Code 24 – seeks innovative and effective noise mitigation measures

Regionalverband FrankfurtRheinMain

Regionalverband Mittlerer Oberrhein

Metropolregion Rhein-Neckar

Planners Toolbox for innovative noise protection

Rotterdam CODE24 Corridor Development Genoa

Investing in Opportunities

This project has received European Regional Development Funding through INTERREG IV B.

nwe INTERREG IVB


CODE24
seeks innovative and effective
noise mitigation measures

Contents

1 Introduction

The preservation and expansion of the economic power in numerous regions is based on the development of rail traffic routes in Europe. The Rhine-Alpine-corridor between Rotterdam and Genoa – according to the respective way of counting marked by no. 24 – represents such a transport axis involving 5 states all in all. To safeguard sustainability, various development aspects must be taken into consideration. Wide acceptance requires the avoidance of additional and the reduction of already existing noise caused by rail traffic. This task is a far-reaching and simultaneously complex challenge, since collisions of superior and specific requirements must be approached as well as regional developments come upon an initial situation already characterized by various sources of noise.

The individual assessment of the heard environment, however, is based on the sum of acoustic incentives, which are present almost everywhere, and whereby the sense of hearing is always challenged, since as an 'alarm organ' it cannot be simply switched off. In this context, the question is not loud or quiet alone, since already hardly audible noise can cause extreme reactions, if certain contents are conveyed. The corresponding intensity, dose and characteristics of this kind of sound events as well as a series of other factors result in a cumulative effect, which more frequently exceeds the tolerable limit. Yet, despite the obvious health risks technically produced noise is not reduced, acoustically appropriate rooms and buildings are not at all the rule, and conscious hearing, whether perceived as a sound or communication, cannot be renounced. In view of the fact that places of calm will become increasingly rare, the importance of an integral acoustical design of the environment and traffic is growing.

Nevertheless, the familiar effects of sound do not cause those affected to 'flee the noise'. Worldwide urbanization is one of the mega-trends instead. Due to the variety of opportunities cities are becoming more and more attractive for a permanently increasing number of people. In this context, individuals are not equally concerned by noise, and the current increasingly critical attitude towards noise of many persons affected must not conceal the fact that there is a widespread simplemindedness in dealing with the audible environment. The priority of acoustical assessment and design of the environment is in fact subject to temporary variations also in dependence of other social, economic and ecological issues. Especially in cities, the question is more and more to achieve a sustainable balance of societal requirements and individual needs characterized by collision and coincidence. This is also manifested by the assessment of the quality of life and the environment.

How is noise assessed? As concerns this question, statistical results are available, whereby it must be assumed that the majority of participants responded in a survey of the Federal Environment Agency[1]. Shares of the population are quantified there stating that they are annoyed by various sources of noise. The transport carriers car, airplane and railway as well as commercial sound sources and the neighborhood achieve more than 20%, road traffic is in the lead with more than 50%. These results alone should sufficiently prove the topicality of the matter. Since the numbers did hardly change within the past decade, the question now is, what are the reasons. Are the sound levels too high, or do they occur „untimely in the wrong place" or in too many places? One answer could be to focus on residential areas, since the topic of a quiet sleep is of significant importance there. But not only a quiet sleep is affected by noise in urban centers but also urban life. It takes place outside of buildings on terraces and balconies, in the streets and squares, in leisure and recreation areas.

An original element of the susceptibility to noise of urban infra-structures is based on historical developments and decisions without any doubt. In many cities, the main traffic roads follow the routes of former horse-drawn streetcars conceptualized long before the automotive era and under completely different assumptions or conditions. In other cities, enormous efforts were made to implement traffic structures after the destructions of World War II, which could no longer be realized according to current methods and approaches of urban and traffic planning. Former prospects were based on totally different assessment criteria. This heritage and the still high requirement of mobility is the challenge of the future.

The outlook is nowadays more than ever to realize the acoustic environmental influences in almost all living environments, and to concretely assess them and to deal with them in an adequate manner in most cases. It is therefore advisable not to emphasize individual aspects or living environments but to give priority to a sustainable overall balance, where the integration in the overall context of environmental design is part of it to establish the acoustic quality as noticeable environmental quality as well as to integrate acoustic issues in the design processes. Interested parties and dedicated persons, people concerned and involved

---

[1] http://www.umweltbundesamt.de/laermumfrage

are confronted by various tasks. First of all, continuous information which is easy to understand must be given and widespread communication must be provided. To objectify this exchange an increasing number of enhanced tools is available. Secondly, more solid findings must be transferred into binding rules. Thirdly, innovative and practical noise control technologies must be integrated in several design conflicts for example between mobility and calm as well as profitability and quality of life.

Thus, the aim of this report is to make contributions to the three aspects with special emphasis on noise emitted by railway traffic. Concrete regulations, processes and persons responsible are defined for each situation. Therefore, this report addresses persons concerned, who are not involved in the technical design process but have the adequate knowledge to make precious contributions to find sustainable solutions.

2 Source and paths of sound

From the physical point of view sound sources generate fluctuations of the air pressure, which propagate as sound waves. These pressure variations occur, if air molecules are excited to oscillate, for example by a loudspeaker membrane or another mechanically oscillating surface area. These surfaces are manifold in practice. Moved, braked and pushed parts of vehicles provide them. Flowing air, however, also generates pressure variations. A fan, an exhaust or wind instrument for example emit partly intensive noise. Changes in an air flow are perceived as especially loud. The valves of musical instruments or the pulsing combustion mechanisms of exhaust gas systems are characteristic examples. Even human articulation physically begins with the generation of an air flow and its modulation by the vocal chords. The sound radiation is generally called emission. If sound waves reach a person, an immission takes place. Sound vibrations are first of all received by the sense of hearing as a sound by a microphone and then classified in dependence of loudness, frequency and time. The physical effect of sound develops into music, speech, signal or noise as a hypernym of all sounds that annoy or even are harmful.

To describe the audible air pressure variations or oscillations in practice the sound pressure is not used with the unit „Pa“ (Pascal) but the sound pressure level with the unit „dB“ (decibel). This characteristic of acoustics is due to the fact that loud sound events generate very high numerical values of the sound pressure, which can be more clearly described by pressure level values. Moreover, the dB scale is better suited to the respective relation between sound events. Thus, doubling the sound pressure for example is subjectively not assessed as double as loud. Several sound pressure level of characteristic sounds are represented in **Fig. 1**, whereby the value 0 dB corresponds to the average absolute threshold of hearing. The unit „dB(A)“ at sound pressure levels signifies the assessment or filtering of sounds corresponding to the frequency dependence of hearing.

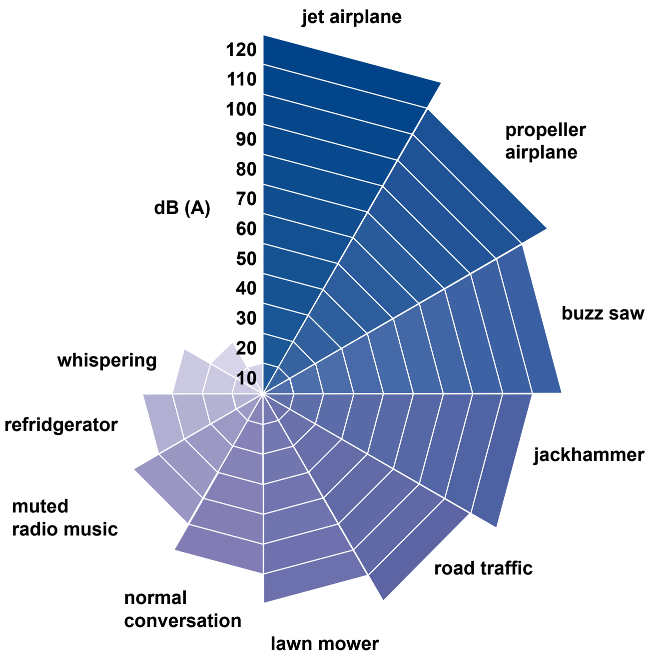
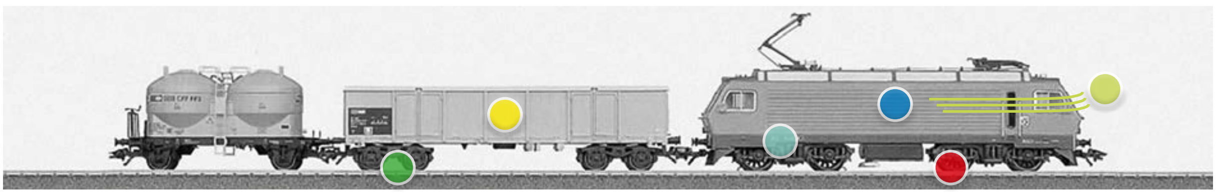


Figure 1: sound pressure levels of characteristic sounds © Fraunhofer IBP

The noise emitted by rail vehicles and railway tracks can have different causes. **Fig. 2** shows the most important sources and places of origin, which add to the total noise in dependence of the vehicle, state of the vehicle and conditions of the tracks. Thus, the dominant sound at the train standstill in the station is emitted by the fans required for motor cooling.



