A COMPREHENSIVE STUDY ON THE SOURCES AND EFFECTS OF RAILWAY NOISE

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Received: January 10, 2026

EXTENDED ABSTRACT

Noise emissions from rail transport constitute a significant and growing concern due to their multifaceted impact on environmental quality, public health, and urban livability. The primary sources of these emissions are rail vehicles and infrastructure, including wheels, tracks, braking systems, and propulsion technologies. The magnitude and characteristics of rail noise are influenced by a complex set of variables, including train speed, track condition, vehicle design, and the effectiveness of noise mitigation measures. In addition to technical factors, operational practices and maintenance regimes also play a crucial role in shaping the acoustic footprint of railway systems. Prolonged exposure to elevated noise levels has been associated with a range of adverse health outcomes, including sleep disturbances, heightened stress responses, and deterioration in mental health. The aforementioned effects are especially pronounced in vulnerable demographics and have the potential to engender long-term physiological and psychological harm. Furthermore, the issue of noise pollution has been demonstrated to have a detrimental effect on the overall quality of life in urban areas, with consequences including reduced residential satisfaction, impaired social cohesion, and declining property values in noise-affected zones.

From the perspectives of sustainability and urban planning, mitigating rail noise is imperative for the promotion of healthier, more resilient communities. The integration of advanced noise reduction technologies is imperative for the effective management of noise in railway environments. Such technologies encompass low-noise track designs, acoustic barriers, wheel dampers, and vibration isolation systems, which, when employed in conjunction with one another, can significantly mitigate noise levels. Infrastructure modernisation, encompassing regular track maintenance and the introduction of quieter rolling stock, is also imperative in order to reduce noise at its source.

1 INTRODUCTION

There is a close correlation between acoustic noise and the condition of railway vehicles. The noise level of railway vehicles can indicate not only the immediate environment, but also the operational condition of the vehicles themselves. Changes, increases, or

variations in noise levels can often indicate the condition of the vehicle and possible problems.
Below are some examples of how acoustic noise can be related to the condition of a vehicle:
- Lack of maintenance: If a rail vehicle is not properly maintained during operation, wear and damage over time can increase noise levels. For example, worn wheels, rubbing parts, or damaged bearings can cause more noise.
• Lack of damping: Wear and tear or lack of soundproofing materials can increase the noise generated by the vehicle. If the soundproofing materials in the vehicle are not working effectively for some reason, noise will leak out of the vehicle and may disturb passengers.
• Engine and transmission problems: A noisy engine or transmission may indicate unusual noises, which could suggest problems with the vehicle's drive or operation.
• Condition of tracks and railway infrastructure: Worn or poorly maintained tracks and other infrastructure elements can also cause noise when vehicles pass over them. Improperly secured tracks, worn bearings, and related infrastructure problems can lead to noisy traffic.
• Condition of brakes and bogies: The condition of vehicles' braking systems and bogies can affect noise levels, particularly in the case of squealing brakes or rattling wheels.

Based on acoustic noise, inspectors and engineers are often able to identify potential problems in vehicles and take timely action to ensure proper maintenance or repair. As a result, acoustic noise measurement and analysis plays an important role in maintaining the safe and efficient operation of railway vehicles.

2 THE RELATIONSHIP BETWEEN ACOUSTIC NOISE AND RAILWAY TRACKS

There is a close correlation between acoustic noise and the condition of the railway track. The condition of the railway track has a significant impact on the noise level generated by vehicles, and noise from the track can also be significant for people living in the surrounding areas [1].

Below are some examples of how acoustic noise can be related to the condition of the railway track:

• Worn rails: Worn, damaged rails can cause extremely noisy traffic. The contact between the wheels of the vehicles and the rails will not be perfect, thus increasing the noise level.
• Rail defects: If the rails have been damaged, for example, if they are broken or cracked, vehicles passing over them may generate more noise.
• Rail and support maintenance: A poorly maintained rail system, including supports, can increase the noise generated by vehicles.
• Track and rail connection: The connection between the track and the rails, such as the condition of bolts and fasteners, affects the stability and vibration of the rails, which can result in noise.

