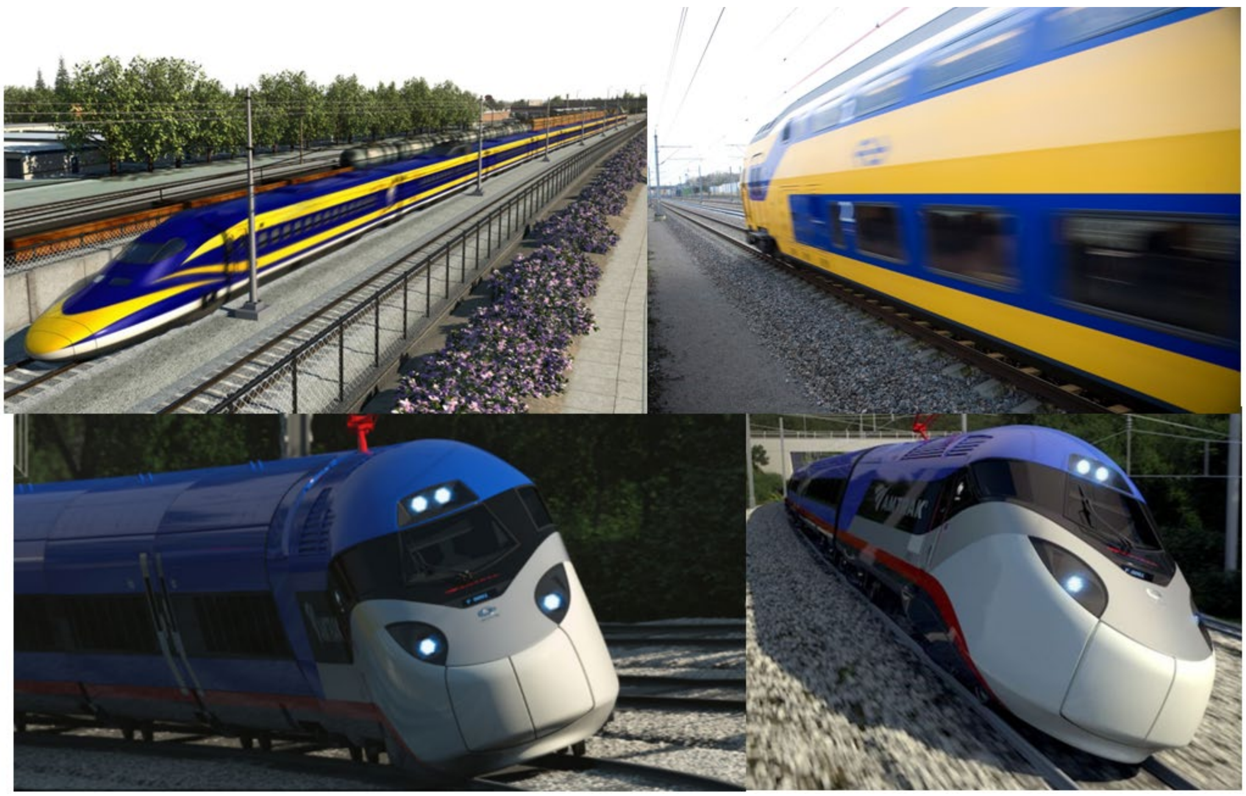
U.S. Department of Transportation

Federal Railroad Administration

High Speed Rail Noise Standards and Regulations

Office of Research, Development and Technology
Washington, DC 20590



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13. ABSTRACT (Maximum 200 words)

This study includes a review of European Union (EU), US and Asian standards, codes, and regulations related to high speed rail. Key results include: 1) a detailed survey performed on the topics of global standards and regulations for transportation noise with a focus on high speed rail applications in Europe (>155 mph), Asia (China and Japan, >155 mph) and US (Tier III: 160–220 mph). Researchers summarized the identified standards and regulations compared and contrasted to provide a reference document for the US rail industry; 2) identified and compared and contrasted high speed rail noise definition methods (metrics) and measurement techniques, as deployed in different global regions; 3) identified and compared and contrasted rolling stock design modifications, sound path interruption and receiver techniques used globally to reduce transportation noise to acceptable levels; and 4) industry stakeholders took part in interviews to review the study results and obtain comments regarding codes, standards, regulations and recommended practices, including compliance and enforcement.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

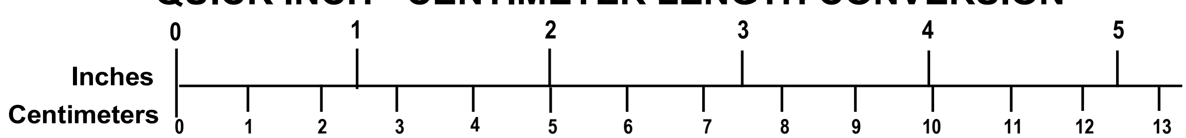
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



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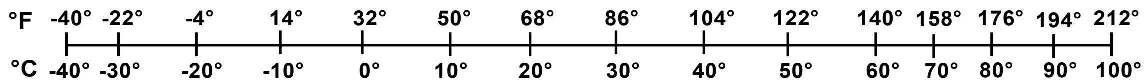

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Contents

Illustrations

Tables

Executive Summary

From April 1, 2016, to May 30, 2017, the Federal Railroad Administration (FRA) initially contracted Ricardo, Inc. to complete a survey of global codes, standards, regulations, and recommended practices for transportation-related noise. The survey focused on regulations, compliance approaches, enforcement, incentives, and penalties associated with existing high-speed passenger rail systems in operation within Europe and Asia, which were then compared to existing US railroad noise regulations. The study also included reviews of national and selected State, regional, and local regulations as well as enforcement procedures. The topics covered: definitions of noise descriptors employed in the various regulations, allowable noise levels (i.e., for both source emission noise and receiver immission noise), measurement procedures and instrumentation, measurement accuracy and repeatability, and recommended practices for noise control. The updated work included additional information from "Guidance on Assessing Noise and Vibration Impacts"[1] and other sources pertaining to US rail noise limits, and took place from June 11, 2019, to June 30, 2020.

A series of tables compared the regulations and compliance practices. This document describes and compares noise mitigation practices, such as source reduction, operational changes, sound path attenuation and insulation approaches. Researchers shared the results with industry stakeholders. These stakeholders provided information and opinions on a variety of topics ranging from noise reduction technologies to suggested regulation changes and direction for future research.

Noise emissions (source) and immissions (receiver) are typically regulated by different branches of government, with emissions being under the jurisdiction of national transportation agencies and immissions overseen by national environmental agencies as well as State and local governments. Rolling stock noise emissions limits are specified in European Union (EU) and US regulations. China and Japan specify immissions limits only. Measuring immission noise levels can be at the receiver and can include mitigation systems such as barriers and insulation. Emissions relate to the vehicle only and specifically exclude sound path and receiver mitigation methods.

In both the EU and US, States, member nations, and local governments also develop separate noise immissions limits. However, in both cases, these separate noise immissions limits cannot supersede the rolling stock emissions limits established respectively by the EU Technical Standards for Interoperability (TSI) and the U.S. Environmental Protection Agency/FRA noise regulations.

The US, by default classifies high speed trains as locomotives and the maximum noise limit is 90 dB(A), based on the $L_{max\ (fast)}$ metric. The limit for US rail car noise is 93 db(A), based on $L_{max\ (fast)}$ metric, with measurements conducted at a distance of 100 feet (30.4 meters) from the track centerline. The noise limit for electric high speed trains in the EU, at a reference speed of 250 km/h (155 mph), is 95 dB(A), based on $L_{pAeq,Tp}$ metric, measured at a distance of 7.5 meters (24.6 feet) from the track centerline. In China, the maximum allowable immissions limit for all rolling stock, including high speed rail, is 70 dB(A) during the day and 60 dB(A) during the

[1] Federal Railroad Administration, "Guidance on Assessing Noise and Vibration Impacts," U.S. Department of Transportation, Washington, DC.

night, based on the L_d and L_n metrics, measured at a distance of 30 meters (98.4 feet) from the track centerline. In Japan, high speed trains must have noise levels of 75 dB(A) or less, based on the L_{pASmax} metric, measured at a distance of 25 m (82 feet) from the track centerline. Figure 1 summarizes these regulations.

It is noted that direct comparisons of regulated noise limits are difficult to perform due to the variations in metrics, measurement locations, and measurement procedures. Researchers recommended that a standardized method be developed to allow direct comparison of limits and test data. An evaluation of noise measurement methods and calculation procedures indicates a global-scale normalization process could be developed as a spreadsheet-based program. The program would allow selection of train type and speed range. A library of available test data would serve as the basis for calculating the various sound measurement parameters, such as L_{max} (fast), L_{max} (slow), $L_{pAeq,Tp}$, L_d, L_n, L_{den} (Community Noise Equivalent Level [CNEL]), and L_{pASmax}, as a function of background noise levels and number of train passing events. From these results, statistical calculations could be completed, including L_{90} (sound level exceeded 90% of the time), and L_{10} (sound level exceeded 10% of the time). Other parameters would include absorption and reflective characteristics of the slab or ballast, track and wheel roughness, rolling stock noise reduction measures, and atmospheric conditions.

Source noise emissions recorded for presently-available high-speed trainsets from key manufacturers indicate current US railroad noise regulation limits will be exceeded for speeds above 200 mph (322 km/h). Calculations indicate the current US limit of 90 dB(A) will be exceeded by 0.4 dB(A) to 5.4 dB(A) based on measurement data for available high-speed trainsets. This report provides information that could help inform US noise regulation for high speed rail projects.

Railroad noise reduction approaches, ranked in order of cost effectiveness are:

1) ***Reducing source noise at the vehicle*****:** rolling noise due to wheel and rail roughness is a key contributor to high speed rail noise emissions. Aerodynamic sources in order of relative contribution to train noise levels are: a). pantograph; b). power car wheels; c). forebody, front window/roof interface; d). cooling fans; e). coach wheels; f). intercar gap; and g). wheel truck (bogie) aerodynamic noise. Noise reduction research for rolling stock is ongoing and many effective design modifications have already been implemented. It is projected that additional reductions of between 5 dB(A) and 10 dB(A) are still possible.

2) ***Interrupting the sound path using barriers and increasing distance to receivers*****:** sound immission levels adjacent to roadways and railroad tracks can be reduced between 5 dB(A) and 12 dB(A) using a variety of materials, with concrete being the most cost effective. Barriers are most cost effective in densely-populated areas. Although not always feasible or practical, increasing the distance from tracks to receiver is also effective at reducing noise levels. When the distance to the train is doubled, the maximum sound level is reduced by 3–6 dB(A).

3) ***Applying sound insulation at the receiver*****:** construction techniques and the selection of materials can reduce receiver immissions (interior) noise levels between 1 dB(A) and 25 dB(A).

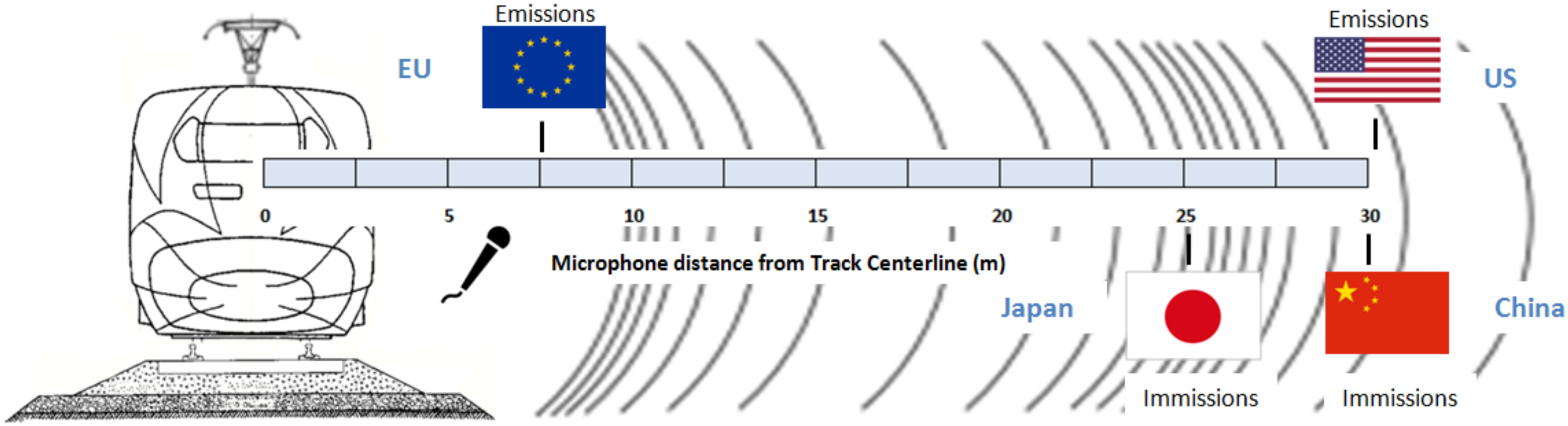
Rail noise regulations typically account for accuracy of measurement procedures. Type 1 sound meters are required by most regulations and have an accuracy of ±0.5 dB(A). Measurement repeatability also contributes to uncertainty; there is a 95 percent confidence that the calculated noise levels are within ±3 dB(A) of the true $L_{Aeq(period)}$ noise levels when at least 20 train passbys of each type under the same operating conditions are measured. For the L_{Amax} assessment parameter, the uncertainty increases to approximately ±5 dB for the same number of train passbys. Sources of the uncertainty include: speed variations, differences in rolling stock (i.e., due to manufacturing tolerances, age of vehicle and associated changes to suspensions, wheel surface roughness, bearings, etc.), track surface roughness, changes in ambient conditions, track alignment/curvature, track structure decay rates, and intermittent effects such as level of wheel hunting and flanging.