(green)	Brakes (freight wagon)	(light blue)	Power train and traction motor (locomotive)
(yellow)	Container etc. (freight wagon)	(blue)	Cooling and ventilation systems (locomotive)
(red)	Wheel and track (locomotive and wagon)	(yellow-green)	Wind noise (locomotive and wagon)

Figure 2: sources and places of origin of noise emitted by rail traffic © Fraunhofer IBP

Intensity and dominance of the most important sound sources are dependent on the vehicle speed as shown in **Fig. 3**. At low velocities for example when passing through built-up areas or during approaching a station the engine units determine the total noise. With increasing velocity and at high speed rolling noise is predominant. Since other sources are negligible, the noise reduction potential can be quantified by this example. Halving speed from 200 to 100 km/h means a reduction of noise of approx. 6 dB.

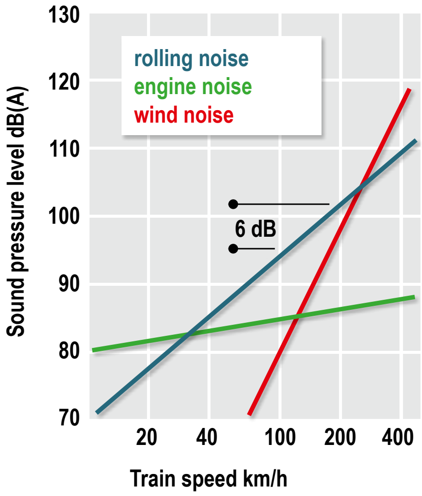
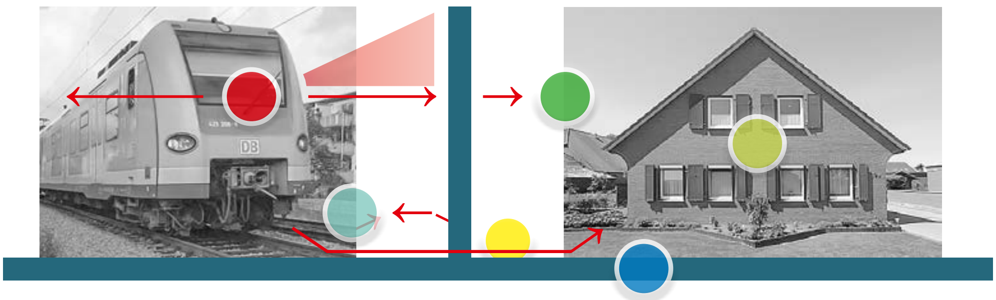


Figure 3: relation of sound pressure levels and the velocity of individual mechanisms of sound generation © Fraunhofer IBP

Lowering the speed, however, is only one of many possibilities of noise reduction, which are represented in detail in chapter 4. Once generated the sound propagates and is equally reduced as well as independently of frequency by the distance, i.e. a distance as large as possible from the sound source offers a secure protection from the noise emitted there. This effect can also be quantified, since it increases between 3 and a maximum of 6 dB with each doubling of the distance between source and receiver.

A further enhancement of noise reduction on the propagation path can be achieved by various obstacles as shown in **Fig. 4**. Noise barriers and noise control wall are typical examples, if they do not allow sound to be transmitted. At the same time they must be sufficiently high or wide to force sound waves to make a detour as large as possible. Nevertheless, a complete acoustic shielding by this kind of obstacles is impossible. The diffraction of the sound waves at the top edge generates a „deviation“ into the shade of the obstacle. This effect is also known from optics and is dependent on the frequency in both cases, meaning that low-pitched sounds are very rapidly diffracted in the shade behind the obstacle so that the shielding effect is lowest in this range.

This is one of the reasons that low-frequency sounds are a special challenge for noise control. Another reason is the generally low attenuation during airborne propagation. After all, sound insulation of the windows and facades of buildings is remarkably reduced at low frequencies.



(red)	Sound source and sound radiation	Sound emission
(yellow)	Sound diffraction at the barrier (top edge)	
(green)	Sound transmission through the barrier	
(turquoise)	Sound reflection and sound absorption at the barrier	
(blue)	Vibrations	
(yellow-green)	Sound receiver (building with noise control measures)	Sound imission

Figure 4: propagation paths of noise emitted by rail traffic © Fraunhofer IBP

Thus, the dB levels alone do not make noise control seem to be complicated. The frequency dependence of sound generation, sound propagation, sound reduction and perception also adds to the overall situation and requires intensive analysis. This is, however, the only reasonable way to deal with the sources and paths of sound.

3 Guidelines and regulations

Although there is no general and widespread right to calm, there are adequate regulations according to the kind, source and place of the occurrence of noise. Based on these regulations the concrete need for action can be determined in many situations. This applies for all neighbors of the corridor. The examples in **Tab. 1** show national legislation with various historical background and form but always very similar approach. Differences do not occur due to different problem-solving approaches but due to different speed of implementation so that a comparison of the guidelines and regulations is not necessary.

CH	Umweltschutzgesetz (USG, 1983), Lärmschutz-Verordnung (LSV, 1986)
DE	Bundes-Immissionsschutzgesetz (BImSchG, 2002)
F	Code de l'environnement (2012), Livre L57 Prévention des nuisances sonores
NL	Wet geluidhinder (WGH, 2012), Regeling geluid milieubeheer (2012)

Table 1: legal framework documents to regulate noise and noise control in the countries along the corridor

All legal regulations on noise and noise control have in common that different noise control levels are defined for different kinds of use. Consequently, the German framework document Federal Immission Control Act refers to various regulations and the like for example the Traffic Noise Control Regulation (1990). This regulation defines the limit values in **Tab. 2** for noise emitted by road and rail traffic, if new public traffic routes are built or significantly altered. The limit values vary with regard to daytime (day and night) and according to the place of occurrence of the noise, i.e. residential or commercial areas or mixed use areas as well as places, which deserve special protection such as hospitals and the like.

	day	night
in hospitals, schools, convalescent homes and old age homes	57 dB	47 dB
in exclusive and general residential areas and small residential estate areas	59 dB	49 dB
in business zones, village areas and mixed use areas	64 dB	54 dB
in commercial areas	69 dB	59 dB

Table 2: Immission limit values for traffic noise during the construction or significant alterations
(16th regulation for the implementation of the Federal Immission Control Act, 16. BImSchV)

Another European-wide regulation concerns the acoustic assessment and treatment of the already existing railway tracks. The Directive of the European Parliament and European Council on the Prevention of Environmental Noise (Environmental Noise Directive) was enforced on July 18, 2002. This directive is aimed at guaranteeing a high level of health and environmental protection by legal regulation of noise and noise emissions. In this context, the following landmarks were defined to restrict the especially harmful effects of noise:

- regular determination of noise pollution,
- securing information of the public by noise maps and reports,
- development of action plans to reduce noise.

The assessment of the current noise situation by means of uniform indices shall be provided on the basis of noise maps, which are exclusively calculated by standardized methods. To describe the noise pollution the indices L_{DEN} (DEN: Day Evening Night) and Lnight were introduced. They are indicated in dB (A), but they are no sound pressure levels in the sense of physical definition but calculated parameters (indices). The immission points for the calculations are always positioned at 4 m height above ground, in urban areas directly in front of the building facades.