• Condition of cross ties: Cross ties serve to firmly secure the subgrade and maintain track stability. Worn, damaged, or poorly secured cross ties can cause noisy travel.
• Track wear: Track wear can also affect noise levels. Worn tracks are unable to absorb vibrations and impacts as well as newer ones, resulting in noise when vehicles pass over them.

Noisy railway tracks can disturb the peace and health of local residents. For this reason, track maintenance, periodic inspections, and renovation when necessary are very important. Thorough maintenance and timely repairs can help improve the condition of railway tracks and reduce the noise levels caused by vehicles, which is beneficial in the long term in terms of both transport efficiency and environmental protection.

Artificial intelligence (AI) offers numerous opportunities to reduce noise caused by rail defects, wear, and support in rail transport systems. The application of AI in this area can contribute to noise reduction and infrastructure maintenance in several ways. In predictive maintenance, artificial intelligence algorithms are able to monitor and analyze the condition of the rail system using sensors and other data sources. Thanks to predictive maintenance, the system can detect potential problems, such as wear or damage to the rails, in a timely manner. This can reduce sudden failures that can cause noise. Furthermore, through structured data collection and analysis, AI can help analyze large data sets generated by sensors and other monitoring devices. Structured data collection and analysis can more effectively identify the causes of noise resulting from rail defects and wear.

3 THE IMPACT OF RAIL TRAFIC NOISE ON HUMAN HEALTH

Noise emissions from rail transport can have a serious impact on people's health and well-being. The general health effects of noise include hearing loss, sleep disturbance, stress, cardiovascular problems, and mental health problems [2]. These effects are described in detail below:

Hearing loss: Long-term exposure to high noise levels can damage your hearing. Noise can be particularly dangerous for railway workers, who are regularly exposed to train noise. But people who live, work, or travel frequently near noisy railway infrastructure are also at risk of hearing loss.

Sleep disturbance: Railway noise, especially at night, can cause sleep disturbance. A continuous, high-noise environment disturbs sleep, which can have a negative impact on people's rest and quality of life in the long term.

Stress and anxiety: Constant exposure to noise can become a source of stress for people. Those living in noisy environments may be more prone to chronic stress and anxiety, which can negatively affect health and quality of life.

Cardiovascular problems: Long-term exposure to noise may be linked to cardiovascular diseases such as high blood pressure and heart disease. A constantly noisy environment increases stress levels, which can contribute to the development of cardiovascular problems.

Mental health: People living in noisy environments may be more prone to mental health problems such as depression and anxiety. The constant presence of noise can be exhausting and unpleasant, and can have a negative impact on people's mood and emotional well-being.

The extent of the health effects of noise exposure depends on the intensity of the noise, the duration of exposure, the frequency of the noise, its nature (intermittent or continuous), and individual sensitivity. More sensitive people, such as children, the elderly, and those with other health problems, are at greater risk of health problems caused by noise.

Noise reduction measures and appropriate noise protection measures in the field of rail transport are important in order to reduce negative effects on health. This may include installing noise barriers and obstacles between noise sources and people, maintaining vehicles and infrastructure, using noise-reducing materials on vehicles, and protecting people living in noisy areas through appropriate architectural design. Such measures can contribute to reducing noise levels and mitigating the health effects of rail transport.

AI can assist in comprehensive health assessments that examine the links between environmental noise and human health. Based on such assessments, more effective noise reduction strategies can be developed to make rail transport systems more environmentally friendly.