The EU and US Regulations Specify Source Noise Levels (Emissions)

EU			
Noise Measurement Metric		$L_{pAeq,Tp}$	
Measurement Location	Distance from Track Centerline	7.5 m (24.7 ft)	
	Elevation	1.2 m (3.95 ft)	From Top of Rail
Max Allowable Noise Level	80 km/h (50 miles/h)	80 dB(A)	
	250 km/h (155 miles/h)	95 dB(A)	

Sound Pressure Levels Emitted by the Passing Train

US			
Noise Measurement Metric		$L_{max\,(fast)}$	
Measurement Location	Distance from Track Centerline	30.4 m (100.0 ft)	
	Elevation	1.2 m (3.95 ft)	From Top of Rail
Max Allowable Noise Level	Locomotives	90 dB(A)	
	Rail Cars	93 dB(A)	



The China and Japan Regulations Specify Receiver Noise Levels (Immissions)

Japan			
Noise Measurement Metric		L_{eq}	
Measurement Location	Distance from Track Centerline	25.0 m (82.2 ft)	
	Elevation (m)	1.2 m (3.95 ft)	Above Ground
MaxAllowable Noise Level	Residential (Zone I)	70 dB(A)	
	Industrial (Zone II)	75 dB(A)	

Sound Pressure Levels Received at Property Boundary

China			
Noise Measurement Metric		L_d and L_n	
Measurement Location	Distance from Track Centerline	30.0 m (98.7 ft)	
	Elevation (m)	1.2 m (3.95 ft)	From Top of Rail
Max Allowable Noise Level	Day, L_d	70 dB(A)	
	Night, L_n	60 dB(A)	

Figure 1: Noise Regulations and Measurement Procedures, EU, US, Japan, and China

Train speed is also a major determinant of noise emissions. The increase in passby noise levels measured for a train traveling at 250 km/h (155 mph) and the same train traveling at 350 km/h (217 mph) ranges from 5 dB(A) to 8 dB(A). Variations in passby noise levels up to 2 dB(A) have been measured for the same high-speed train operating on two different sections of track. Other research indicates variations in rolling noise (e.g., wheel/rail surface roughness effects), that can range to 9 dB(A). The standard deviation of these measurements was 7 dB(A).

Although penalties are included in most noise regulations, ranging from reduced track access to monetary fines, enforcement is infrequent and not uniformly applied.

Other conclusions and comments expressed during the study, many obtained during interviews with industry stakeholders, include:

Rolling Stock:

- Integrating source and noise path solutions as a system provide opportunities for cost-effective noise reduction.
- Current rolling stock noise reductions are generally driven by contractual terms rather than regulations because rail operators are anticipating stricter future noise limits. Current high-speed rail vehicles offered by the major manufacturers meeting noise regulations are now in effect, but do not meet many of the recently submitted and proposed contractual requirements. For example, High Speed Two (HS2) (UK) has very complicated and strict noise specifications that will require new vehicle designs. (Stakeholder Interviews 1 and 7, see Section 7) and [1]. In Australia, Switzerland, and Sweden, operators set targets that are more stringent that the EU Technical Standards for Interoperability (Interviews 1 and 7) and [2] [3]
- Noise due to aerodynamic sources becomes greater than rolling noise at higher speeds. The speed at which aerodynamic noise becomes predominant varies with the train design and wheel/track conditions, but is generally in the range of 320 km/h (199 mph) to 340 km/h (211 mph), with the pantograph being the key noise source at speeds above these values.

Testing of candidate trainsets within the US will present challenges because no tracks are rated for speeds above 160 mph (257 km/h).

Noise Measurement Procedures:

- Standardizing noise tests for high speed trains in the US is recommended. This includes definitions of track conditions, test conditions, and instrumentation specifications.
- Regulations should indicate whether they apply to the vehicle only or to the entire system of rolling stock and wayside mitigation systems

Compliance, Enforcement, Penalties:

- More research is needed to determine cost effective approaches to lowering noise source levels. Stricter regulations are expensive to implement and could adversely affect the rail industry. Rating criteria, perhaps based on life cycle costs and number of people affected, should be developed.

- US Federal regulations regarding high speed rail noise take precedence over local and State levels due to the interstate nature of transportation systems. The EPA website states: "While primary responsibility for control of noise rests with State and local governments, Federal action is essential to deal with major noise sources in commerce, control of which require national uniformity of treatment. EPA is directed by Congress to coordinate the programs of all Federal agencies relating to noise research and noise control" [4]. Alternatively, States have also used litigation to force Federal regulation and more aggressive policies [5].
- Noise regulations should include well-defined penalties for noncompliance as well as time periods for attaining compliance should noise limits be exceeded.

Public Concerns:

- Public concerns in countries that have implemented high speed rail provide direction for implementing new high-speed projects, including approaches that have met public demands.
- Noise reduction systems accepted by the public in the EU and Asia provide guidance for new high-speed projects.

1. Introduction

Ricardo, Inc. prepared this report in support of the strategic objectives of the Federal Railroad Administration's (FRA) Office of Research, Development and Technology relative to the Rolling Stock Equipment Research Division and to provide beneficial insights for the US rail industry. Noise is one of the primary concerns to residents in the vicinity of high-speed rail lines. As the interest in high-speed rail grows and environmental impact assessments (EIA) continue, there is a need to understand current global codes, standards, regulations, and recommended practices, as well as enforcement procedures and options for compliance.

High-speed rail systems have been operating in Europe and Asia for many years. Evaluation of the associated noise regulations, codes, standards, recommended practices, noise measurement procedures, compliance approaches, attenuation methods, incentives for reducing noise and penalties for noncompliance, and identification of agencies having jurisdiction, are intended to provide information to assist with high-speed rail systems being developed for the US.

There are five existing or planned high speed passenger rail lines within the US at different levels of development [6]:

1. California High Speed Rail Authority ([CaHSRA] owned by the State of California). Construction is underway in three regions of the state, and an additional 350 miles of track is under development [7].
2. Northeast Corridor High Speed Rail (Amtrak with cooperation of other infrastructure owners: New York State, Connecticut Department of Transportation, and the Massachusetts Bay Transportation Authority): Alstom Avelia Liberty trainsets, capable of speeds up to 186 mph (300 km/h) are expected to begin operating during 2021 [8] [9].
3. Texas Central High Speed Rail (privately owned): project is in the fundraising stage [7].
4. Washington State Department of Transportation, Portland to Vancouver high-speed rail line. This is currently in the planning stage [7].
5. Virgin Trains USA, Las Vegas to Southern California high speed train, expected to begin construction during 2020.
6. Virgin Trains USA, Miami to Tampa route, portions of system are in operation with train speeds to 125 mph. Construction on remaining sections began during 2019 [7].

Working definitions of the terms "regulations," "codes," "standards," "recommended practices," and "agencies having jurisdiction" are shown below:

***Regulations*:** Regulations are rules established by government agencies such as the Federal Government with the effect of laws. They are benchmarks promulgated by a regulatory agency, created to enforce the provisions of legislation [10].

***Codes*:** Codes are sets of rules and guidelines, mandated ordinances, or statutory requirements for design, prepared and enforced by a designated governmental and/or professional group, which are intended to protect public safety and welfare. Some standards are recognized as codes [10].

***Standards*:** Standards are requirements set by authorities, custom or general consent and established as criteria. They are universally or widely accepted, agreed upon, or established means of determining what something should be. Major classifications of this term include: (1) material or substance whose properties are known with a level of accuracy that is sufficient to allow its use as a physical reference in calibrating or measuring the same properties of another material or substance; (2) concept, norm, or principle established by agreement, authority, or custom, and used generally as an example or model to compare or measure the quality or performance of a practice or procedure; and (3) written definition, limit, or rule approved and monitored for compliance by an authoritative agency (or professional or recognized body) as a minimum acceptable benchmark. This is the usual meaning of the plural term (standards). See also specification [10].

***Recommended Practices*:** Recommended practices are typically developed by industry organizations to facilitate interfaces/interoperability between equipment as well as standardized designs and operations.

***Authority Having Jurisdiction (AHJ)*:** The AHJ's responsibility for interpretation and, in some cases, enforcement of applicable regulations, codes, and standards.

1.1 Background

There is increasing US interest in high speed rail applications, especially as the rest of the world is increasing their deployments as a means of providing high efficiency, low carbon alternatives to interregional travel. However, high speed rail can bring augmented levels of sound noise and vibration, which, in some regions such as Europe and Japan, initially produced public outcry following initiation of operations. Hence, there is a need to understand (1) how different national jurisdictions have established acceptable noise regulations for high speed rail, (2) how the noise and associated vibrations are being measured, and (3) the current industry practices to provide effective source noise reduction methods, noise barriers and receiver noise mitigation strategies.

High speed rail can be a time efficient, low emission, profitable means of passenger transportation. Europe and Asia (specifically Japan and China) have extensive high-speed rail networks with speeds from 125 mph (201 km/h) to well over 200 mph (322 km/h). In comparison, the US currently has very limited high-speed rail with a network in the mid-west operating at 110 mph (177 km/h) and a high-speed line in the Northeast which can reach peak speeds of 149 mph (240 km/h). The current average speeds on US rail lines are below 100 mph (161 km/h). However, there is much interest in constructing extensive regional networks of high speed rail lines with speeds as high as 250 mph (402 km/h). Wider adoption of high speed rail in the US is anticipated in the future [11] [12].

For successful adoption of high speed rail, the associated noise and its impact on residents and businesses local to the train lines must be addressed. The establishment of the US Noise Control Act of 1972 was to require regulation of noise pollution with the intent of protecting human health and minimizing annoyance to the general public [13]. Federal, State, and local agencies have also defined noise regulations. Federal noise regulations for rail operations are contained in 40 CFR and 49 CFR. There is some concern that high-speed rail operations might exceed US regulated noise limits at train speeds greater than 200 mph (322 km/h) due to the corresponding increase in track/wheel and aerodynamic noise. Thus, additional research on the topic of high speed rail noise limits is needed. Also of interest is the cost of compliance including impact on train operators, enforcement agencies, and the public.

Noise measurement parameters, also known as metrics, include startle (onset rate), peak level and time-adjusted values recorded during passby events. One argument for accepting increased peak noise levels for high speed trains is the total duration of the noise event is shorter. It is important to address these potential noise concerns and understand mitigation options to inform regulation of high speed operations. Fortunately, experience of high speed rail operations up to and beyond 200 mph (322 km/h) can be obtained from reviewing the practices in Europe and Asia and indicating how these might be relevant or different to the existing noise regulations and standards in the US.

1.2 Objectives

The key objective of this study is to identify global standards, codes, regulations, and recommended practices associated with railroad noise with focus on high speed rail operations in Europe, Asia, and the United States, including definition of noise measurement techniques, and ranking of noise reduction methods.

1.3 Overall Approach

A survey of global codes, standards, regulations, and recommended practices for transportation-related noise was completed. Specific focus was placed on regulations, incentives, and penalties associated with existing high-speed passenger rail systems in operation within Europe and Asia, which were then compared to existing US railroad noise regulations. The study also included reviews of national regulations and selected State, regional, and local regulations as well as enforcement procedures. Results of these surveys were compared and contrasted.

In addition, an assessment was completed of current global practices, strategies, and techniques for minimizing harmful noise exposure from high-speed rail. This included noise source reduction, operational changes, and sound path attenuation approaches. Results and opinions were shared with industry stakeholders.

1.4 Scope

Researchers divided the project into four primary tasks: 1) administration, 2) regulations, 3) measurement, and 4) compliance. Table 1 summarizes these, along with the key subtasks. The scope includes an assessment of railroad noise codes, standards, regulations, and recommended practices with a focus on high speed rail. Other modes of transportation are not included.

Table 1: Project Scope of Work Includes Four Key Tasks

Task	Description	Subtasks
1	Program Administration, Team Review, Selective Stakeholder Outreach, Reporting	• Partner Coordination • Preparation of Final Report
2	Compare and Contrast Global High Speed Rail Noise Codes, Standards, Regulations, and Recommended Practices	• Define Key Noise Metrics • Collate Key Information • Compare and Contrast Findings for EU, US, and Asia
3	Review Current Techniques for Noise Measurement and Compliance Verification	• Define Noise Measurement Techniques • Evaluate Compliance • Identify Concerns (public, technical, governmental) • Compare and Contrast
4	Assess Global Practices, Strategies, and Techniques for Noise Compliance based on Literature Search and Interviews	• Define Noise Attenuation Techniques • Rank Approaches to Noise Compliance • Define Best Practices • Compare and Contrast

1.5 Prior Research

The U.S. Environmental Protection Agency's (EPA) Office of Noise Abatement and Control conducted background investigations in conjunction with issuing standards governing noise emissions from interstate rail carriers. Section 17 of the Noise Control Act of 1972 issued these standards. EPA's informational document reviews environmental, technological, and economic aspects of railroad noise [14]. The document states, "no state or local subdivision may adopt or enforce any noise emission standard on locomotives or rail cars unless it is identical to the Federal standard" (page 1–4 [14]). Since the regulations predated US high speed rail programs, the focus of the background research was on freight rail operations and diesel engine motive power units. The current state of the art for high speed passenger trains is electric propulsion and dedicated tracks (i.e., not shared with freight operations).

