted noise goals. In these cases, there may be the option for negotiation (in terms of offering suitable compensation) with the impacted community in return for increased noise limits. Such negotiated agreements should be developed through a process of community consultation and dissemination of information on how best available techniques will be adopted. Also the public should be notified of scheduled activities that will result in high noise levels such as blasting. However, there are options available to the site operator for certain aspects of the work and best available techniques for noise control should be adopted. In New South Wales, the practice of applying receiver-based architectural treatments (e.g. façade insulation, acoustic glazing) is included in a suite of measures currently available to large-scale mining operators.

BOX 6.6

OPEN CUT COAL MINING, AUSTRALIA

Australia supplies around 35% of the world market in thermal coal. Most of this is sourced from large open cut operations on the eastern seaboard of Australia (NSW and Queensland) where single mines often range from 20 to 50 million tonnes per annum and cover areas of 5–10 km in length.

The major noise issue for these mines relates to their diesel-electric haul trucks which have a capacity of up to 300 tonnes and produce sound power levels of greater than 125 dB(A). With fleets of up to 80 trucks, it is generally not possible to meet stringent noise criteria as low as 35 dB(A) without significant attenuation (Parnell et al., 2009). To achieve a sound power level of around 115 dB(A) requires an attenuation package that costs in the order of $1 million (a 25% additional cost) to each haul truck.

Even after taking all reasonable and feasible measures, there are often numbers of residences which experience excessive noise levels and are required to be purchased. This demonstrates the significant cost of undertaking noisy activities.

6.8 CONCLUSION

The assessment of industrial noise is quite different to that of transportation noise. Whereas transportation noise can generally be predicted given a set of input datasets, no such predictive techniques exist for industrial noise. The best way to determine the emission of an industrial source is through measurement. In some cases, this is not possible and international databases or previous similar experience may be utilised to make an informed estimate. If best practice is to be followed, this poses two significant problems for any authority who wishes to assess all existing sites of industrial noise across a city region. First, all sites must participate in some sort of measurement campaign which requires a tremendous amount of resources. Second, all measurements must be conducted in a standard uniform fashion. Given the variation in the type of noise, the times of operation and the location of noise sources across each industrial site, it is not always possible to do this. Inevitably, default values or some simplifications will be introduced to the assessment procedure.

Similar to transportation sources, industrial noise may be perceived in a completely different manner across different industries. Industrial noise often contains more intrusive acoustic characteristics such as impulsive or tonal elements and as such industrial noise often attracts more stringent noise criteria than the transport sector. These intrusive characteristics tend to increase noise annoyance and should be included in any noise assessment aiming to assess the acoustic impact of a site.

There are a number of different methodologies and procedures used to assess different types of industrial sources. This chapter has summarised the main procedures behind traditional industrial sources as well as highlighting the different procedures guiding the assessment of port noise, wind farm noise and construction noise.

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