4 NOISE CAUSED BY VIBRATION

There is a close correlation between vibrations and measurable acoustic noise in rail transport. Both are related to the operation and condition of rail vehicles and infrastructure. Noise and vibrations together determine t

The following section explains how vibrations and acoustic noise are related in rail transport:

Vibrations can cause noise: Vibrating components such as engines, brakes, wheels, and train wheels can generate noise when they come into contact with the infrastructure. For example, the contact between a vibrating wheel and the rail can cause noise, which can be a source of acoustic noise.

Vibrations and infrastructure condition: The condition of the infrastructure, such as rails, track bed, cross ties, and supports, affects the level and propagation of vibrations. If the infrastructure is in poor condition, vehicles passing over it can cause greater vibrations and thus more noise.

Effect of vibrations on acoustic noise: Vehicle vibrations affect the spectrum and characteristics of acoustic noise. For example, uneven wheel wear or vibrations in the chassis generate sounds at different frequencies, which affect the nature of the noise they generate.

Vibration control measures for noise reduction: Reducing or absorbing vibrations can also have a significant impact on reducing acoustic noise. For example, the use of noise-reducing materials in vehicles and infrastructure, as well as vibration-reducing measures such as vibration-absorbing track inserts, can contribute to reducing noise pollution.

It is important to emphasize that the relationship between vibrations and acoustic noise is complex and depends on several factors. Effective noise reduction requires a comprehensive approach that takes into account the vibration characteristics of vehicles, infrastructure, and the environment, as well as the acoustic noise resulting from them. Such measures can help reduce noise pollution from rail transport and promote more environmentally friendly, quieter transport.

5 THE EFFECT OF SPEED ON NOISE LEVELS

In rail transport, there is a close correlation between speed and noise emissions, and the same is true for the load on carriages and noise emissions. Both speed and the load on carriages have a direct impact on noise emissions, which in turn affects the noise pollution and environmental impact of rail transport. These relationships are described in detail below:

Speed and noise emissions: In general, vehicles traveling at higher speeds tend to generate more noise. Vehicles traveling at higher speeds generate wind noise, which results from friction between the moving vehicles and the surrounding air [3]. In addition, higher speeds increase the frequency of contact points between the wheels and the rails, which increases noise emissions. Therefore, high-speed trains are generally noisier than slower trains.

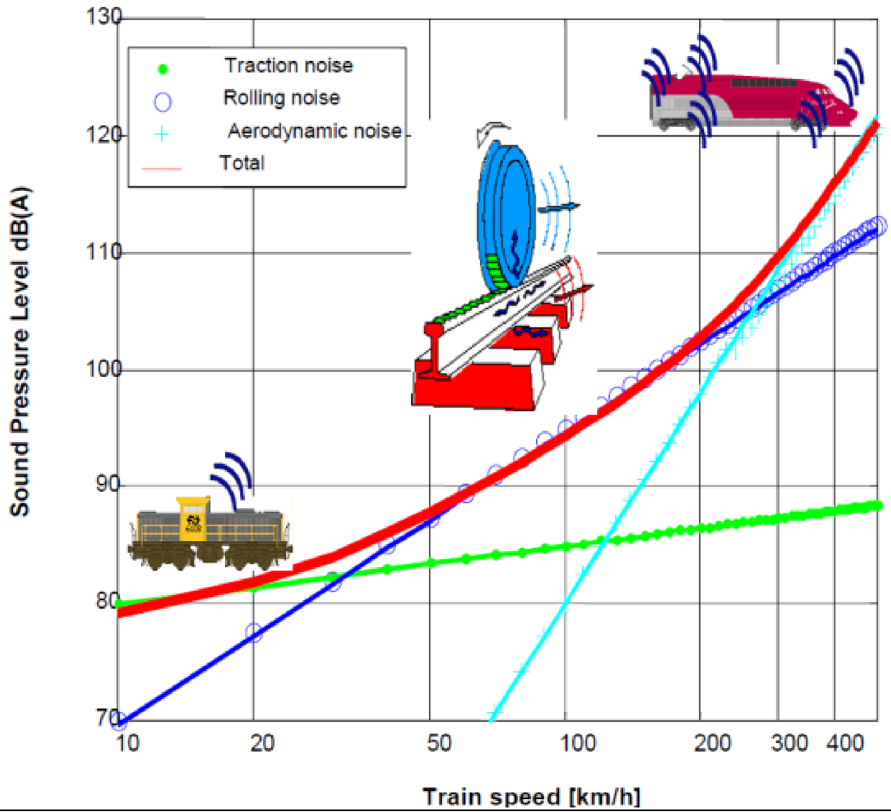

Figure 1: Noise sources as a function of speed [4]