Early research and development of high speed trains began in France during 1966 with the first Train à Grande Vitesse (TGV) being placed in service between Paris and Lyon in 1981 [15]. During the late 1950s, development of the Japanese Shinkansen train was underway and the first of these high-speed trains, connecting Tokyo, Nagoya, and Osaka, was placed into service during 1964 [16]. Development of these high-speed train systems and others in Europe and China included assessments of noise impacts [17] [18]. This research continues to the present day and includes innovations in reducing source noise through vehicle modifications and sound path interruptions resulting from a variety of reflection, absorption, and insulation methods. As these noise mitigation methods evolve, regulations for high speed rail are also undergoing change, generally prompted by resident annoyance complaints. [19] [20] [21].

Within the EU and US, the primary focus of railroad noise mitigation research has been on reducing noise at the source. Thus, regulations specify maximum sound pressure levels measured at specified distances from the train. In China and Japan, noise mitigation methods are addressed as a system and include both vehicle and noise path modifications. Thus, the regulations for these two countries specify maximum sound pressure levels at the boundary of the railroad property. In the US, research on noise related to high speed rail increased during the early 1990s with greater interest in advanced passenger trains [22].

***Modeling Impact of Railway Noise*:** Hansen et al. (2012) describes models for predicting high-speed train noise and vibration as well as criteria for assessing the magnitude of potential impacts. General Noise Assessments employ simplified models (based on sound exposure level [SEL]), for identified train categories (e.g., electric and fossil-fuel-powered), speeds, distance, and length of train, to estimate both train noise and ambient noise which can be assessed using defined impact criteria and are typically employed during early stages of a project. Detailed Noise Analysis models allow site-specific noise predictions and mitigation evaluations based on noise defined for each subsource component, with each component defined in terms of a noise-generating mechanism (e.g., propulsion, wheel-rail, and aerodynamic), reference noise level, location along the train, and speed dependency, using precise methods for estimating horizontal and vertical geometry, ground adsorption, and shielding. Detailed noise analysis and modeling is appropriate for evaluating noise impacts of high-speed rail projects after track locations and trainsets have been selected.

FRA has conducted several studies on the impact of railroad noise and vibration that include the following [24]:

- The Chicago Rail Efficiency and Transportation Efficiency (CREATE) Noise and Vibration Model [25]
- The FRA High Speed Ground Transportation Noise & Vibration Assessment Manual [23]
- A report on European Noise and Vibration Measurements [26]
- A locomotive horn noise impact zone model
- The Handbook for Railroad Noise Measurement and Analysis [28]

1.6 Organization of the Report

Section 2 includes an introduction to high speed noise metrics with definitions of terms employed in the codes, standards, regulations, and recommended practices. Sections 3, 4, and 5 offer reviews of codes, standards, regulations, recommended practices, and measurement methods related to noise originating from high speed rail operations within the European Union (EU), United States, and Asia (China and Japan), respectively. Section 6 compares and contrasts this information to assess the implementation approaches, enforcement, attenuation methods, and effectiveness. This section also includes summaries of identified codes, standards, regulations, and recommended practices, along with links to the original publications. Section 7 presents the results of the industry stakeholder interviews.

2. Definitions and High-Speed Rail Noise Metrics

Boeker et al. (2009) provides a good introduction to sound level measurement procedures for US railroad regulatory compliance. Hanson et al. (2010) includes procedures for predicting and assessing noise and vibration impacts of high-speed ground transportation projects. Both references provide good introductions to acoustic principles, noise metrics and their applications to noise sources associated with railroad equipment and operations. This section defines the noise metrics associated with the codes, standards, regulations, and recommended practices identified during research related to high speed rail operations in the EU and Asia (i.e., principally Japan and China).

Due to the wide range of metrics, measurement procedures, and environments (e.g., open fields, with and without noise barriers, track roughness), it is challenging to directly compare the current regulations as well as expected compliance of train sets operating under each country's regulations. As a result of these challenges, FRA initiated two studies aimed at gaining an understanding of current noise regulations (and associated measurement requirements) and noise mitigation techniques (including costs):

1. High Speed Rail Noise Standards and Regulations (i.e., the current study, which also identifies mitigation methods currently being implemented as well as methods being researched).
2. High Speed Rail Cost of Compliance for Noise Mitigation Procedures (i.e., which includes spreadsheet-based methods for comparing EU, US, China, and Japan regulations and impacts of noise mitigation methods as well as costs for application of these methods to two representative US high speed routes).

For the current study, comparisons were made of global practices, strategies and techniques for noise compliance in three key areas:

- Noise Source Reduction
- Along the Source-to-Receiver Propagation Path
- At the Receiver

Section 6 includes comparison tables.

2.1 Definition of High Speed Rail

The definition of high speed rail varies by country. Within the EU, high speed rail is defined as trains operating at speeds in excess of 250 km/hr (155 mph) [29] [29] [30]. Within the US, the definition of high speed rail is currently divided into three categories [31] [32]:

1. *Tier I Passenger Train* means a short-distance or long-distance intercity passenger train providing service at speeds that include those exceeding 125 mph (201 km/h). These trains may operate on shared tracks with freight trains [33].
2. *Tier II Passenger Train* means a short-distance or long-distance intercity passenger train providing service at speeds that include those exceeding 125 mph (201 km/h) but not exceeding 160 mph (257 km/h).

3. *Tier III Passenger Train* means a short-distance or long-distance intercity passenger train providing service at speeds of up to 220 mph (354 km/h). Tier III passenger trains are permitted to operate in a shared right-of-way (i.e., one shared with freight trains and other tiers of passenger equipment) at speeds up to 125 mph (201 km/h), but must operate in an exclusive right-of-way without grade crossings at speeds exceeding 125 mph (201 km/h) up to 220 mph (354 km/h). The requirements provide for the sharing of rail infrastructure among various types of rail equipment, especially in more urban areas, while providing for dedicated passenger rail service at maximum speeds up to 220 mph (354 km/h) [34].

Discussions with industry representatives (see Section 7) indicate the consideration of "High Speed" noise in the US will focus on speeds above a threshold between 150 mph (241 km/h) and 160 mph (257 km/h).

2.2 Acoustic Concepts

The definition of noise is unwanted sound. The threshold of hearing is the quietest sound that can typically be perceived. This varies somewhat among individuals, but is typically in the micropascal range. The reference sound pressure is the standardized threshold of hearing and is defined as 20 micropascals (0.0002 microbars) at 1,000 Hz [35].

At the upper end of human hearing, noise causes pain, which occurs at sound pressures of about 10 million times that of the threshold of hearing. On the decibel scale, the threshold of pain occurs at 140 dB(A). This range of 0 dB(A) to 140 dB(A) is not the entire range of sound, but is the range relevant to human hearing. [36] The decibel (dB) is a logarithmic unit used to express the ratio of sound pressure to the reference sound pressure of 20 micropascals (i.e., the decibel is used to express the level of the other values relative to this reference [37]).

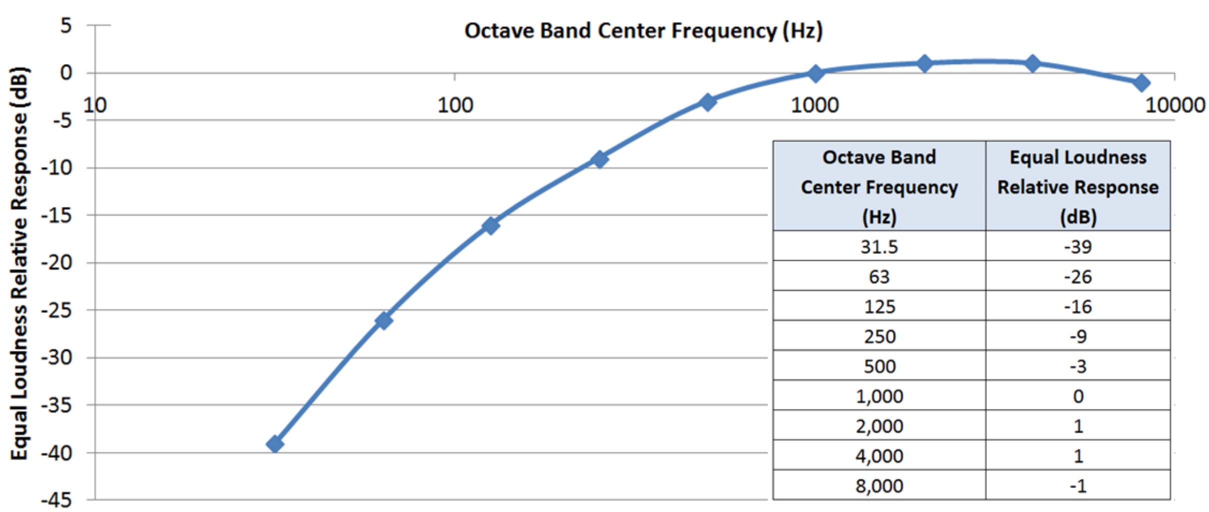
Figure 2 shows the sound level of a typical high-speed rail train, as measured at a distance of 100 feet from the track, relative to other sound sources.

A-weighting is defined in International Standard IEC 61672:2003 (i.e., the International Electrotechnical Commission [IEC] of the International Organization for Standardization [ISO] Standard for Sound Level Meters) and various national standards and is related to the measurement of sound pressure level [38]. A-frequency-weighting is specified internationally for environmental monitoring for both the exponential sound level and also for the integrated metrics of L_{eq} and SEL or L_{AE} [39]. All regulations identified during the current study list sound pressure levels in units of dB(A).

A-weighting is applied to instrument-measured sound levels to account for the relative loudness perceived by the human ear, as the ear is less sensitive to low audio frequencies [40]. To convert a set of octave band sound pressure levels into an equivalent A-weighted sound level, the A-scale correction factors for the nine standard octave center frequencies are applied and combined with the corrected values by decibel addition [41]. The A-scale correction factors are the values of the A-weighting network at the center of each particular octave band. The value derived by combining the corrected values for each octave band is designated the A-weighted sound level, dB(A), as shown in Figure 3.

Sound Pressure Level (dB(A)		Example Environment
	194	Sound Waves become Shock Waves
	180	Rocket Launch
	170	Automobile Airbag Deployment
	160	Shotgun
	150	Fighter Jet at Take Off
	140	Threshold of Pain, Firecracker, Air Raid Siren
	130	Jet Aircraft at Take Off (200 ft. Away), Peak Stadium Crowd
	120	Operating Heavy Equipment, Thunderclap
	110	Sporting Event, Rock Band (Live)
	100	Construction Site, Motorcycle (Riding)
	91	High Speed Passenger Train (300 km/hr, 100 ft. Away)
	90	Boiler Room, Lawn Mower
	80	Freight Train (100 ft. Away), Alarm Clock, Garbage Disposal
	70	Classroom Chatter, Shower, Dishwasher
	60	Conversation (3 ft. Away), Air Conditioner
	50	Urban Residence, Light Traffic, Refrigerator
	40	Soft Whisper (5 ft. Away), Babbling Brook, Computer
	30	Soft Whisper (1 ft. Away)
	20	Rusling Leaves, Silent Study Room
	10	A Pin Dropping
	0	Threshold of Hearing (1000 Hz)

Figure 2: Noise Comparison by Source



Octave Band Center Frequency (Hz)	Equal Loudness Relative Response (dB)
31.5	-39
63	-26
125	-16
250	-9
500	-3
1,000	0
2,000	1
4,000	1
8,000	-1

Figure 3: Corrected Octave Band for the A-Weighted Sound Level, dB(A)

Noise is generated at the source and perceived by the receiver. As illustrated in Figure 4, the path is seen as a means to attenuate the noise generated by the source towards the perception of the receiver [23].