The results and noise maps are available in the Internet free of charge, and give a survey of the situation at the respective locations. **Fig. 5** shows the example of railway tracks of the trains of the German Railways in the Mannheim region. Here, the noise index L_{DEN} is shown as representative of a 24-hour value. The respective areas in the vicinity of the railway tracks can be assessed by means of a color scale correlated to the L_{DEN} sound pressure levels. On the basis of these maps, which are available for the individual road, railway and air traffic as well as for industrial and commercial zones the impression of the overall noise emitted at a certain location can be gained. This also allows the integration of a new assessment in case of potential alterations of one or more sound sources.

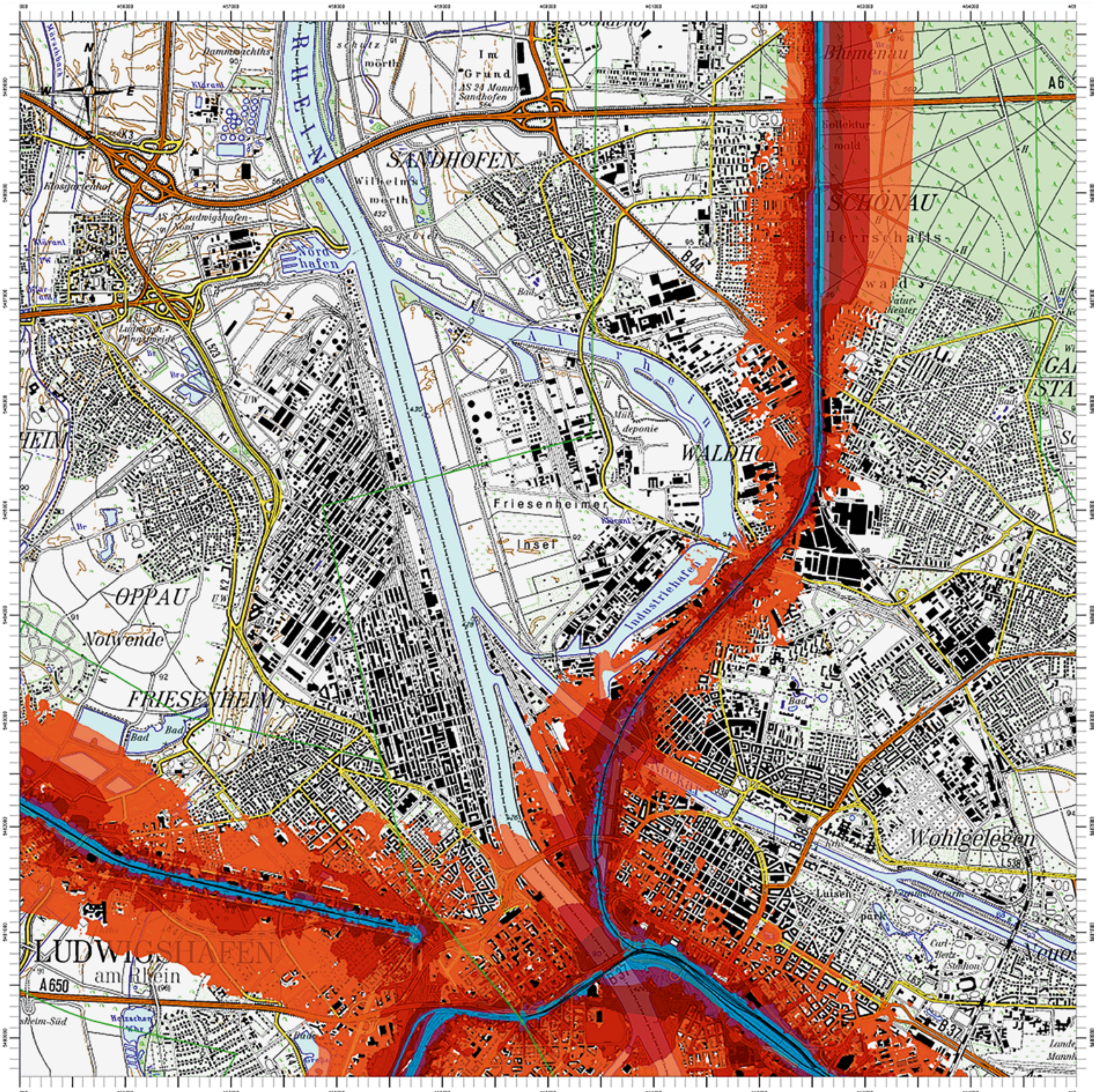


Figure 5: noise maps of the railway tracks of the German Railways in the Mannheim region (data basis: © Federal Railway Office, 2009)

The guideline for environmental noise, however, is still more far-reaching and includes the regulation of establishing noise action plans on the basis of the recorded stock. In the context of a process of unrestricted public participation regional noise conditions are investigated and assessed as well as potential solutions of noise reduction are discussed and summarized.

The noise action plan of the German Federal State of Hesse for rail traffic may be given as an example, which takes into consideration all aspects of this topic in a profound and detailed manner, and the focus of which finally are the following key points effective for noise control.

- limit values for the sound emission of new rail vehicles,
- abolition of the so-called „rail bonus“[1],
- development of an ecologically oriented price system for railway lines,
- noise monitoring,
- introduction of noise quotas[2],
- operational configurations[3],
- realization of by-pass lines as well as
- a 10 point program „Calm Rhine Valley“ to reduce the noise emitted by trains by 10 dB in comparison to 2010.

At this stage already it is obvious that mapping as well as well-founded action planning requires considerable efforts and financial means. Still more expensive, however, will be the logical consequence of the EU guideline for environmental noise in most cases, the implementation of noise control measures identified as being adequate. In this context, a characteristic difficulty of rail traffic must be taken into consideration. The respective territorial authorities are responsible for the noise action planning but neither for the construction, operation and maintenance of the railways nor for potential noise reduction measures.

Here at least, the organizational, technical and of course economic limits of implementation become obvious. Moreover, there is frequently a lack of acceptance of certain and easily realizable noise control measures, if they are for example accompanied by changes of the appearance of the environment, which are assessed as unsustainable.

As a matter of fact, however, the variety of regulations and guidelines or the resulting information allows a clear cut need for action in many situations. Based on the aim of influencing the situation and exploiting the scope of action it must be recommended to obtain a comprehensive overview of the conventional and innovative noise control measures, which are thoroughly discussed in the following chapter. Due to an integral assessment of potential solutions in the respective cases adequate noise control measures can be finally selected.

---

[2] German regulation, where a correction value of 5 dB (A) is deducted in the calculation method to take into consideration the supposed „lower interference effect“ of rail traffic noise.
[3] Limitations of noise emissions along certain sections of the line during certain times, i.e. in the evening or at night.
[4] Subsequent orders of environmental protection towards considerable noise pollution, for example by speed limits or the van on vehicles.

4 Noise control measures

A great variety of noise control measures are available and already realized in practice in many cases. Thousands of sound-insulating windows and many kilometers of noise barriers are representative examples of the many billions of Euros invested noise control so far. These enormous and economically relevant means clearly demonstrate the dimension of this topic as well as the fact that the costs of noise control cannot and will not be reduced, since already existing as well as future conditions require them. Yet, more and more organizational, technical and constructional opportunities are available for realization. New noise control technologies are developed and political efforts are made to motivate new initiatives for further noise reduction.

Adequate planning, however, is the condition for noise control in any case. This process includes the technical assessment and treatment of the respective situation. To avoid a clash of interests includes participation in the planning, i.e. adequate information of and communication with the persons affected and involved. This will not necessarily simplify discussions but is a basic condition of finding sustainable compromises and solutions.

The first planning step comprises the assessment, analysis and evaluation of the current or future situation to be expected. Many data are necessary for this purpose, for example the kind and characteristic of the section of the line, the kind and number of trains, the urban and landscape topography, and the significant places and limit values of immission. Prognosis programs can be fed by these data, which deliver corresponding values by means of which the supposed noise emission can be assessed and the effect of noise control measures can be quantified. The available software offers various processes, however, but they are equally based on the respective guidelines for calculation. Trained staff can use it to produce the previously mentioned noise maps or a 3-dimenisonal model with the relevant acoustic information, and work out potential measures.