Car load and noise emissions: The number of passengers on a train and the load on the cars can also have a significant impact on noise emissions. Fully loaded trains generally generate more noise than less loaded trains. This is because the heavy load causes the engines and braking systems to work harder, which results in noise.

It is important to note that, in addition to noise emissions, speed and car load can also have other effects. For example, higher-speed trains generally consume more energy, which can also have a significant environmental impact. Similarly, heavier trains consume more fuel, which also increases the environmental impact.

Measures such as noise reduction on vehicles and infrastructure, vehicle maintenance and modernization, infrastructure improvements, route optimization, and the use of low-noise vehicles and technologies can be implemented in rail transport to reduce noise emissions. Minimizing noise emissions and effectively implementing noise reduction measures are important for sustainable and environmentally friendly rail transport.

6 POSSIBILITIES FOR REDUCING NOICE POLLUTION FROM RAIL TRANSPORT

There are a number of methods and procedures available to reduce noise pollution from rail transport. These measures may include changes to vehicles, infrastructure, and the immediate environment, as well as technological developments aimed at minimizing noise emissions. Some of the more common noise reduction procedures are listed below:

Use of noise-reducing materials: The use of noise-reducing materials on vehicles and infrastructure helps to reduce noise emissions. Noise-reducing materials reduce the effects of resonance and transmitted noise, thereby reducing noise pollution. In the case of the Tata Steel Silent Track damping system, rubber inserts placed on both sides of the rail result in noise reduction of 3-7 dB [5], [6].

Vibration damping measures: Vibration damping measures, such as vibration-absorbing track inserts or vibration-damping components on vehicles, reduce vibrations that can lead to noise.

Vehicle maintenance and modernization: Regular maintenance of vehicles and replacement of old, noisy components with more modern, quieter versions [7] contributes to reducing noise emissions.

Track and infrastructure maintenance: Improving the condition of infrastructure, for example by replacing rails, repairing crossings, and maintaining the track bed, can reduce vibrations and noise levels.

Modifying speed and timetables: Reducing vehicle speeds or optimizing timetables in areas where noise pollution is particularly significant can reduce noise emissions [8].

Noise barriers and barriers: Installing noise barriers and barriers along the track can reduce the spread of railway noise to surrounding areas.
Innovative technological developments: Innovative technological solutions, such as electric trains or noise-reducing equipment, can significantly reduce noise emissions.
It is important to note that noise reduction measures must be implemented comprehensively and tailored to specific circumstances. Individual railway lines, infrastructure, and vehicle types may have different noise emission characteristics, so thorough analysis and planning are necessary for effective noise reduction. Noise reduction measures can result in quieter and more environmentally friendly rail transport, improving people's quality of life and creating a more liveable urban environment.

7 NOISE REDUCTION COSTS

There are a number of possible solutions for reducing railway noise pollution, including noise reduction, infrastructure development, vehicle modernization, and operational optimization. The costs involved can vary and depend on the type of measures taken, the condition of the infrastructure and vehicles, and the characteristics of the railway line in question [2]. Below, I present some possible noise reduction solutions and their expected costs [9]:

Use of noise-reducing materials: The use of noise-reducing materials (mineral wool, STERED) on vehicles and infrastructure is an effective method of reducing noise pollution [10]. Noise-reducing coatings, coverings, and materials can help reduce noise emissions. Their cost can vary depending on the type of materials used and the size of the areas treated. These types of measures can generally be relatively low cost, especially when applied only to critical noise sources. The use of sandwich structures optimized for noise absorption can be another effective solution [11].