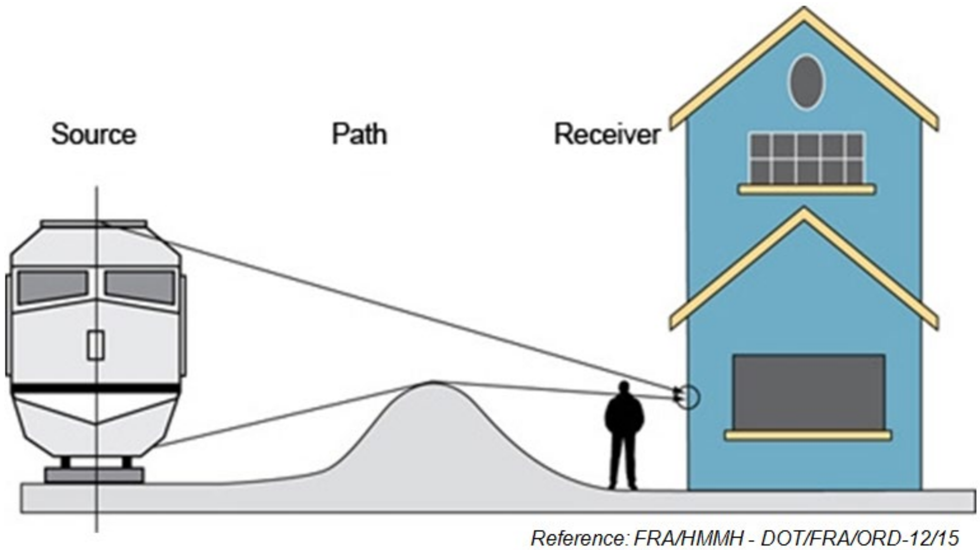


Figure 4: Noise Source, Path, and Receiver Concept

Noise Annoyance Levels

FRA reports that community attitudinal surveys ranked transportation noise as a significant cause of community dissatisfaction [27], and provides the graph below showing the range of people highly annoyed as a function of day-night sound level (L_{dn}). The scatter is due to variations in individual tolerance, as seen in Figure 5.

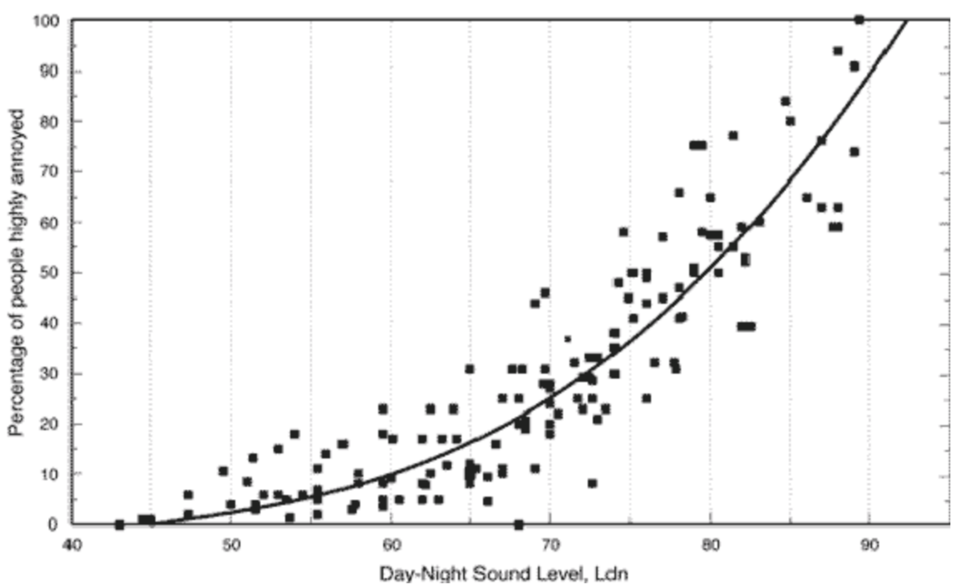


Figure 5: Transportation Noise Annoyance Levels [27] [42]

More information is available on the topic of noise annoyance levels in the FRA High Speed Ground Transportation Noise and Vibration Impact Assessment Manual [23].

2.3 Noise Standards and Associated Metrics

Railroad source (emission) noise standards and regulations are related to specific events (e.g., passby and horn activation) and include specifications for microphone positions and reporting metrics. Receiver (immission) noise standards and regulations typically limit allowable noise level(s) at different times of day for different zoned areas (i.e., residential, commercial, and industrial). For the current study, it was found that the allowable immission noise levels are higher during daytime hours and lower during nighttime hours.

Metrics for measuring noise vary with location (i.e., source and receiver) and applicable regulations (i.e., emissions, immissions, and regulatory body). Table 2 summarizes the noise standards and metrics for the four regions (i.e., EU, US, China, and Japan).

Table 2: Noise Standards and Associated Metrics

Region	Regulation	Measurement Location	Metric*	
			Symbol	Description
EU	European Commission Environmental Noise Directive 2002/49/EC	Receiver	L_{dn}	Day-Night equivalent sound pressure level
			L_{den}	Day-Evening-Night equivalent sound pressure level
			L_n	Night equivalent sound pressure level
	EU Technical Specifications for Interoperability; TSI NOI 1304/2014	Source	$L_{pAeq,Tp}$	The equivalent continuous sound pressure level produced by the train as measured during a pass-by event. These values are normalized to train speeds of 80 km/hr and 250 km/hr, designated as $L_{pAeq,Tp\ (80\ km/h)}$ and $L_{pAeq,Tp\ (250\ km/hr)}$.
US	National Environmental Policy Act (NEPA)	Receiver	None	There are no statutory or prescriptive linkages to noise emissions (pollution) standards in the EPA regulation.NEPA establishes a broad mandate for Federal agencies to incorporate environmental protection and enhancement measures into the programs and projects they help promote, approve, and/or finance
	40 CFR Part 201: Noise Emission Standards for Transportation Equipment and 49 CFR Part 210 Railroad Noise Emsission Compliance Regulations	Source	$L_{max\ (fast)}$	Maximum sound level during a single noise event obtained using the "fast" response setting on the sound level meter (0.125-second averaging time). This metric is used to identify excessively noisy locomotives and rail cars which are sometimes arbitrarily caused by a single component and often defective components. $L_{max(fast)}$ is thus equivalent to L_{pAFmax}
China	Ministry of Transportation Standard GB12525-90 an Ministry of Environmental Protection Standard	Receiver	L_d	Equivalent sound level measured during the day time.
			L_n	Equivalent sound level measured during the night time.
Japan	Ministry of Environment, Law No. 91 of 1993, Basic Environmental Law, Updated 2000, Environmental Quality Standards for Shinkansen Railway	Receiver	L_d	Equivalent sound level measured during the day time.
			L_n	Equivalent sound level measured during the night time.
			L_{eq}	The equivalent sound pressure level during train operation for a selected time period (e.g. full day, evening, night time).
*All metrics are expressed in units of dB(A)				

Details of the noise metrics associated with railroad operations within the EU, US, Asia (China and Japan) are included in report Sections 2.4, 2.5 and2.6.

2.4 Definitions and Noise Descriptors Applicable to EU Regulations

The European Commission Environmental Noise Directive is the main EU instrument to identify noise pollution levels and to trigger necessary actions both at Member State and at EU level [43]. To pursue its stated aims, the Environmental Noise Directive focuses on three action areas:

- The determination of exposure to environmental noise

- Ensuring that information on environmental noise and its effects is available to the public
- Preventing and reducing environmental noise where necessary and preserving environmental noise quality where it is good

The directive addresses noise to which receivers are exposed (immissions), particularly in built-up areas, in public parks or other quiet areas in an agglomeration, in quiet areas in open country, near schools, hospitals and other noise-sensitive buildings and areas. It does not apply to noise caused by the exposed person himself, noise from domestic activities, noise created by neighbors, noise at work places or noise inside means of transport or due to military activities in military areas.

The directive requires Member States to prepare and publish, every 5 years, noise maps and noise management action plans for:

- Agglomerations with more than 100,000 inhabitants
- Major roads (more than 3 million vehicles a year)
- Major railways (more than 30.000 trains a year)
- Major airports (more than 50.000 movements a year, including small aircrafts and helicopters)

When developing noise management action plans, Member States' authorities are required to consult the concerned public. It is important to note, however, that the directive does not set noise exposure limits or target values, nor does it prescribe the measures to be included in the action plans, thus leaving those issues at the discretion of the competent Member State authorities. Thus, the directive has key influence regarding development of new rail projects and non-railroad (receiver) mitigation methods.

In implementing the directive, the European Commission is supported by the Noise Regulatory Committee and the Noise Expert Group, as well as the European Environment Agency. The directive does not limit rolling stock noise, but directs nations to establish noise exposure limits. Thus, although it is not explicitly stated in the EU regulations, Member States create immissions limits based on rolling stock emissions (source) measurements made at the rail property boundary. It is similar to the U.S. National Environmental Policy Act (NEPA) law (see Section 2.6) which establishes a broad mandate for Federal agencies to incorporate environmental protection and enhancement measures into the programs and projects they help promote (see Section 5).

While each EU Member State develops its own noise exposure plans, railroad source noise is regulated by the Technical Specification for Interoperability (TSI). The TSI are specifications drafted by the European Railway Agency and adopted in a decision by the European Commission, to ensure the interoperability of the trans-European rail system [44]. The interoperability issues apply to the lines within the Trans-European Rail network. The European Railway Agency is mandated to issue single safety certificates and vehicle (type) authorizations valid in multiple European countries and to ensure an interoperable European Rail Traffic Management System, in the development and implementation of the Single European Railway Area. It regularly publishes TSI status summaries [45].

Member States of the EU having ratified the TSI governing rolling stock noise regulations, are prohibited from imposing legislation for which there is already an EU standard. This means that the TSI has become de facto national legislation for all Member States with regard to noise emission of rolling stock. Currently, EU countries do not have the option to adopt regulations that are stricter than those contained in the TSI, thus facilitating inter-country operations. Generally, the only influence local EU communities and legislative bodies have on noise legislation for high speed rail is in the planning stages, during which the limits for their areas are set.

EU Metrics Related to Receivers (Immissions)

The following metrics are employed within the EU Member States to report sound pressure levels at receivers. Specific metrics vary between Member States as well as local municipalities; however, reporting of exposure levels has been standardized to L_{dn}, L_{den}, or L_n. An example Member State report, in this case for the Netherlands, as required by the EC Environmental Noise Directive is shown in Figure 6 [46].

The information below shows the number of people exposed to high levels of noise above the EU reporting thresholds for various environmental noise sources such as road, rail, aviation and industry.

	Lden >= 55 dB			Lnight >=50 dB		
	2007	2012	2017	2007	2012	2017
Road	1,890,800	3,099,600	3,296,500	1,056,000	1,742,700	1,875,200
Rail	214,100	0	221,100	152,900	0	121,800
Air	69,200	2,900	59,400	10,500	100	2,500
Industry	94,900	71,600	49,800	18,400	6,500	3,400

Lnight >=50 dB
Lden >= 55 dB

Figure 6: Example EU Noise Directive Reporting (Netherlands) [46]

The receiver noise metrics are:

L_{dn} is the A-weighted average day-night equivalent sound pressure (defined in Figure 7) level as perceived at defined distances from the noise source and defined in [47] [48] with daytime defined as 6:00 a.m. until 10:00 p.m., and nighttime defined as 10:00 p.m. until 6:00 a.m.

L_{den} is the A-weighted average day-evening-night equivalent sound (defined in Figure 8) pressure level as perceived at specific distances from the noise source and defined in [47] [48]; with daytime defined as 7:00 a.m. until 7:00 p.m., evening defined as 7:00 p.m. until 11:00 p.m., and nighttime defined as 11:00 p.m. until 7:00 a.m.

L_n is the A-weighted average night equivalent sound pressure level as perceived at specific distances from the noise source and defined in [49] [50], with nighttime defined as 11:00 p.m. until 7:00 a.m.

Day-Night Sound Level (L_{dn}): The L_{dn} is an energy average of the measured daytime L_{eq} (L_d) and the measured nighttime L_{eq} (L_n) plus **10 dB**. The **10-dB** adjustment to the L_n is intended to compensate for nighttime sensitivity. As such, the L_{dn} is not a true measure of the sound level but represents a skewed average that correlates generally with past sound surveys which attempted to relate environmental sound levels with physiological reaction and physiological effects. For a steady sound source that operates continuously over a 24-hour period and controls the environmental sound level, an L_{dn} is approximately **6.4 dB** above the measured L_{eq}. If both the L_d and L_n are measured, then the L_{dn} is calculated using the following formula:

$$L_{dn} = 10\log_{10}\left(\frac{15}{24}10^{L_d/10} + \frac{9}{24}10^{(L_n+10)/10}\right)$$

Figure 7: L_{dn} Definition [37]

Community Noise Equivalent Level (CNEL or L_{den}): A metric similar to the L_{dn}, except that a **5 dB** adjustment is added to the equivalent continuous sound exposure level for evening hours (i.e., L_e) between 19:00 to 22:00 hours (7:00 p.m. to 10:00 p.m.) in addition to the **10 dB** nighttime adjustment used in the L_{dn}. For a steady sound source that operates continuously over a 24-hour period and controls the environmental sound level, the CNEL is approximately **6.7 dB** above the measured L_{eq}. If the L_d, L_e (i.e., evening L_{eq}) and L_n are measured, then the CNEL is calculated using the following formula:

$$L_{den}(CNEL) = 10\log_{10}\left(\frac{12}{24}10^{L_d/10} + \frac{3}{24}10^{(L_e+5)/10} + \frac{9}{24}10^{(L_n+10)/10}\right)$$

Figure 8: L_{den} Definition, Also Referred to as the Community Noise Equivalent Level [37]

Both the L_{dn} and L_{den} provide penalties for the higher annoyance evening and nighttime periods, with 5 dB added to the evening measurement and10 dB added to the nighttime measurement [48].