Numbers and figures can also be generated or visualized by these tools. Only a few experts, however, can combine concrete hearing experience with dB(A) values. Most people can make a statement only after the realization of noise reducing measures, for example in how far their demand of calm is fulfilled. This may be compared with music, the tonal richness of which can be assessed by a few persons by means of the musical score. The hearing experience imparts the impression. This is why in the meantime environmental noise is made audible and its reduction can be pursuit, and it is offered online in form of software. Based on the really perceived sound of sound sources, for example tram or rail traffic, measured for noise reduction are calculated and made audible. This kind of simulation is called **Auralisation**. The hearing impression is emphasized instead of the assessment of numbers. This kind of software can accompany the planning and assessment process as well as contribute to objectify the discussion.

Noise control measures are manifold (organizational, technical and constructional), and they can be applied at various places (source, propagation, receiver) from the cause to the effect. **Fig. 6** shows a variety of concrete opportunities.

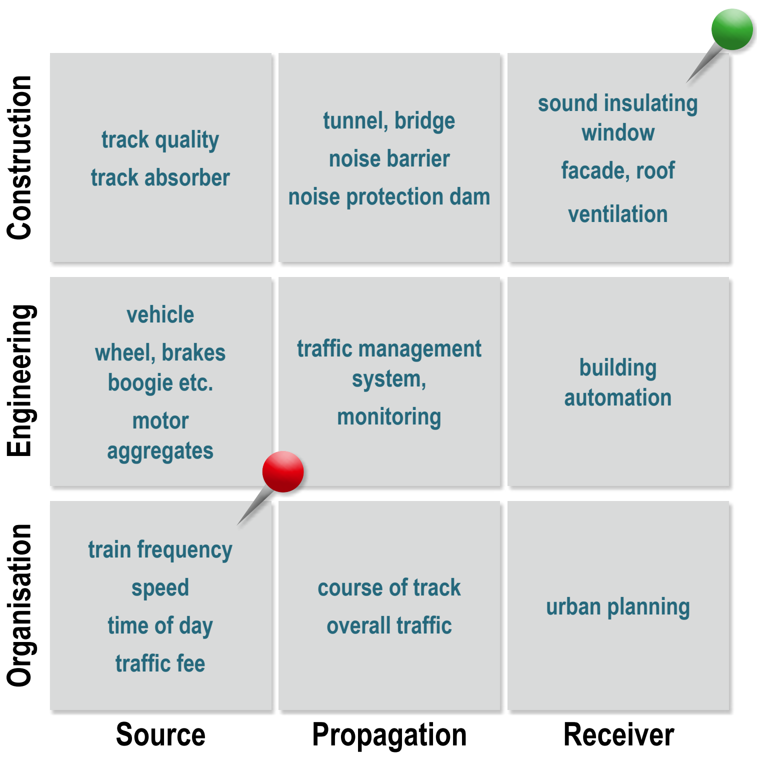


Figure 6: Examples of noise control measures subdivided by kind and application

4.1 Noise control measures at the source

Measures at the source are most effective and frequently more economical and ecological than measures applied to obstruct the propagating sound.

- ***Number of trains:*** Since the absolute sound level is directly proportional to the number of train pass-by per day, the noise control measure should not entail an increase in the number of trains. It is frequently vice versa in practice, since an increase in traffic results in a higher need of noise control. All measures must always be considered in combination with traffic density. The sound level can be reduced by 3 dB in halving the train frequency.

- ***Speed:*** As already explained in **Fig. 3** the reduction of velocity has a noise control effect in a wide range. The driving speed, which is reduced from 80 km/h to 50 km/h achieves a sound level reduction of approx. 5 dB, and this is an evident effect.

- ***Traffic fee:*** A traffic fee or railway line price system is a motivation to favor modern and more quiet vehicles. There are various models for implementation. In the meantime, this system is successfully put into practice in Switzerland and Germany. A longer period of observation, however, is necessary to assess the quantifiable effect. But a noise reducing effect can already be perceived due to increasingly calmer freight trains.

- ***Wheels:*** Especially in case of freight trains brake pads or brake lining carriers can have a more noise reducing effect ,even if older wagons are retrofitted. If new so-called K, L or LL brake lining carriers (composite brake lining carriers) are used instead of conventional gray iron brake pads, noise reductions between 2 and 10 dB can be achieved. This effect occurs due to a smoother wheel surface, which in connection with the tracks (wheel-rail contact) contributes to a reduced rolling noise. The reduction value, however, is dependent on several boundary conditions. The K brake lining carriers reduce noise slightly more than the L brake lining carriers, but require adjustments of the brake system, whereas the L brake lining carriers can be installed without any adjustments. Thus, the adjustment to K brake lining carriers is more cost-intensive although they have been admitted since 2003. Profitability studies, however, show that the retrofitting of freight trains for noise control by composite material brake lining carriers show a high cost-benefit ratio. This can be still enhanced if combined with other noise reducing measures, among them for example wheel absorbers or otherwise acoustically optimized wheels achieving a reduced sound radiation of the vibrating wheel surfaces by attenuation.

- ***Bogie:*** The optimization of bogies offers a high potential to reduce noise according to the studies. A noise reduction effect of up to 10 dB can be achieved by means of special wheel absorbers and brakes. This is also a measure at the source, which is independent of the topographical location and the position of the significant immission places. It can be also applied to already existing section of the line.

- ***Motor and aggregates:*** Noise emitted from motors, cooling aggregates and respective ventilators are predominant during slow speed and standstill according to **Fig. 3**. Although they are on a lower level as rolling noise during full speed, they are nevertheless interfering in the vicinity of settlements. In most cases the noise is a low-frequency humming or the like, which is difficult to reduce.

- ***Track quality:*** Mechanical vibrations have already been mentioned as cause of noise generation in chapter 2. Any reduction of these vibrations simultaneously results in noise reduction. As in case of the wheels with smooth wheel arch surfaces and attenuated wheel surfaces a lot can be done with the tracks. A reduced roughness of the tracks can achieve a noise reduction between 2 and 5 dB. Other measures, for example vibration absorbers at the tracks, have a similar effect. Since the quality of the tracks decreases with the time due to utilization, maintenance intervals have to be define accordingly.

4.2 Noise control measures on the propagation path

The effect of measures on the propagation path between the place of emission (sound source) and place of immission (place to be protected) is always dependent on the local environment.

- ***Distance:*** The distance between sound source and place of immission is a „safe parameter“ of noise reduction. Each doubling of the distance achieves a reduction between 3 and a maximum 6 dB.

- ***Infrastructure system:*** Due to a longer-term planning scope acoustic advantages can be achieved by the „layout“ of the rail network. The courses of the rail line, tunnels, stations and the like can be reasonably integrated with regard to location and configuration from the very beginning, and can be adjusted to the respective situation. As already indicated in the measures at the source logistics and noise control go hand in hand. Relief is of course only achieved in the range, where infrastructural modifications are effective. The existing network, however, does not profit from selective measures.

- ***Noise control structures:*** Nowadays, these constructional noise control measures offer a great scope for action, which is increasingly exploited. Since they partly interfere directly with the urban and landscape appearance, especially the visible integration should be in the focus of planning and selection besides acoustic considerations.

- ***Tunnels and underground sections of the railway lines:*** Underground, deepened or built-over courses of rail traffic allow an evident acoustical shielding. Underground or aboveground tunnels in particular can almost completely prevent sound propagation so that acoustical treatment is only necessary at tunnel mouths to reduce the sudden and noisy sound radiation at tunnel exits. The situation is different concerning the deepened sections of the railway lines. In this case, the sound sources disappear from sight, and the side walls have a similar acoustic effect as noise barriers as shown in **Fig. 4** and will be explained in the following chapter.

An important aspect of noise control can be explained by the example of deepened routing, and this is the necessity of a sound-absorbing surface of the side walls. These walls shall not only reflect the sound, since it would then „move upwards“ successively and without any attenuation due to multiple reflection as shown in **Fig. 7**. Therefore, these lines as well as other ground-level sections with noise barriers at both sides must be equipped by sound-absorbing layers. At present, this property is required for approx. 70% of the noise barriers.