Vibration damping measures: The use of vibration damping measures, such as vibration-absorbing track inserts and vibration-damping components on vehicles, can significantly reduce vibrations and thus noise emissions. Their cost depends on the technology used and the size of the infrastructure, but is generally moderately high.

Infrastructure development and maintenance: Improving the condition of infrastructure, for example by replacing rails, repairing crossings, and maintaining the track bed, can effectively reduce noise emissions [12], [13]. The cost of these measures can be high, especially if the improvements cover large areas and long railway lines.

Vehicle modernization: Modernizing old, noisy vehicles by replacing them with quieter, low-noise versions can significantly reduce noise pollution. Vehicle modernization can be costly, but it can be an effective and sustainable solution in the long term.

Operational optimization: Optimizing train schedules and speeds, for example by slowing trains in noise-sensitive areas, can help reduce noise exposure. The costs of operational optimization can vary, but are generally moderate and can be effective in the short term [33].
The cost of noise reduction measures depends on the specific situation and the measures implemented.

Railways around the world have invested significant financial resources in reducing or mitigating noise pollution caused by railways. One of the long-term goals of the German DB railway is to halve the noise level emitted. The total cost of this is €2.3 billion, including double-glazed windows. France is investing €193 million in noise barriers and rail dampers [14], [15]. The costs of noise reduction amount to approximately 0.1 to 0.5 percent of European GDP [16]. In Europe, approximately €150-200 million is spent annually on noise barriers and window insulation [17].

It is important to note that although some measures involve significant costs, reducing noise emissions can bring considerable long-term benefits, such as improving people's health and quality of life, reducing environmental pollution, and improving the sustainability and efficiency of transport. Therefore, when developing and implementing noise reduction solutions, it is important to comprehensively assess the impact of the measures and consider the long-term benefits.

8 COMPARISON OF RAILWAYS AND ROADS IN TERMS OF NOISE EMISSION

In terms of noise pollution, rail and road transport differ significantly. Both forms of transport are sources of noise, and the level of noise pollution depends on the means of transport, infrastructure, and operating conditions. Below, I present a comparison of noise pollution from rail and road transport in a few key areas [18]:

8.1. Noise sources:

Rail transport: Sources of noise in rail transport include train wheels and axles, engines, brakes, and noise generated by contact with rails and infrastructure. Friction with the rails, wheel-rail contact, and moving air can also be significant sources of noise when trains pass by. In addition, audible signals, which are closely related to transport safety, can also be a significant source of noise. [14], [19]

Figure 1 shows the effect of each component as a function of speed.

Road traffic: Sources of noise in road traffic include vehicle engines, wheels, and brakes, as well as noise from contact with the asphalt. In road traffic, the passage of vehicles, the contact between tires and the road surface, and road traffic itself can also cause noise pollution. These factors are of practical importance, as road noise pollution can have a serious impact on the quality of the living environment and people's quality of life. Constant noise emissions can cause discomfort and stress, which can contribute to sleep disorders, mental fatigue, and health problems. In addition, long-term exposure to noise is associated with a number of health risks, including hearing loss and cardiovascular disease. As a result, managing and reducing road noise sources is a priority in creating a sustainable and livable urban environment. Among the transport sectors, road transport is the largest source of noise in terms of area and number of people affected [20], with noise emissions influenced by traffic volume and composition, road surface type and quality, and vehicle condition [21], [22]).