EU Metrics Related to Sources (Emissions)

The TSI employed the following metrics to report sound pressure levels at the source (vehicle). The TSI defined the procedures to allow noise levels to be calculated at various train speeds based on measurements made at 80 km/hr (50 mph) and 250 km/hr (155 mph). The following definitions are taken from European Commission and European Union Agency for Railways (ERA) publications and two journal articles [37] [47] [48] [49] [50] [51] [52].

For the source rolling stock, the Passby Level ($L_{pAeq,Tp}$) is the average of noise energy a train generates from all cars during the time of the passby of the entire train. This descriptor is defined within Technical Specifications Interoperability Noise Regulation Number 1304/2014 (TSI NOI 2014) [53].

$L_{pAeq,Tp}$ is the A-weighted equivalent continuous sound pressure level produced by the train as measured during the passby event and is defined in the EU TSI [37].

$L_{pAeq,Tp}$ is defined by the following equation [37]:

$$L_{pAeq,T_p} = 10 \lg \left(\frac{1}{T_2 - T_1} \int_{T_1}^{T_2} \frac{p_A^2(t)}{p_0^2} \mathrm{d}t \right) \quad \text{dB}$$

where

$L_{pAeq,Tp}$ is the A-weighted equivalent continuous sound pressure level for the passby time in dB(A)

$Tp = T_2 - T_1$ is the measurement passby time interval beginning at T_1 and ending at T_2

$P_A(t)$ is the A-weighted instantaneous sound pressure in Pa

P_0 is the reference sound pressure: $p_0 = 20$ µPa

The relationship between L_{pASmax} and $L_{pAeq,Tp}$ is shown graphically in Figure 9.

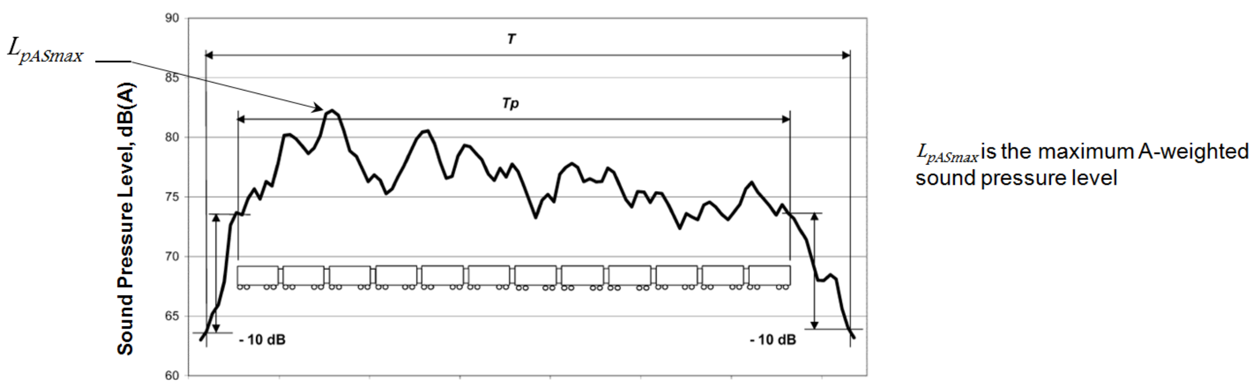


Figure 9: Relationship between L_{pASmax} and $L_{pAeq,Tp}$

2.4.1 Normalizing Passby Noise for V_{max} > 250 km/hr (155 mph)

If the maximum operational speed V_{max} of the train is equal to or higher than 250 km/h (155 mph), the passby noise is to be measured at 80 km/h (50 mph) and at its maximum speed with an upper test speed limit of 320 km/h (199 mph). The measured passby noise value $L_{pAeq,Tp}$(vtest) at 80 km/h (50 mph) shall be normalized to the reference speed of 80 km/h (50 mph), $L_{pAeq,Tp}$(80 km/h) using *Formula (1)* [37] [50] [53].

The normalized value is not to exceed the limit value $L_{pAeq,Tp}$(80 km/h) as set out in point 4.2.3 of the TSI [37].

Formula (1): $L_{pAeq,Tp}$(80 km/h) = $L_{pAeq,Tp}$(vtest) – 30 * log (vtest/80 km/h)

where vtest =actual speed during the measurement

The measured passby noise value at maximum speed $L_{pAeq,Tp}$(vtest) is to be normalized to the reference speed of 250 km/h (155 mph), $L_{pAeq,Tp}$(250 km/h) using *Formula (2)* [37].

The normalized value shall not exceed the limit value $L_{pAeq,Tp}$(250 km/h) as set out in point 4.2.3 of the TSI [37].

Formula (2): $L_{pAeq,Tp}(250\text{ km/h}) = L_{pAeq,Tp}(\text{vtest}) - 50 * \log(\text{vtest}/250\text{ km/h})$

where vtest =actual speed during the measurement

2.4.2 Normalization of Passby Noise, Train Speeds 80 km/h < V_{max} < 250 km/h

If the maximum operational speed, V_{max}, of the train is higher than 80 km/h (50 mph) and lower than 250 km/h (155 mph), the passby noise is to be measured at 80 km/h (50 mph) and at its maximum speed. Both measured passby noise values $L_{pAeq,Tp}$(vtest) are to be normalized to the reference speed of 80 km/h (50 mph), $L_{pAeq,Tp}$(80 km/h) using *Formula (1)* [37] [50] [53].

The normalized value is not to exceed the limit value $L_{pAeq,Tp}$(80 km/h) as set out in point TSI, see Section 4.2.3.

Formula (1): $L_{pAeq,Tp}(80\text{ km/h}) = L_{pAeq,Tp}(\text{vtest}) - 30 * \log(\text{vtest}/80\text{ km/h})$

where vtest =actual speed during the measurement

2.4.3 Transient Exposure Level (TEL)

Another noise metric that has been replaced by $L_{pAeq,Tp}$, but is still found in some of the European train noise literature is the TEL, which is normalized by the time period T_p in the equation below:

$$\text{TEL} = 10\log_{10}\left\{\frac{1}{T_p}\int_{t_1}^{t_2}\frac{p^2(t)}{p_{\text{ref}}^2}dt\right\}$$

where $T_p < t_2 - t_1$

The TEL results measured for various high speed trains were found to be between 0.5 dB(A) to 1.5 dB(A) higher than the corresponding $L_{pAeq,Tp}$ results [54].

2.5 Definitions and Noise Descriptors Applicable to US Regulations

Two Federal; agencies are responsible for US standards and regulations affecting noise originating from railroad operations: EPA and FRA. EPA developed the standards for noise exposure levels as directed by the Noise Control Act (1972). FRA then issued regulations to enforce the EPA noise emissions standards.

It is noted that US regulations do not limit “immissions” (sound pressure levels at receivers). Rather, guidance and procedures, as required by NEPA, are used to assess exposure from planned infrastructure projects. Noise immissions from ongoing railroad operations in the US are not directly regulated. Also, the term “immissions” is not commonly used in US.

2.5.1 Noise Control Act

Section 17 of the Noise Control Act of 1972 (Public Law 92-574) directs the US EPA to publish noise emission standards for surface carriers engaged in interstate commerce by railroad. Section 17 also requires the Secretary of Transportation to put into effect regulations to ensure compliance with the EPA standards. Responsibility for the development and enforcement of these regulations has been delegated to the Administrator of FRA.

On January 17, 1976, the EPA issued standards (41 FR 2184, 40 CFR Part 201) that established limits on the noise emissions generated by railroad locomotives, under both stationary and moving conditions and by railroad cars under moving conditions. These standards became effective on December 31, 1976.

The relationship between the Noise Control Act, EPA noise emission standards for surface carriers, and FRA railroad noise regulations is illustrated in Figure 10.

The US railroad noise regulations are thus emissions limits with specific measurement protocols. According to Section 3.2.3, the FRA Noise & Vibration Manual [23], abatement of noise sources from high-speed train systems is embodied FRA's Railroad Noise Emission Compliance Regulation [55]. Rather than specific environmental regulations, the compliance regulation is intended to enforce the Noise Emission Standards for Transportation Equipment: Interstate Rail Carriers promulgated by the EPA [56]. These standards limit the amount of noise emitted from power cars and rail cars under stationary and moving conditions. FRA strongly encourages noise abatement on high-speed train projects, especially where severe noise impacts are identified according to methods of the Noise & Vibration Manual [23].

On August 24, 1977, FRA published 49 CFR Part 210, Railroad Noise Emission Compliance Regulations (42 FR 42323) to ensure compliance with the EPA noise emissions standards (limits) for railroad locomotives and cars. These were updated on October 1, 2010.

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⇩

US 49 CFR 210 – Railroad Noise Emissions Compliance Regulations Summary	
Category	**Entry**
Code of Federal Regulations SuDoc Number	AE 2.106/3:40/
CFR Title Number and Date	Title 49 – Transportation, October 1, 2010
CFR Part Number	Part 210 – Railroad Noise Emission Compliance Regulations
CFR Subtitle	Subtitle B – Other Regulations Related to Transportation
CFR Chapter	Chapter II – Federal Railroad Administration, Department of Transportation
Authority	Sec. 17, Pub. L. 92-574, 86 Stat. 1234 (42 U.S. C. 4916); sec. 1.49 (o) of the regulations of the Office of the Secretary of Transportation, 49 CFR 1.49(o)
Source	48 FR56758, December 23, 1983.
References: CFR: 40 CFR 201; Federal Register: 48 FR 56758; U.S. Code: 42 U.S.C. 4916; Statutes at Large: 86 Stat. 1234; Public Law 92-574.	

Figure 10: Relationship of EPA Standards and FRA Regulations

US Railroad Noise Regulations are defined in Titles 40 and 49 of the Code of Federal Regulations (CFR) In the following parts:

- 40 CFR Part 201, Noise Emission Standards for Transportation Equipment; Interstate Rail Carriers [56]
- 49 CFR Part 210, Railroad Noise Emission Compliance Regulations [55]
- 49 CFR Part 222, Use of Locomotive Horns at Public Highway-Rail Grade Crossings [57]
- 49 CFR Part 227, Occupational Noise Exposure [58]
- 49 CFR Part 228, Hours of Service of Railroad Employees; Recordkeeping and Reporting; Sleeping Quarters [59]
- 49 CFR § 229.121, Locomotive cab noise [60]

- 49 CFR § 229.129, Locomotive horn [61]

Enforcement of FRA noise regulations is the responsibility of regional offices. Noise related issues are addressed by industrial hygienists assigned to each region (see Section 7).

Noise complaints rarely result in fines to the railroad operators within the US, even though the regulations and penalties are codified by EPA and enforceable by FRA. The regulations are difficult to enforce without corresponding test data performed by certified acousticians (comments from FRA industrial hygienist during stakeholder interviews (see Section 7).

2.5.2 Rolling Stock Noise

Noise descriptors applicable to both idle and passby events are defined in 40 CFR Part 201 [56] and 49 CFR Parts 210, 222, 227, 228, and 229 [55] [57] [58] [59] [60] [61] and are summarized by Hanson et al. (2012) and Barron (2003):

$L_{max\ (fast)}$: Maximum sound level during a single noise event obtained using the "fast" response setting on the sound level meter (0.125-second averaging time). This metric is used to identify excessively noisy locomotives and rail cars which are sometimes arbitrarily caused by a single component and often defective components. L_{max}(fast) is thus equivalent to L_{pASmax}

$L_{max\ (slow)}$: Maximum sound level during a single noise event obtained using the "slow" response setting on the sound level meter (1-second averaging time). This metric de-emphasizes the effects of non-representative impacts and impulses.

Other noise metrics associated with US rail noise assessments (environmental impact assessment [EAs] and environmental impact statement [EISs]) under NEPA and described in the FRA Noise & Vibration Manual [23] include:

L_{90}: Statistical sound level exceeded 90 percent of the time

L_{10}: Statistical sound level exceeded 10 percent of the time

L_{eq}: Receiver's cumulative noise exposure from all events over a specified time period

$$L_{eq}(hour) = 10\log_{10}\left[\frac{1}{T}\int_{t_1}^{t_2} 10^{L_A(t)/10}\,dt\right]$$

where the 1-hour time interval extends from t_1 to t_2 and $T = t_2 - t_1 = 1$ hour

L_{dn}: Receiver's cumulative noise exposure from all events over a 24-hour period. The basic unit used in calculating L_{dn} is the L_{eq}(h) for each 1-hour period. It is the noise exposure, totaled after increasing all nighttime A-levels (between 10 p.m. and 7 a.m.) by 10 dB(A).

$$L_{dn} = 10\log_{10}\left[\frac{\sum_{hour=7am}^{10pm} 10^{L_{eq}(hour)/10} + \sum_{hour=10pm}^{7am} 10^{(L_{eq}(hour)+10)/10}}{24}\right]$$

where: the 15-hour period from 7 a.m. to 10 p.m. is defined as daytime (unweighted), and the 9-hour period from 10 p.m. to 7 a.m. is defined at nighttime (with 10 dB(A) weighting).