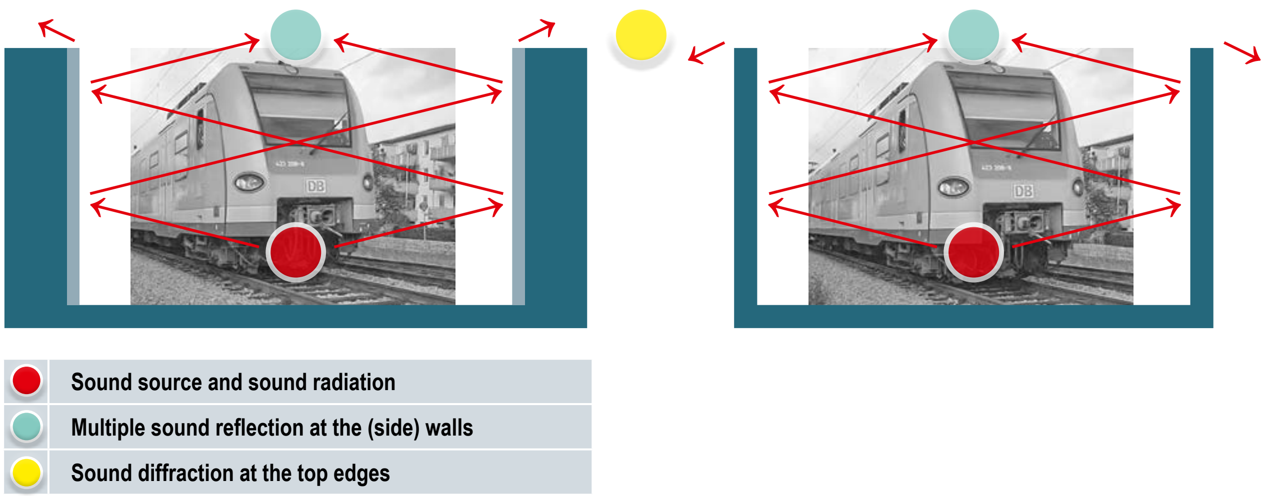


Figure 7: Sound propagation at deepened lines and noise barriers at both sides from which the necessity of sound absorption of the vertical walls arises. © Fraunhofer IBP

Fibrous materials (mineral or wood fibers) as well as bound granular materials, for example gravel glued with cement slurry or other granulates with an appropriate bonding are suited as sound-absorbing materials. A thickness of 5 cm to 15 cm is usual and sufficient according to the material.

The essential acoustic effect of noise barriers and noise control walls, however, is the acoustic shieling of the sound. It amounts to between 5 and 15 dB for all modalities and materials, and is mainly dependent on the respective geography or topography. The decisive factors for the acoustic shielding are the distance to the sound source, the distance to the place of immission and the height of the wall. Material and production are of secondary importance concerning acoustics in case of a flawless execution. Without any doubt, the appearance is of significant importance. The results of a non-representative survey within the framework of the EU project CODE24 show that concrete walls are well-known but rated as being the least attractive, similarly as metal walls, whereas green and greened walls make an acceptable impression, followed by transparent elements and wooden walls. These stated impressions and experience are of course influenced by the state of maintenance of the walls. The following survey of the types and constructions of noise control structures intensifies the scope for design to find out the adequate solution.

- ***Noise protection dams*** are suited in regions close to nature with sufficient space, since the dams require a comparatively large area. Under these conditions, they can be very well integrated in the landscape and environment due to their natural and green appearance, and consequently the acceptance is very high.

- ***Noise barriers made of concrete*** are most frequently used due to their high and strong stability as well as economic efficiency with regard to production and installation. In the course of time, a certain diversity of shape and wide range of colors were achieved so that this kind of construction is not only suited for industrial and business zones. These walls, however, are unfortunately „desired objects“ for unwanted graffiti and the like, which are difficult to remove. The neglected look of many a carelessly designed concrete noise barrier has a negative effect on the acceptance of this kind of walls. Targeted greening by specific systems can provide for higher acceptance. The necessary maintenance of the plants, however, proves to be an economic challenge.

- ***Noise barriers of gabions*** consist of mesh cages filled with chopped stones and are combined to noise barriers. Especially natural stones can imitate the appearance of an old town wall and the like. In this environment and in regions close to nature high visible acceptance can be achieved. Modern systems fulfill all acoustical requirements without any problems including sound absorption, and the cost effectiveness with regard to material and installation is indeed competitive.

- ***Noise barriers of metal*** are beneficial due to the combination of low weight, high stability and large pre-assembly, which is not only profitable for high noise barriers. There is a wide range for design, and the practical life span including a permanently respectable appearance achieves a high level due to the clearly enhanced quality of processing. Arrangements can be made for a targeted greening of these walls.

- ***Noise barriers of wood*** are advantageous due to the raw material used, which is natural and renewable. Former significant disadvantages with regard to weathering can be managed by means of constructional solutions without chemical preservatives and suited local woods. Due to the wide range for design and the large pre-assembly of the building components high acceptance is achieved in regions close to nature as well as in small and suburban towns.

- ***Low noise barriers*** are only effective close to the tracks, since they prevent the propagation of the rolling noise. Noise control of up to 6 dB (wall height of 74 cm) can be achieved, which is, however, dependent on several application and environmental conditions. Based on these prospects and the decent appearance due to the low height efforts were recently made to implement this technology, whereby all materials discussed so far can be applied.

low noise barriers © Keyrail Netherland

- ***Transparent noise barriers*** are not the most cost-effective type of sound absorption but an attractive basis for design to harmonize sound insulation and landscape, whereby almost infinite variations are possible between transparency and translucency. Pre-assembly is also possible with these elements, their life span is adequate and transparent sound absorption on the basis of micro-perforated components will be realized in future (**Fig. 8**). It must also be pointed out that a combination of various materials is possible for example by adding extensions of glass or artificial glass to the previously described wall materials.

transparent noise barriers © Fraunhofer IBP

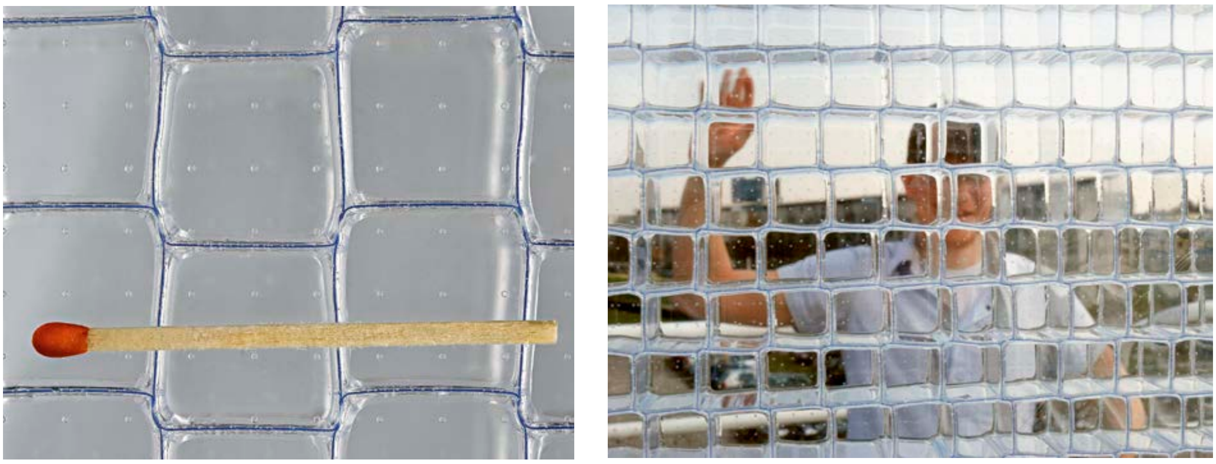


Figure 8: Transparent honeycomb structure with micro-perforated plastic elements on both sides for transparent and sound-absorbing noise barriers. © Fraunhofer IBP

- ***Air-permeable noise barriers*** can be helpful in urban situations, where an obstacle is necessary from the acoustic point of view but should not prevent (fresh) air movement all too much. This can be achieved by lamellar arrangement according to **Fig. 9** by leaving gaps between the lamellas and attenuating sound propagation in the resulting „labyrinth“. The rear side of the slats must be designed to have a sound-insulating effect, and the side towards the gap a sound-absorbing effect. An acoustical shielding effect of up to 15 dB can be achieved in this way.