8.2. Noise intensity:

Rail transport: Rail transport generally causes higher noise levels, especially on sections where high-speed or heavy trains operate. The condition of the infrastructure, the type of trains, and the speed have a significant impact on noise emissions. Although rail transport covers a much smaller area than road transport, is periodic, short-lived and affects far fewer people, the nature of the noise it causes (which in many cases stands out more than background noise) can be considered significantly more unpleasant. Within the sector, freight transport, especially at night, trains passing near residential areas, and audible signals cause noise levels to exceed the permitted limits. The maximum passing noise level is determined primarily by the instantaneous speed of the vehicle and secondarily by the combination of track and vehicle (track type, vehicle type) [23]. Along railway lines passing through populated areas, equivalent levels of 70–72 dBA can be measured during the day, and the noise does not fall below 68–70 dBA at night [24].

The noise level measured on high-speed railways increases with increasing speed, as shown in *Figure 2*.

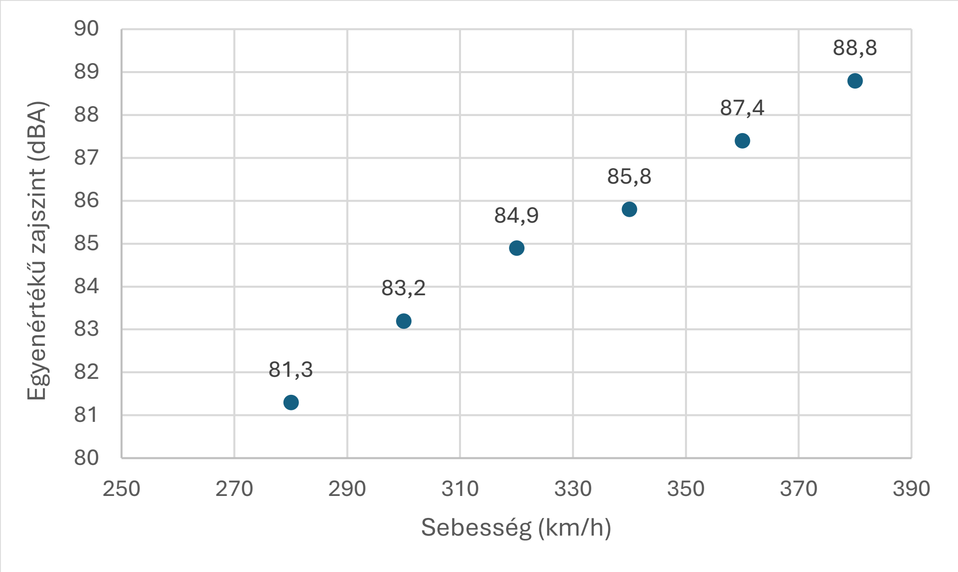

Figure 2: Increase in noise level as a function of speed [25]

Road traffic: Noise pollution from road traffic can vary and depends on the type of vehicle, its speed, and the traffic environment. Noise pollution is generally higher in urban areas and on congested roads. In general, trucks, heavy vehicles, public transport vehicles, and motorcycles are noisier than passenger cars. Approximately 50% of Hungary's population is exposed to noise from road traffic. Particularly along major urban roads, noise levels exceed health-threatening limits [26]. Along major urban roads, daytime noise levels range from 75 to 82 dBA, while night-time levels range from 68 to 77 dBA [27].

8.3. Distance and propagation

The "strength" of sound can be characterized by sound intensity, i.e., the sound power (W/m2) passing through a unit area perpendicular to the direction of sound propagation [28]. In practice, instead of sound intensity, we use the sound intensity level expressed in dB or dBA, or, for measurement reasons, the corresponding sound pressure level. The determination of the equivalent noise level is particularly important in assessing the harmful effects of noise, as it gives equal weight to both the intensity of the noise and the duration of exposure.