2.5.3 National Environmental Policy Act

NEPA's basic policy is to assure that all branches of government give proper consideration to the environment prior to undertaking any major Federal action that significantly affects the environment [63]. NEPA (i.e., 42 U.S.C. Section 4321 *et seq* 1969) requirements are invoked when Federal activities are proposed. EAs and EISs, which are assessments of the likelihood of impacts from alternative courses of action, are required from all Federal agencies and are the most visible NEPA requirements.

The EPA plays a unique role in the NEPA process. The EPA is charged under Section 309 of the Clean Air Act to review the EISs of other Federal agencies and to comment on the adequacy and the acceptability of the environmental impacts of the proposed action. EPA also serves as the repository (EIS database) for EISs prepared by Federal agencies and provides notice of its availability in the Federal Register [64]. Impact assessments of planned Federal actions are a requirement under other environmental laws, including NEPA, and there are no statutory or prescriptive linkages to noise emissions (pollution) standards in the NEPA regulation.

2.6 Definitions and Noise Descriptors Applicable to Asian Regulations

Railroad regulations in China are defined by the National Standards for Noise in Urban Areas, Allowable Noise of Vehicles, and National Procedures for Measuring Vehicles Noise [65] [66] and in Japan by the Environmental Standards for the Shinkansen Super Express Railway [67], Environmental Quality Standards for Noise [68], Noise Regulation Law [69], and Technical Standards on Laws Concerning Railways [70] [71].

L_A A-weighted measured sound pressure level; here it is used to denote the equivalent continuous sound pressure level produced by the train noise level generated by each train during a pass by event, dB(A). This would correspond to $L_{pAeq,Tp}$ for the EU regulations.

$$L_A = 10\log_{10}\left[\frac{1}{T}\int_0^T 10^{\frac{L_i(t)}{10}}dt\right]$$

where T is the length of the time period over which the sound pressure measurements are made (train passing event), $L_i(t)$ is the instantaneous time-varying A-weighted sound pressure level during the time period T.

L_{eq} The equivalent sound pressure level during train operation for a selected time period (e.g., full day, evening, night time). Unless the regulation specifically states otherwise, the standard noise limits are listed as L_{eq}. It is calculated based on the following formula:

$$L_{eq} = 10 \log_{10} \left[\frac{1}{T} \int_0^T 10^{L_A(i)/10} dt \right]$$

where T is the time period over which the measurement is made, and $L_A(i)$ is the noise level of each train pass by event

L_d The A-weighted equivalent sound level measured during the day time, dB(A). The sound level averaged on an energy basis is:

$$L_d = 10 \log_{10} \left[\sum_{j=1}^{N} t(j) 10^{\frac{L(j)}{10}} \right]$$

t(j) is the fraction of time during which sound pressure level, *L(j)*, occurs during time period over which L_d applies

L_n The A-weighted equivalent sound level measured during the night time, dB(A). The equation for L_n would be the same as that for L_d with the sound levels corresponding to the time period defined as night.

L_{10} The A-weighted cumulative percentage sound level during which the measured values exceeded a defined maximum value more than 10 percent of the time, dB(A).

L_{50} The A-weighted cumulative percentage sound level during which the measured values exceeded a defined maximum value more than 50 percent of the time, dB(A).

In Japan, the Shinkansen Superexpress high-speed train noise immissions are governed by the provisions of Article 16 of the Basic Environmental Law (Law No. 91 of 1993) [67]. The standards for regulating noise are established as Article 9 of the Basic Law for Environmental Quality Standards. These standards require noise measurements to be carried out by recording the peak noise level of each of the Shinkansen trains passing in both directions, in principle, for 20 successive trains. Measurements are to be performed outdoors and in principle at the height of 1.2 meters above the ground. Measurement points shall be selected to represent the Shinkansen railway noise levels in the area concerned, as well as points where the noise is posing a problem. Any period when there are special weather conditions or when the speed of the trains is considered lower than normal are to be avoided when selecting the measurement time. The Shinkansen railway noise is to be evaluated by the energy mean value of the higher half of the measured peak noise levels. This requires the measuring instrument to meet the requirements of Article 88 of the Measuring Law (Law No. 207 of 1951), with A-weighted calibration and slow dynamic response [20]. Thus, the metric used for the 20 passby measurements is:

$L_{max\ (slow)}$: Maximum sound level during a single noise event obtained using the "slow" response setting on the sound level meter (1-second averaging time). This metric de-emphasizes the effects of non-representative impacts and impulses.

These environmental quality standards apply to Shinkansen railway noise from 6 a.m. to 12 midnight.

3. EU Codes, Standards, Regulations, and Recommended Practices

Within the EU, it is estimated that over 8 million people are exposed to rail traffic noise levels above 55 dB(A) (L_{den}) [72]. It is also estimated that around 20 percent of the EU population is subjected to noise levels that are considered unacceptable [73].

Historically, rail networks within Europe were national networks only, with very limited international connections. Different countries had different technical developments concerning power supply, gauge width and train protection systems. All this led to national systems that were incompatible with each other. At borders, locomotives had to be switched or passengers had to switch trains from one system to another

With the advent of the EU after World War II came the increasing need for cross-border transportation of goods and passengers. Especially the last decades, with competition for international passenger transportation by low-cost airlines, and increased global trade and transportation of goods, the inefficiency of this situation became apparent [74].

To remedy this, the EU adopted a series of resolutions, which stated the intention to create a single market with one set of rules for rolling stock, infrastructure and the operation of rail networks. It was argued that economies of scale could be reached for manufacturers of rolling stock, inefficiencies would disappear for cross-continent transport and travel, the market would be opened for new entrants to compete with the incumbent, mostly state-owned rail operators and very importantly, a higher level of safety could be reached [75].

All this started with the high-speed rail network, followed by freight transport and international passenger transport, and recent national passenger transport. The transfer of authority from countries to the EU has been gradual and fraught with exceptions and compromises due to the different views on open markets that exist in different countries.

However, as far as technical specifications are concerned, a lot of ground has been covered. To harmonize rules and regulations, an agency has been mandated by the European Commission (i.e., ERA). Its goal is, as quoted form its website:

> The construction of a safe, modern integrated railway network is one of the EU's major priorities. Railways must become more competitive and offer high-quality, end-to-end services without being restricted by national borders. The European Railway Agency was set up to help create this integrated railway area by reinforcing safety and interoperability [76].

3.1 Noise Regulations Protecting Receivers

The EU Environmental Noise Directive 2002/49/EC covers the noise regulations protecting receivers (e.g., residents), nature preserves and other sensitive areas [49]. The Noise Directive requires Member States to prepare and publish, every 5 years, noise maps and noise management action plans. The Noise Directive does not quantify sound pressure limits or targets, nor does it prescribe the measures to be included in the action plans, thus leaving those issues at the discretion of the competent Member State authorities. Since Member States of the EU ratified the TSI which rolling stock noise regulations, they are prohibited from imposing legislation for which there already is an EU standard. As discussed in Section 2.5, the only influence local EU communities and legislative bodies have on noise legislation for high speed rail is in the planning stages, during which the limits for their areas are set. This is similar to the planning process of other jurisdiction-transcending infrastructure projects. Local legislation does not influence emission limits for rolling stock. Enforcement of noise levels is (usually) not a local, but rather a national matter. The vehicle/infrastructure noise "emissions" are set at the EU level with the TSI. Local exposure or "immissions" levels are then used to assess proposed infrastructure projects. It is only national exposure limits that account for the entire system of vehicle, infrastructure, and any path mitigation. Noise immissions are often correlated to land use designations, such as residential or industrial [59]. Should communities or individuals feel they have been treated unfairly, the country's justice system provides the opportunity to pursue their interests [77].

EU Member States are obligated to prepare and publish, every 5 years, noise maps and noise management action plans for major railways which are defined as railways being used by more than 30,000 trains per year. Theoretically there can be high speed lines that can be excluded based on this criterion. However, this seems highly unlikely since that would mean that the return on the (sizable) investment is very low due to the low frequency of traffic [49].

Before building a high-speed rail line, an environmental impact analysis is usually made, in which the effect of the new line is determined and with which mitigating measures can be defined. Member States are free to decide how they want to integrate a high-speed line into the environment, provided they adhere to the relevant TSI, other EU legislation, and their own approaches to planning major infrastructure projects [49]. There is an opportunity to ask for an exception to TSI limits in certain specific circumstances, however this is rarely done and for high-speed rail rolling stock there have been no exceptions requested or granted [53] [78] [79].

A survey of legislation, regulations and guidelines related to the control of community noise was conducted during 2009 by the International Institute of Noise Control Engineering (I-INCE) covering EU member countries, the UK, and the US [80]. The document includes references to noise legislation publications, noise measurement metrics and procedures, and responses to stakeholder surveys.

3.2 Noise Regulations for Rolling Stock—TSI

EU regulated noise emission limits vary by rolling stock (by type) and specific infrastructure. The noise limits for rolling stock are typically based on passby events, in addition to start-up, and idling. These are defined in the EU TSI [50] and discussed in Section 3.3.1.

Measurements are required at specified distances and elevations relative to the track and for specified time periods and durations. In the case of passby noise, the following variables are recorded: the length of the train and the duration of the event (based on train speed). Generally, these standards are infrastructure-independent, although a provision for slab track instead of ballast is usually considered [78] and acceptable levels of track roughness are required by the TSI.

3.2.1 EU Technical Specifications for Interoperability

The portion of the TSI relating to noise emission of rolling stock is designated NOI TSI and has EU Reference Number 1304/2014 with the most recent publication date of November 26, 2014. The ERA is mandated to draft and regularly update application guides intended to help the stakeholders in the application of the TSIs. Key elements of NOI TSI are: 1) Stationary Noise, 2) Starting Noise, 3) Passby Noise, and 4 Driver's Cab Interior Noise [53].

The ERA developed the TSI framework. It seeks to harmonize technical specifications for rolling stock, including crashworthiness, brake capacity, running behavior, acceleration and environmental standards, provisions for people with reduced mobility, etc. In addition, a new standard for train protection called the European Rail Transport Management System (ERTMS), which also links the rolling stock TSI to the infrastructure TSI (as does the power supply standard, especially for new international corridors), has been developed. TSI's are continually improved and updated, for instance to reflect technological innovation, hence the need to identify the year of applicability together with the name when referring to specific requirements [53].

Table 3: Key Application Areas of the TSI

	EU Technical Specifications for Interoperability
NOI	Noise
LOCPAS	Locomotive & Passenger
WAG	Rolling Stock
INF	Infrastructure
ENE	Energy
CCS	Control Command and Signaling
OPE	Operation and Traffic Management
TAF	Telematic Applications for Freight
TAP	Telematic Applications for Passenger Service
PRM	Persons with Reduced Mobility
SRT	Safety in Railway Tunnels

Railway Group Standards (RGSs) have three principal roles in the context of the European standards system. The UK Rail Safety Standards Board (RSSB) produced Figure 11, which sets out RGSs in their European context, showing how they are used to meet requirements deriving from the Interoperability Directive 2008/57/EC and the Railway Safety Directive 2004/49/EC [81].