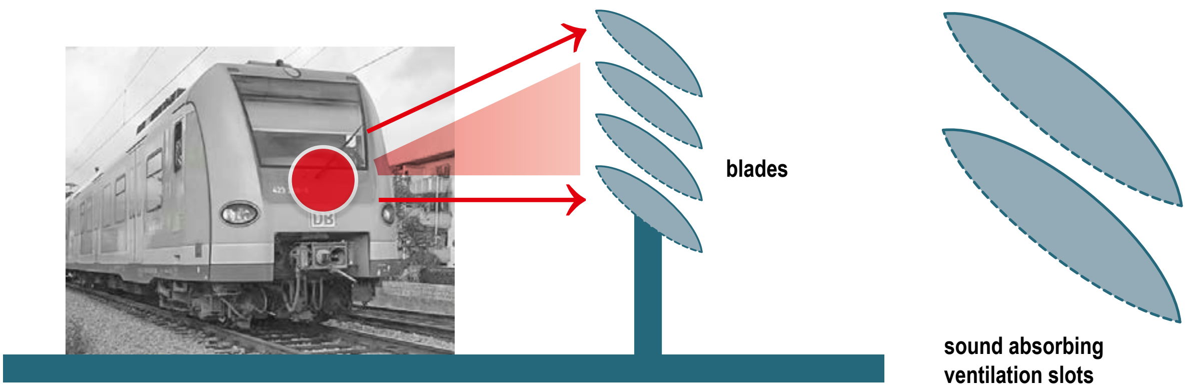


Figure 9: Air-permeable noise barrier with sound-insulating slats and gaps in between. © Fraunhofer IBP

- ***Multifunctional noise barriers*** use the potential of most large and spacious noise control structures of not only offering sound-insulating functions but also leaving space for other applications on the large-size surfaces. Greened walls as well as green areas make a contribution to the improvement of the air and climate, if only to a small degree. Walls equipped with photovoltaic systems are also a convincing example. Another possibility is the reduction of air pollutants in urban centers by means of various chemical (photo-catalysis) or physical (filtering) effects. These systems will be included in the future repertory of noise barriers and open up new possibilities of amortization.

- ***Temporary noise barriers*** allow an acoustical comparison with other noise barriers, their application, however, is restricted to a limited time. This is the case for example at building sites, where a permanent stable wall construction with adequate greening is not reasonable as concerns the economic efficiency. At present, inflatable elements of fabric-reinforced plastic membranes prove to be a proper solution for this kind of temporary noise pollution. They can be easily installed, they are recyclable and fully adequate in acoustical application.

4.3 Noise control measures at the place of immission

Measures at the place of immission are generally **sound insulating windows**, since (normal) windows are usually the „weakest point " of the façade concerning acoustics. Sometimes, however, facades including conservatories and roofs require retrofitting. The resulting overall sound insulation of a facade with windows can be calculated, whereby especially large components with the lowest sound insulation dominate the overall standard.

The obvious disadvantage of this noise control measure is the fact that the noise in the living environment is not reduced. It is simply „locked out" so that outdoor areas like balconies or gardens do not benefit from it. Sound insulating windows, which are opened for ventilation, have no effect at all, even in tilted position sound insulation is almost ineffective. Therefore, an air-conditioning system with optimized sound insulation at the openings for exhaust and supply air must be designed to provide fresh air in closed buildings. The systems should be quiet in operation, and occasionally offer even better air quality than natural ventilation due to filtering, for example pollen filters for persons suffering from allergy. Against another background these requirements also apply for low-energy and passive houses.

In Germany, the value of sound insulating windows is defined in a guideline of the Association of German Engineers (VDI 2719 „Sound insulation of windows and auxiliary equipment"). The windows are classified in sound insulation classes by means of various sound reduction indices, see **Tab. 3**, whereby „6" represents the highest class. At present, classes 1 and 2 are no longer referred to as sound insulation, since modern insulated glass windows at expert assembly achieve a sound reduction index of approx. 30 dB.

Sound transmis-sion class	In-situ sound reduction index	Laboratory sound reduction index
1	25 bis 29 dB	≥ 27 dB
2	30 bis 34 dB	≥ 32 dB
3	35 bis 39 dB	≥ 37 dB
4	40 bis 44 dB	≥ 42 dB
5	45 bis 49 dB	≥ 47 dB
6	≥ 50 dB	≥ 52 dB
Tilted window::	< 27 dB	< 27 dB

Table 3: sound transmission classes of windows according to VDI 2719

The high sound insulation level, which can be achieved by full-value windows etc. can provide for comfortable quietness in buildings and improve the energy efficiency at the same time. Concerning thermal insulation old windows frequently do not have any adequate insulation effect. Higher quality, however, entails higher costs so that it must always be assessed, whether appropriate means of funding are available for energetic redevelopment or noise control measures.

It must be mentioned that there are influencing factors, which can reduce the effective sound insulation of facades and windows, but which are not taken into consideration in any guideline so far. The design values of glazing elements, windows and facades are determined by laboratory testing by means of sound level difference between two rooms. A diffuse and non-directional sound field is predominant there. In practice, however, sound excitation is done in a strongly directional way, for example in the case of inclined glazing elements or higher stories of buildings. Thus, sound insulation can come below the design value by one to two sound transmission classes in direct vicinity of the sound source, for example railways.
In addition, the shape of the building components has also an effect on sound insulation. The standard format in the laboratory is almost square. If in practice high or small formats are used, the actual sound insulation of the window can fall below the laboratory value by one sound transmission class.

The last statement refers to the relation between sound and thermal insulation of modern windows with triple glazing. As concerns thermal insulation they can be recommended without any doubt. It must, however, be taken in to consideration that triple glazing has a lower sound insulation effect of 2 to 4 dB than double glazing with the same mass. The condition of the same mass is frequently fulfilled, if windows are exchanged, since the building substance cannot bear heavy building components. Detailed planning and information are also essential here.

This survey presents an overall illustration of the difference of noise control effects of several practicable measures, which can also be combined at high sound levels. Anyhow, it is not sufficient to relate only the acoustical effect and the financial costs. Other decisive aspects must be added, for example the different kinds of acceptance of persons affected and involved. An adequate balance of objective requirements and subjective needs must be achieved, when reducing noise and not only for the effect or assessment of noise.

5 Suggestions to assess and deal with characteristic scenarios

Noise indices and sound pressure levels are object parameters and suited to quantify sound by calculation and measurement and make comparisons. They can, however, explain the degree of the interference of noise for those affected only in an insufficient way. But it is just this degree, which is especially important for the subjective assessment. Therefore, approaches were investigated among other things, how conclusions could be make on the interferences from noise indices. One approach is the train noise index defining the percentage of affected persons, who feel troubled by train noise during the day and complain about wake-up responses at night. **Fig. 10** shows an example of the central Rhine Valley. The train noise index for the period at night indicates the probability of wake-up responses in relation with residents with the noisiest facades. This index can become any high.