The importance of knowing the sound power level is particularly evident in the context of design. Prior knowledge of the expected sound power level can help in assessing what noise reduction equipment needs to be designed or what noise reduction measures need to be taken [29]. The sound source (a flexible body or medium that converts the energy communicated to it into sound energy [30]). The vibration of the medium propagates in the form of longitudinal sound waves [31]. The propagation of vibration occurs through the fluctuation of the physical state of the medium (pressure, particle velocity, displacement) around a given equilibrium position in space and time. The wavelength

of sound is determined by the ratio of the speed of sound propagation to the frequency of the signal under investigation [30].
In a study conducted in Debrecen, a reduction of 2.52 dB was measured at a distance of 5 m from the noise source (74.87 dB), while a reduction of 6.57 dB was measured at a distance of 20 m [32].
Rail transport: Rail noise generally travels much further than road noise. Trains usually travel on designated infrastructure routes, and the noise can be heard at considerable distances, especially in the case of high-speed trains.
Road traffic: The spread of road noise is more limited, as vehicles travel on public roads. The noise usually occurs near the roads and decreases with distance.

8.4. Impact of noise pollution:

Noise pollution from both modes of transport can have a negative impact on human health, well-being and environmental quality. Noise pollution can cause hearing loss, sleep disturbance, stress and cardiovascular problems.
Overall, both rail and road transport are sources of noise and can cause noise pollution. However, there are significant differences between the two modes of transport in terms of noise intensity, propagation, and effects. In order to reduce noise pollution, it is important to apply noise reduction measures and technologies in both areas to make transport more sustainable and environmentally friendly.

8.5. Permissible noise levels

The permissible noise levels generated by railways in residential areas may vary from country to country. In France, it is 60 dBA during the day and 55 dBA at night; in Italy, it is 65 dBA during the day and 55 dBA at night; in China, it is 60 dBA during the day and 50 dBA at night; in the US, it is 65 dBA both day and night; and in Germany, the permissible equivalent noise level is 59 dBA during the day and 49 dBA at night [25].

9. THE ECONOMIC IMPACTS OF TRAFFIC NOISE

Traffic noise has significant economic impacts that affect society, the business sector, and infrastructure in various areas. The economic impacts of noise pollution include:
Health costs: Noise pollution can have negative effects on human health, such as hearing loss, sleep disturbance, stress, and cardiovascular problems. This can have an impact on health systems and increase healthcare costs, such as the costs of treatment, examinations, and rehabilitation.
Property values: Properties located in noisy transport environments may generally have lower values, as noise pollution reduces their attractiveness to buyers and tenants. This has an impact on the property market, and property values and market demand may decline in affected areas.
Tourism and hospitality: Noise pollution can negatively affect the tourism and hospitality sector. Noisy transport environments can make areas less attractive to tourists and visitors, reducing tourism revenues and demand for hospitality services.
Quality of life and work performance: Noise pollution can result in a poorer quality of life for people living in noisy areas. Living with constant noise can cause stress and fatigue, which can affect work performance and efficiency in the workplace.

Transport infrastructure development: Noise reduction measures and technologies are needed to reduce noise pollution, which can be costly. Modernizing transport infrastructure and reducing noise pollution requires financial resources from the state and local governments.
Environmental damage caused by noise pollution: Noise pollution can affect the environment, for example wildlife and ecosystems. In the long term, this can place a financial burden on environmental measures and damage restoration.
In order to reduce constant noise pollution, it is essential to develop and implement sustainable and environmentally friendly transport solutions and to introduce effective noise reduction measures. This can contribute to reducing noise pollution, improving people's quality of life, and promoting environmental sustainability.

10. SUMMARY

There are a bunch of noise sources in rail transport that are part of different vehicles, infrastructure, and transport processes. Besides the ones we talked about earlier, there are other noise sources too. For example, railroad crossings, signals, and other traffic signs can also be noise sources in rail transport. Furthermore, bells and signals used at level crossings also generate noise for the sake of traffic safety.

The use of artificial intelligence (AI) to analyse noise and identify problems in rail transport can be extremely useful. Rail transport is a complex system with many critical elements, and the use of information carried by noise can help in the early detection of malfunctions, increasing maintenance efficiency, and improving safety.

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