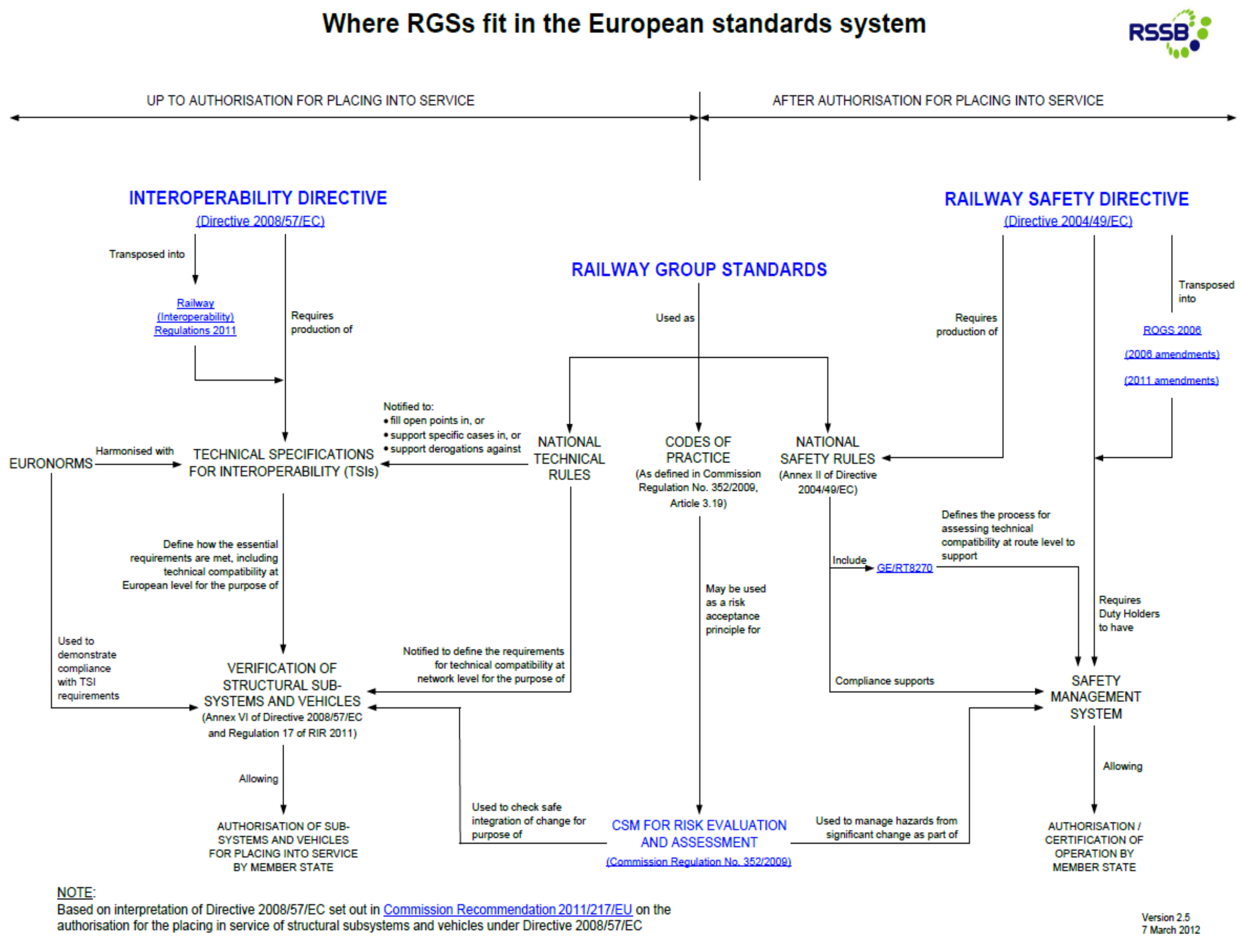

Figure 11: Relationship Between UK and European Rail Standards

It is important to note that ERA is required to consult with the stakeholders in the sector, such as operators, manufacturers, infrastructure providers, and with the Member States. One of the goals of this collaboration is avoiding adoption of unattainable standards. However, this leads to the possibility of reaching compromised positions that weaken the regulation or its application. TSI's continue to evolve, but are generally considered to be effective. Interestingly, some TSI's have been used in other areas of the world outside of the EU, like Morocco, Brazil and the US. The reference to TSI 2008 noise regulations is in the noise paragraph of the draft specification for trainsets for the CaHSRA [82]. It is important to note that this reference to the EU TSI by CaHSRA is a contractor specification and does not reflect US Federal policy, guidance, or regulation.

3.2.2 TSI Noise (2014)

The TSI NOI (2014/1304/EU Commission Regulation of November 26, 2014, on the technical specification for interoperability relating to the subsystem 'rolling stock—noise') governs noise emission from rolling stock. The latest 2014 version also includes high speed rolling stock, where previous versions excluded rolling stock with service speeds in excess of 250 km/h (155 mph) (they were governed by the TSI High Speed Rolling Stock, as stated below). This TSI covers noise emission at idle, start up (acceleration), pass by and in the driver's cab [37].

TSI Noise does not define noise limits for:

- Interior passenger space (viewed as a comfort requirement dealt with by manufacturers)
- Brake squeal (too dependent on infrastructure – hard to objectify)
- Curve squeal (too dependent on infrastructure – hard to objectify)
- Onset (startle) noise (part of the passby noise criterion)

Startle is the reaction of humans to rapid increases in sound pressure levels. In the Netherlands, this subject is included in the noise assessment of trains at railway yards related to the action of pneumatic air system pressure relief valves, which are a key source of annoyance to people living near the yards. These events are limited by local noise immission regulations at the railroad boundaries. Startle noise is not included in the TSI and interviews with EU rail stakeholders indicate that there are currently no proposals to add startle noise requirements to the TSI.

TSI Noise provides clear pass or fail limits for passby noise as shown in Table 4:

Table 4: EU TSI NOI Limit Values for Passby Noise

Category of the rolling stock subsystem	$L_{pAeq,Tp\ (80\ km/h)}$ [dB]	$L_{pAeq,Tp\ (250\ km/h)}$ [dB]
Electric locomotives and OTMs with electric traction	84	99
Diesel locomotives and OTMs with diesel traction	85	n.a.
EMUs	80	95
DMUs	81	96
Coaches	79	n.a.
Wagons (normalised to APL = 0,225) (*)	83	n.a.

(*) APL: the number of axles divided by the length over the buffers (m^{-1})
Where OTMs refers to On Track Machines, EMU refers to Electric Multiple Units, and DMU refers to Diesel Multiple Units

Noise pressure levels are measured at 7.5 m from centerline of track at 1.2 m above top of rail, and for speeds > 250 km/h (155 mph). Aerodynamic noise is measured at 3.5 m above top of rail (location of pantograph). Speeds are normalized back to 80 km/h (50 mph) and 250 km/h (155 mph) respectively, to facilitate comparisons between rolling stock. The demonstration of conformity refers to EN ISO 3095:2013 which defines measurement conditions and procedures.

TSI NOI also provides limits for stationary, starting, and driver's cab interior noise as seen in Table 5 through Table 7 [53].

Table 5: TSI NOI Limit Values for Stationary Noise

Category of the rolling stock subsystem	$L_{pAeq,T\ [unit]}$ [dB]	$L^{i}_{pAeq,T}$ [dB]	L^{i}_{pAFmax} [dB]
Electric locomotives and OTMs with electric traction	70	75	85
Diesel locomotives and OTMs with diesel traction	71	78	
Category of the rolling stock subsystem	$L_{pAeq,T\ [unit]}$ [dB]	$L^{i}_{pAeq,T}$ [dB]	L^{i}_{pAFmax} [dB]
EMUs	65	68	
DMUs	72	76	
Coaches	64	68	
Wagons	65	n.a.	n.a.

Table 6: TSI NOI Limit Values for Cab Interior Noise

Noise within the driver's cab	$L_{pAeq,T}$ [dB]
At standstill with horns sounding	95
At maximum speed v_{max} if v_{max} < 250 km/h	78
At maximum speed v_{max} if 250 km/h ≤ v_{max} < 350 km/h	80

Table 7: TSI NOI Limit Values for Rolling Stock

Category of the rolling stock subsystem	$L_{pAF,max}$ [dB]
Electric locomotives with total tractive power P < 4 500 kW	81
Electric locomotives with total tractive power P ≥ 4 500 kW OTMs with electric traction	84
Diesel locomotives P < 2 000 kW at the engine output shaft	85
Diesel locomotives P ≥ 2 000 kW at the engine output shaft OTMs with diesel traction	87
EMUs with a maximum speed v_{max} < 250 km/h	80
EMUs with a maximum speed v_{max} ≥ 250 km/h	83
DMUs P < 560 kW/engine at the engine output shaft	82
DMUs P ≥ 560 kW/engine at the engine output shaft	83

The earlier version of TSI Rolling Stock was put into effect during 2008 and has been superseded by TSI NOI [37]. However, the design of many high-speed rail systems currently operating within the EU adhere to the 2008 standard, which includes the noise limits for train speeds ranging from 200 km/h (124 mph) up to 320 km/h (199 mph). The design criteria for the 2008 standard are shown in Table 8:

Table 8: Passby Limiting Values $L_{pAeq,Tp}$ from 2008 TSI NOI

Rolling stock		Speed [km/h]			
		200	250	300	320
Class 1	Trainset		87 dB(A)	91 dB(A)	92 dB(A)
Class 2	Trainset or variable formations	88 dB(A)			

where:

Class 1: Rolling stock having a maximum speed equal to or greater than 250 km/h.

Class 2: Rolling stock having a maximum speed of at least 190 km/h but less than 250 km/h.

Comparing the TSI High Speed Rolling Stock 2008 with the new TSI NOI is difficult given the different ways of measuring and calculating noise emissions. A calculation performed by Peen

(2016) of Ricardo Rail indicated the TSI Noise value for speeds in excess of 250 km/h (155 mph) is 0 to 2 dB(A) less stringent than the corresponding value in the (earlier) TSI High Speed Rolling Stock, see Table 9. For rolling stock with lower maximum speeds, the new TSI Noise became stricter.

Table 9: Comparison of Netherlands and TSI Noise Regulations

Regulation or Code: →		Netherlands (stricter limits)				TSI HS 2002				TSI HS 2008				TSI NOI 2014			
Train Speed (km/hour): →		200		250		200		250		200		250		200		250	
Allowable Sound Pressure Levels indicated in regulations, dBA		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
Transient Exposure Level (TEL) at 25 meters		82	82	85	85			87	88								
$L_{pAeq,Tp}$ at 25 meters	from TEL to $L_{pAeq,Tp}$ = 0.25 - 1 dB reduction	81	81.75	84	84.75			86	87.75	88	89	87	88				
$L_{pAeq,Tp}$ at 7.5 meters	From 25 to 7.5 meter is 6 - 7 dB addition	87	88.75	90	91.75	Not Specified		92	94.75	94	96	93	95	Not Specified		95	95
$L_{pAeq,Tp}$ at 7.5 meters & 80 km/h	Normalized to 80 km/h: Reduction 30log(v/80)	75.1	76.8	75.2	76.9			77.2	79.9	82.1	84.1	78.2	80.2			80.2	80.2

Source: Calculations by Ricardo Rail

Minimum (min) and Maximum (max) values are based on 1 dB(A) allowance for measurement apparatus accuracy range in the TSI HS 2002 and subsequent calculation uncertainties.

Note that TEL was an earlier version of the passby noise limit $L_{pAeq.Tp}$, and had a different exposure time period.

Up to 2014, the noise requirements for high-speed trains and conventional trains were addressed in two documents. For high speed trains, the requirements were included in the TSI-RST-HS (2008/232/EG) and for conventional speed the requirements in the TSI-NOI (2011/229/EU including 2012/464/EU). Both regulations included noise limit requirements, however the prescribed microphone locations were different: for high speed lines the indicated distance was 25 m from the track centerline and for conventional speed operation the microphone location was specified as 7.5 meters from the track centerline. During 2014, it was decided to combine both rolling stock categories into one legislation (1304/2014), and specify one measurement location (microphone located at 7.5 meters from the track centerline). The introduction of normalized noise limit values was introduced to consolidate the TSI Noise regulations to one document. The increase in train speed is not a key reason for this consolidation since the current TSI also limits train speeds to 320 km/h (see 1304/2014 including 2019/774 chapter 6.2.2.3.2.1. sub 3: if the maximum operational speed, v_{max}, of the unit is equal to or higher than 250 km/h, the passby noise is to be measured at 80 km/h and at its maximum speed with an upper test speed limit of 320 km/h.)

An initiative to reduce the costs and uncertainty of rolling stock noise emissions measurements is being promoted by manufacturers and operators within the EU [83] and is reviewed in European Railway Agency Report ERA/CON/2013-01/INT [84]. Virtual Testing (VT) is proposed as a way of complying with TSI NOI requirements, which involves a virtual vehicle acoustically representing a real vehicle as a set of noise sources. Once certified, the simulation tool can be used to determine the noise level of the train at stationary or passby. The verified train noise emissions can then be employed to calculate receiver immissions by representing adjacent structures, track conditions, sound barriers, etc. To that end, it is necessary to have accurate noise emissions data for the vehicles. Measuring noise at closer distances to the passing vehicle, for example at 7.5 m (24.6 ft.) instead of 25 m (82 ft.), ensures less impact of non-train sources.

Létourneaux et al. (2011) describes other approaches for revising the TSI NOI to simplify procedures and reduce costs . Objectives for the revisions include the procurement of a reference track available in every EU Member State in a non-discriminatory way, and an introduction of some flexibility in the general assessment process, such as making use of calculation methods as a complement to measurements, making use of comparable analysis to a known type. Thus, making measurements in closer proximity to the train (7.5 m vs. 25 m, 24.6 ft. vs. 82 ft.) improves the quality of the data for the calculation procedure. The impact of rail roughness on rolling noise generation is defined in BS EN 15610:2009 [85]. The NOise Emission Measurement campaign for high-speed Interoperability in Europe (NOEMIE) project assessed the noise emissions values of high speed trains operating within the EU and employed specific measurement methods to assess track characteristics and their influence on noise [86] [87]. The study concluded that the then (2004) revised TSI reference track definition (i.e., at locations where noise emissions tests are considered acceptable) allows the least influence of the track on the overall noise emission value.

The concept of employing rolling stock noise emissions measurement data, recorded under specified conditions (e.g., test conditions and instrumentation) as input to acoustic modeling codes for the prediction of receiver immission noise levels has also been utilized in other countries, including the UK. The evaluation of noise and vibration impacts of the planned high speed rail line between the West Midlands to Manchester and Leeds, also known as High Speed Two (HS2), employed a three-dimensional approximation of the study area and a railway noise calculation methodology to perform statistical calculations on the resulting receiver noise levels [88] [89].

Summary Regarding TSI and Country/Local Noise Emission Regulations

As noted above, member countries do not currently have the option to adopt regulations that are stricter than those contained in the TSI based on the TSI framework (basic tenant of TSI). The stricter limits imposed earlier by the Netherlands were based on a "voluntary" agreement which was part of a high-speed rail tender for operation, and preceded the current version of the TSI [90]. For trains operating at 250 km/h (155 mph), normalized to 80 km/h (50 mph) (to allow direct comparisons), the following noise emissions limits apply:

- Netherlands requirements stricter than TSI: 75.2–76.9 dB(A); range based on calculation uncertainty.
- TSI HS RST 2002: 77.2–79.9 dB (range based on calculation uncertainty)
- TSI HS RST 2008: 78.2–80.2 dB (range based on calculation uncertainty)
- TSI NOI 2014: 80.2 dB (no allowance provided for calculation uncertainty)

Noise requirements at 250 km/h (155 mph) have not been modified since the TSI regulations were originally put in place. Noise measurements procedures as required by the TSI are defined within ISO 3095.