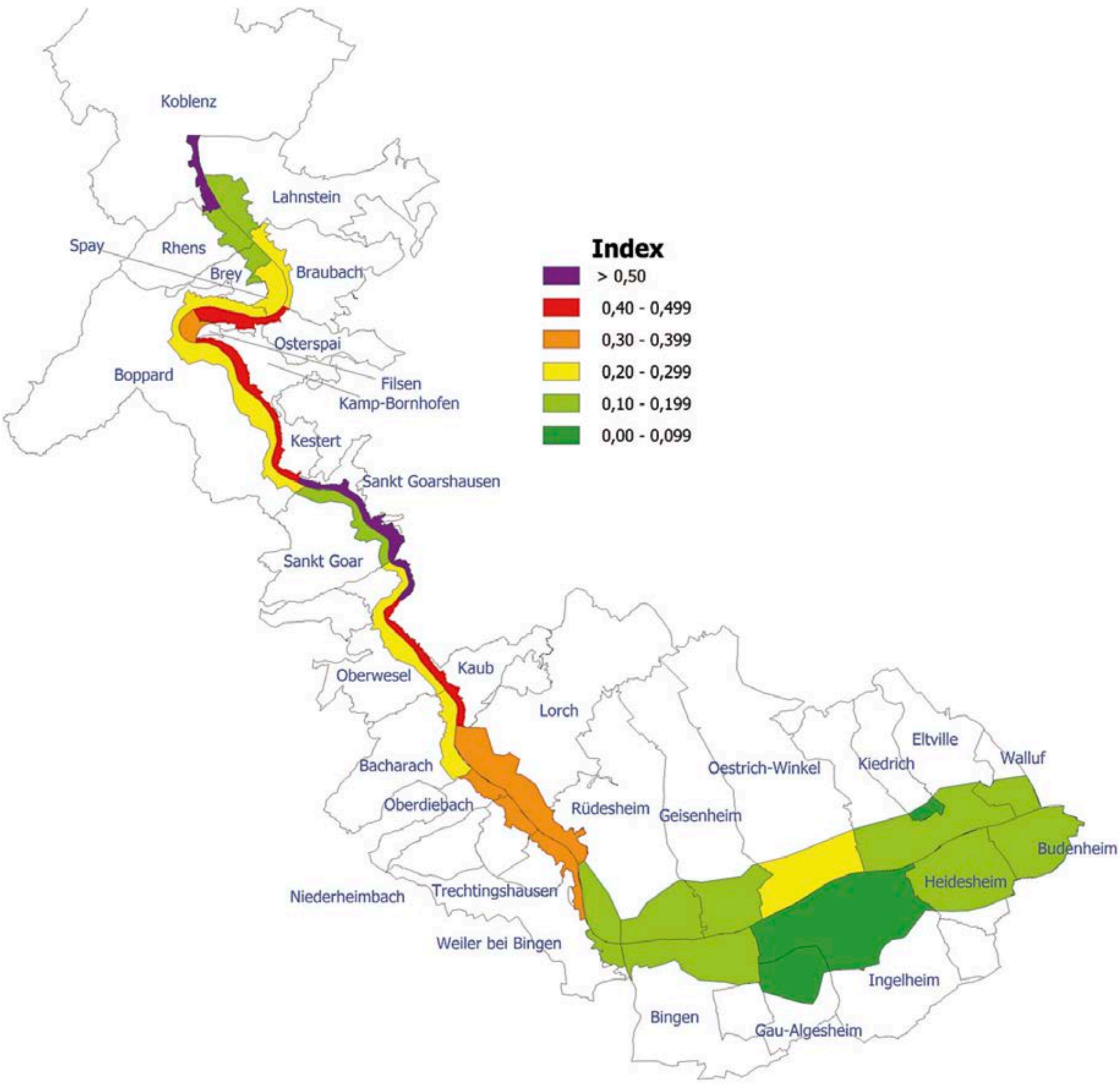


Figure 10: Train noise index for the central Rhine Valley during the day. Source: Giering, K., Augustin, S.: University of Applied Sciences of Trier, DAGA 2012.

This index, however, is dependent on the sound pressure level, but this dependence between interference and sound pressure level differs from one sound to another. As **Fig. 11** shows more than 80 % of those affected feel extremely troubled by train noise at a continuous sound pressure level determined during daytime or index L_{day} higher than 75 dB.

Another relation must be taken into consideration in interpreting these correlation and in assessing noise control measures. The threshold of perception in the sense of the (frequency dependent) absolute threshold of hearing becoming discernable at approx. 0 dB in Fig. 1 are different from the threshold of perception to modifications of the levels. A modification, for example a noise reduction by 1 dB is hardly perceivable above sound levels of 40 dB. Distinct perceptibility can be expected from approx. 3 dB. This fact should also be taken into consideration in planning and deciding efforts and benefit. In this context, the tool and hearing aid of auralisation to calculate the reduction effects to be expected shall be mentioned once again. It conveys own experience with these „thresholds of hearing".

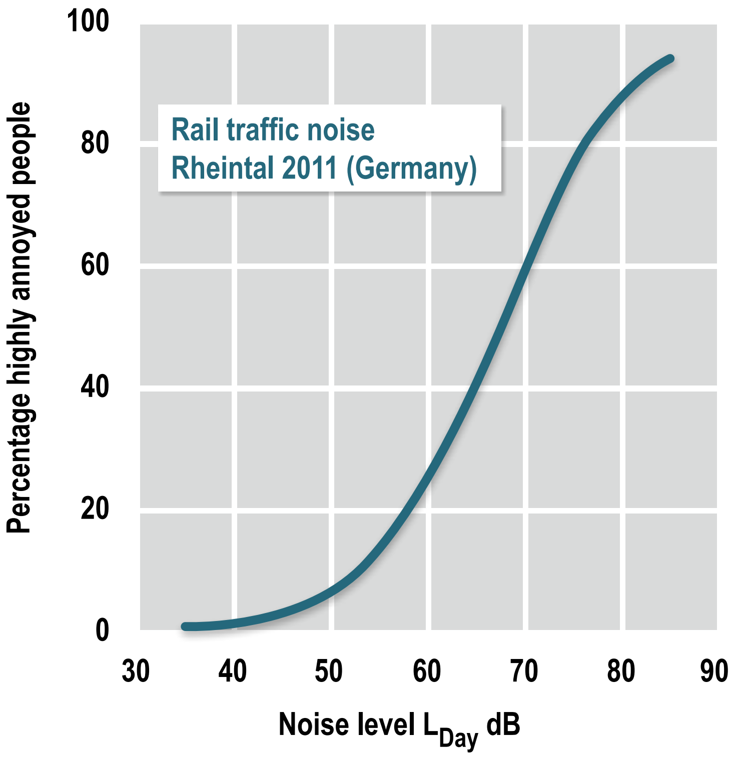


Figure 11: Share of extremely troubled persons in dependence of noise index L_{Day}. Source: Giering, K., Augustin, S.: University of Applied Sciences of Trier, DAGA 2012.

Recurrent constellations or scenarios can be found along the sections of the corridor differing in their constructional and logistical infrastructure, use and acoustic assessment and treatment. All these scenarios share characteristics, since noise is emitted from the respective railway line. As soon as users permanently stay in the environment, the need of noise control must be examined and assessed. Another similarity is that a series of noise control measures almost always have an effect, among them for example calm vehicles, the reduction of speed, low-noise lanes, noise-dependent line prices, traffic organization by means of "ban on night-time driving" etc. Therefore, implementation should always be contemplated and assessed.

A consequence of the various scenarios results from the respectively different effect of other usual noise control measures, which are favored due to technical, design, economic or any other reasons. Thus, it is worth typing the scenarios, describing them and then consider adequate noise control measures. These scenarios are characterized in the following by means of traffic and settlement features, and adequate noise control measures are assigned to the respective acoustic overall situation (see chapter 4).

1	Central station
	Characteristics of traffic
	▪ more than 4 tracks with high utilization in most cases ▪ intensive transportation (limited speed), high share of transport of goods ▪ typical sound sources (e.g. brakes, ventilators of electric locomotives, loudspeakers etc.)
	Characteristics of settlements
	▪ city centers with mixed development (mixed use areas) ▪ highest population density ▪ high overall noise level due to road traffic and other sources
	Adequate noise control measures
	▪ underground railways ▪ largely closed station building (separated areas in the building for platforms and passing of a train) ▪ sound-insulating interior lining, directed loudspeakers


© Axel Heiter Fotodesign

2	**Main railway lines in the city center**
	Characteristics of traffic
	▪ 2, 4 or more tracks with high utilization ▪ intensive transportation (limited speed), high share of the transport of goods ▪ stations, stops and crossroads
	Characteristics of settlements
	▪ city center with mixed development (mixed use areas) ▪ highest population density ▪ high overall noise level particularly due to road traffic
	Adequate noise control measures
	▪ noise barriers or sound-insulating windows according to economic considerations ▪ Sound-insulating windows (in combination with ventilation equipment) are effective to overall noise, noise barriers may have an effect only to rolling noise.

© Regionalverband Mittlerer Oberrhein

3	Main railway lines in densely populated areas
	Characteristics of traffic
	▪ 2, 4 or more tracks with high utilization ▪ intensive transportation (high speed), high share of transport of goods ▪ stops with distance standards, for example noise control
	Characteristics of settlements
	▪ suburbs with residential development and maybe nearby recreational areas ▪ high population density ▪ low overall noise level, hardly any sound sources
	Adequate noise control measures
	▪ separate tracks with noise barriers, high noise barrier besides the line ▪ in case of historical buildings for example gabions (due to aesthetic reasons) as wall type ▪ sound-insulating windows according to economic considerations

4	Freight traffic lines in densely populated areas
	Characteristics of traffic
	▪ 2 tracks with high utilization ▪ little transportation, high share of freight traffic (low speed) ▪ a few stops
	Characteristics of settlements
	▪ suburbs with residential development and maybe nearby recreational areas ▪ high population density ▪ low overall noise level, hardly any sound sources
	Adequate noise control measures
	▪ low noise barrier (wheel-rail noise at average speed) ▪ transparent or greened noise barriers ▪ deepened tracks without or with superstructure (internal sound absorption) ▪ in case of historical buildings for example gabions (due to aesthetic reasons) as wall type

5	Local transportation line in densely populated areas
	Characteristics of traffic
	▪ 2 tracks with high utilization ▪ intensive transportation (low speed), low share of freight traffic ▪ stations, stops
	Characteristics of settlements
	▪ suburbs with residential development and maybe nearby recreational areas ▪ high population density ▪ low overall noise level, hardly any sound sources
	Adequate noise control measures
	▪ low noise barriers (wheel-rail noise at average speed) ▪ stations with high noise barriers (for example transparent), directed loudspeakers

6	Main railway line in rural areas
	Characteristics of traffic
	▪ 2 tracks with high utilization ▪ intensive transportation and freight traffic (high speed) ▪ stops, occasional stations
	Characteristics of settlements
	▪ rural area, nearby recreational areas ▪ low population density ▪ low overall noise level, hardly any sound sources
	Adequate noise control measures
	▪ preferably calm vehicles ▪ sound-insulating windows ▪ noise barriers of noise control walls (landscape design) according to economic consideration

7	Freight traffic line in rural areas
	Characteristics of traffic
	▪ 2 tracks with high utilization ▪ average transportation and intensive freight traffic (high speed) ▪ a few stops or stations
	Characteristics of settlements
	▪ rural area, nearby recreational areas ▪ low population density ▪ low overall noise level, hardly any sound sources
	Adequate noise control measures
	▪ preferably calm vehicles ▪ sound-insulating windows ▪ noise barriers uneconomic, ▪ noise control walls (landscape design)

8	Transit traffic line in places located in valleys
	Characteristics of traffic
	▪ 2 to 4 tracks with high utilization ▪ low transportation, intensive freight traffic (high speed) ▪ roads in the vicinity
	Characteristics of settlements
	▪ rural area, villages, nearby recreational areas ▪ average population density ▪ low overall noise level, average road traffic load
	Adequate noise control measures
	▪ preferably calm vehicles ▪ superstructures (tunnels), maybe transparent ▪ sound-insulating windows (keep in mind the protection against vibrations)

© rolibi/pixelio.de

Especially these places located in valleys with traffic roads that can hardly be influenced, with close development and particularly difficult sound propagation are areas of conflict. Moreover, if there is a low population density, potential noise reduction measures are very critically assessed from the economic point of view.

6 Conclusion

In the last chapter of this brochure, it became apparent that settlement areas, infrastructure and landscape have to be analysed holistically for the corridor's development. Hence, the quality of the living space is determined by the spatial, visual and acoustic properties of these elements. In doing so, typical overall situations show regularly appearing conflict fields between the development of settlements and the expansion of infrastructures. For instance, on the one hand the demand for rail-bounded logistics services is growing resulting in an expansion of the railway network and consequently higher utilization rates. On the other hand, noisy freight trains prevent from developing residential areas and from reactivating inner urban conversion areas.

There is a diverse spectrum of measures to reduce noise. Local solutions are as a rule a bundle of measures that concern both the source (type of train, speed, rolling stock, track quality) and the way of spreading (routing, structural noise protection, injection of route sections, noise protection walls etc.). These measures have to be oriented to the specific local conditions.

The regional and local acceptance is crucial for the implementation of the project's measures for the development of the corridor. This acceptance cannot increasingly be only reached in the formal planning and participation process. In fact, an open, transparent and direct dialogue is necessary. This includes searching for substantial compromise solutions and optimisation possibilities, besides illustrating the leeway for decisions and unavoidable burdens. Therefore, the total package has to contain both concessions to the affected persons as well as inevitable stresses in order to ensure an effective realisation. Such a dialogue requires transparency, comprehensibility and reliability in order to reach sustainable results. The traditional procedures to include noise issues in the planning process (traffic forecast, acoustic studies, noise protection measures in the case of limit exceedance) are only suitable to a small extent for promoting such a dialogue and for overcoming fears.

The "Planner's toolbox", developed by Code24 in Action 6, is able to mediate in this dialogue. The project demonstrated an instrument via the so-called auralisation that enables an audio impression of noise reduction measures for different types of trains within different traffic and settlement situations. It has been shown, that such a software accompanies the planning and evaluation process and can often contribute to an objectification of the dialogue about acoustic issues. The auralisation can be used to discuss planning alternatives and the design of noise protection measures within the participatory planning process. Hence, the communication with the persons involved on site can be improved.

That is why, appropriate simulations should be supported for decisions-makings of plans. Finally, measures can be developed on site in this way, that exceed the focus on calculated decibel figures and that take into consideration the resulting noise situation of the overall context referring to the specific transport situation.

In all countries alongside the corridor, there is still a high potential to reduce the noise at the source by a modern and optimized rolling stock. In some transit countries along the corridor, measures are currently being taken in order to exploit these potentials and to reduce the effects of the rail system to the people's living space. This opens new possibilities for the design of noise reduction concepts. Especially, noise reduction measures at the source cause cross-border dependencies in particular with regard to the transit traffic. This illustrates that a tool like the auralisation is not restricted to a subspace but its application along the entire corridor can develop a positive effect on the planning and decision-making process.

In the future, participatory dialogue forms and acoustic simulation will help to solve cross-border conflicts of goals between the settlement and traffic development and to implement more effectively the variety of innovative noise protection measures so that the quality of life is improved for the affected residents.

Glossary

Sound
Air pressure variations in the audible frequency range between approx. 16 Hz and 16 kHz.
(see subsonic noise and ultra-sound)

Frequency spectrum, spectral
Another description of frequency range, spectral means the consideration in the sense of frequency.

Noise
Sound, which human beings perceive as interfering or annoying, which causes health problems or is harmful to health.

Sound or noise level
The amplitude of sound or noise indicated as decadic logarithm of this amplitude in relation to the reference. The unit is dB.

A-weighting, dB (A)
The auditory perception of hearing is frequency dependent. These specifics are taken into consideration by the A-weighting of measured or calculated sound levels. A-weighted sound levels are expressed in the unit dB (A).

Single number value
Specification of the temporal sound or noise level progression (measured or calculated), where a temporal mean value is formed and summarized over all frequencies.

Noise index
Continuous sound pressure level, i.e. noise levels, which were averaged during a certain period of time and introduced by [1], for example L_{DEN} for day, evening and night. The level value L_{DEN} is a single number value.

Noise map
Graphical form of representation of the noise level (or of noise indices) in an urban or rural area. Differently high values are represented by different colors. The noise levels can be measured or calculated. They can be represented as sum levels (single number value) over all audible frequencies or levels in single frequency ranges.

Noise reduction
Organizational, constructional and technical measures to reduce noise generation and propagation.

Impressum

TITLE	Planners Toolbox for innovative noise protection
EDITOR	Regionalverband Mittlerer Oberrhein Baumeisterstraße 2 76137 Karlsruhe
AUTHOR	Prof. Dr. Philip Leistner, Fraunhofer Institut for building physics, Stuttgart
TEXT, EDITORIAL STAFF	Dr. Sebastian Wilske, Regionalverband Mittlerer Oberrhein
LAYOUT	Christian Ertel, Karlsruhe
COPYRIGHT	Reprinting – even in extracts – is subject to the permission by editor indicating references and delivering specimen copies. Title image © wikimedia Commons/ÖBB399
DOWNLOAD	http://www.region-karlsruhe.de

Regionalverband FrankfurtRheinMain

REGIONALVERBAND MITTLERER OBERRHEIN

Metropolregion Rhein-Neckar

ROTTERDAM CODE24 CORRIDOR DEVELOPMENT GENOA

Regionalverband Mittlerer Oberrhein
HAUS DER REGION
Baumeisterstraße 2
76137 Karlsruhe
Tel. +49 (0) 721-35502-0
Fax +49 (0) 721-35502-22
rvmo@region-karlsruhe.de
www.region-karlsruhe.de

Investing in Opportunities
This project has received European Regional Development Funding through INTERREG IV B.
nwe
INTERREG IVB