3.2.3 TSI Infrastructure (2013, 2014)

The TSI for High Speed Infrastructure of 2014 contains regulations that must be addressed when planning and building a high-speed rail line [91] [92]. This TSI also defines interfaces with which train operators and manufacturers can work when designing and specifying rolling stock. The earlier version of TSI Infrastructure (INF TSI 2007) contains one excerpt, quoted here:

> *INF TSI Section 4.2.19 Noise and vibration*
> The environmental impact of the projects concerning the design of a line specially built for high-speed or on the occasion of line upgrading for high-speed shall take into account noise emission characteristics of the trains complying with the High-

> Speed Rolling Stock TSI at their maximum allowed local speed. The study shall also take into account other trains running on the line, the actual track quality (2) and the topological and geographical constraints. The vibration levels expected along new or upgraded infrastructure during the passage of trains complying with the High-Speed Rolling Stock TSI shall not exceed the vibrations levels defined by national rules in application [91].

Thus INF TSI 2007 requires the calculation of rolling stock noise which is limited by the TSI high speed rolling stock. It also implies that local limits for immission should not be exceeded, based on the noise production of rolling stock and the speed for which the line was designed. INF TSI 2007 assumes that rolling stock (and its designed speed) and local or national immission limits are defined and are to be addressed in the design of the high-speed line and its associated noise mitigating measures. INF TSI 2007 was replaced by INF TSI 2014 to mitigate the resulting confusion.

INF TSI now encompasses all infrastructure, thereby eliminating the need for a specific TSI for high speed infrastructure. There is currently no TSI-based noise excerpt related to infrastructure.

3.3 Example Country: Netherlands

The Netherlands and Germany were chosen as specific examples because of variations of population density, size of rail network, recent construction of high speed lines, and public attention to noise. The two countries represent the range of EU Member State experiences with high speed passenger service. The high speed rail network in Germany is established and mature, while the Netherlands is developing its high speed systems. These two countries illustrate different approaches regarding compliance with EU immissions guidelines, with the Netherlands illustrating the strictest regulations.

The Netherlands, located in the northwest of Europe has a population of around 17 million and is densely populated (i.e., 1,055 inhabitants/square mile vs. 85 inhabitants/square mile for the entire US and 251 inhabitants/square mile in California). In the US, only New Jersey is more densely populated with 1,218 inhabitants/square mile. The population of the Netherlands' 10 largest cities range from 825,000 to 170,000. It is topologically flat with about half of the land area at or below sea level within a delta formed by three large rivers. Politically it is a monarchy and a parliamentary democracy. It was a founding member of the EU and as an open economy puts a lot of value in enabling trade and financial services. It has the 17th largest economy and the 10th highest Gross Domestic Product in the world. Administratively, the country is divided in 13 provinces and 393 municipalities [93].

3.3.1 Rail Sector in the Netherlands

Rail transport in the Netherlands started in 1839 with a short line between Amsterdam and Haarlem in the west. Soon afterwards new tracks followed, to Rotterdam, Utrecht, and Arnhem. At one point, it was decided that the State would build the infrastructure, over which private enterprises could transport passengers. From the beginning of the 20th century a consolidation of railway undertakings took place, culminating in the founding of the Nederlandse Spoorwegen ([NS], Dutch Railways—the principal passenger railway operator in the Netherlands) in 1938. NS was (and is) 100 percent State-owned and included also the infrastructure. In the early 1990s, due to legislation from the EU and a changing view on the governance of the rail sector, infrastructure management and rail operation were divided. Infrastructure (management) was seen as a State's responsibility for a new organization (ProRail) [94], whereas rail operation was retained by NS for both passenger and freight. A new development was that not only NS (as the incumbent State-owned operator) could operate passenger- or freight services, but also other companies. The new EU-mandated liberalization of railways started with freight services and led to the selling of NS freight to a third party and a large number of freight operators active in the Netherlands. The liberalization of passenger services led to branch lines being tendered and won by new companies, mostly subsidiaries of German or French State-owned rail operators (Deutsche Bahn and SNCF, respectively). NS still holds the concession for the main lines (Hoofdrailnet), in which the High-Speed Line South (HSL-South) is incorporated. The HSL-South runs from Amsterdam via Rotterdam and Breda to the border, where it connects to the Belgian line to Antwerp and Brussels. It is part of the European high-speed rail network [95] [96].

The Dutch rail network of 3,013 route km (1,872 route miles) is very dense. The network is mostly focused on passenger rail services and connects virtually all major towns and cities. The network is depicted in Figure 12. Trains are frequent, with one or two trains per hour on lesser lines, two to four trains per hour on average, and up to eight trains an hour on the busiest lines [97]. The Amsterdam to Antwerp (Belgium) high speed line was inaugurated during 2009 and has a maximum speed of 300 km/h (199 mph), as shown in Figure 13.

Figure 12: Netherlands Rail Lines Map with Train Speeds[2]

[2] Reference: Holland Dutch rail speed map

Figure 13: Amsterdam to Antwerp High Speed Rail Line[3]

Noise Emissions of Rolling Stock

The emission of rolling stock is governed by the TSI framework, under EU law which is de facto national law.

The sector as a whole accepted a differentiated track access charges scheme: when an operator can demonstrate that they have taken measures to improve noise emissions of their rolling stock, a discount on the calculated track access charges will be granted. This way there is an incentive to operate silent rolling stock. This scheme is valid for all rolling stock operators and was used mostly by freight operators.

Noise Immissions

Because the Netherlands has the obligation to comply with the EU Environmental Directive, noise maps must be prepared and immission sound pressure limits established. Figure 14 shows an example of such map. In the Netherlands, the infrastructure (both rail and road) is divided into three categories: national, provincial, and local, with different jurisdictions attached to each. The core rail network including the HSL-South is categorized as a national network and is subject to national legislation [98].

The current law, with regard to noise, is the Wet Milieubeheer (law for managing the environment), specifically Chapter 11, which was added in 2011 to an already existing law; it is also known as the SWUNG law. Its acronym stands for working together towards a new noise policy [99].

The SWUNG law of 2011 has three pillars on which policies are based:

1. Managing increasing noise nuisances
2. Reducing (too) high nuisance situations
3. Encourage mitigating measures at the source

[3] References: Rijkswaterstaat/Ton Poortvliet and Rijkswaterstaat/Joop van Houdt

Pillar 1 is also the mechanism with which current and future developments on all national infrastructure, both highway and rail, are gauged. To this end 57,000 reference points have been introduced along the infrastructure (for rail: the core network). The noise nuisance in 2008 plus 1.5 dB along the infrastructure has been taken as a base for the so-called Geluidsproductieplafonds (GPP) or Noise Production Ceilings. These GPP are the upper limit for noise immission at that point.

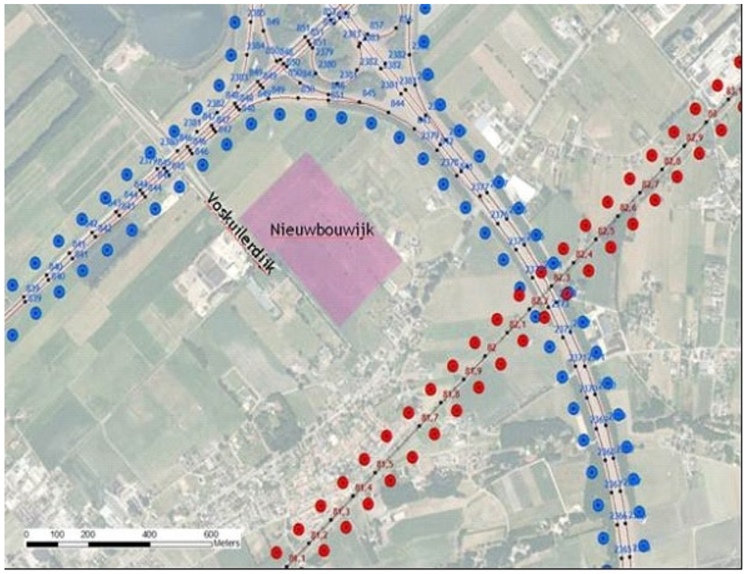

Figure 14: Example Noise Measurement Location Map[4]

The preferred value of these GPPs is 50 dB(A), measured as L_{den}. However, due to grandfather rights and differing environments, most specific preferred values are defined between 50 and 65 dB(A). For points along the rail network the preferred value is 55 dB(A).

The Netherlands national computation method for predicting immission noise levels, published in "Reken en Meetvoorschrift Railverkeerslawaai '96, Ministerie Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, 20 November 1996." This method is referred to as RMR [100] [101].

If there are developments (e.g., more traffic and higher running speeds) that would negatively affect the noise nuisance, these GPPs will still protect the residents from high noise immissions; Figure 15 shows an illustration of the rail noise map. The infrastructure manager has the obligation to do a yearly check on whether there are any reference points where more noise has been produced. If that is the case, then measures can be taken, such as lower speed limits, lower frequency of trains, or attenuation measures in the infrastructure or at residences. In 2014, noise calculations showed that at 0.8 percent of the reference points the GPP were exceeded.

Determining whether limits are exceeded is through calculations rather than measurements for which detailed requirements are defined in the Reken en Meet voorschrift ([RMV], calculation and measurement instructions). To this end all elements of the system—rolling stock, infrastructure, noise mitigating measures, etc.—have reference values attached to them, and together with speed and passing frequency an objective assessment can be done. Other reasons for calculating instead of measuring include the number of reference points, the impossibility of

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[4] Reference: Frank Elbers, dBVision

measuring planned developments and the elimination of other noise sources when assessing a specific piece of infrastructure.

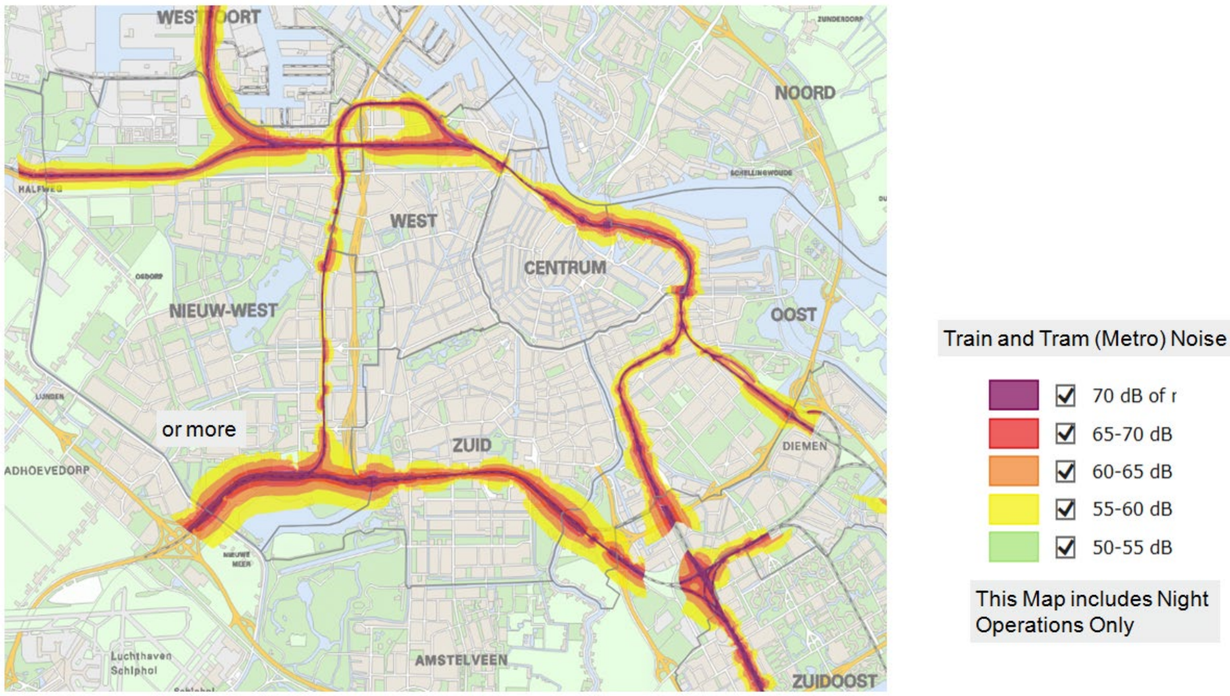

Figure 15: Rail Noise Map of Amsterdam, Calculated Immission Values[5]

When a GPP is exceeded, noise reduction and attenuation methods are required.

Pillar 2 of The SWUNG law of 2011 has to do with remediating undesirable situations that may have arisen in the past. Various measures can be taken to reduce noise levels, ranging from insulating residences to erecting noise barriers.

Pillar 3 involves measures at the source, such as using noise-efficient tarmac for highways or silent brake blocks for freight trains.

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[5] Reference: City of Amsterdam. Noise map 2018.

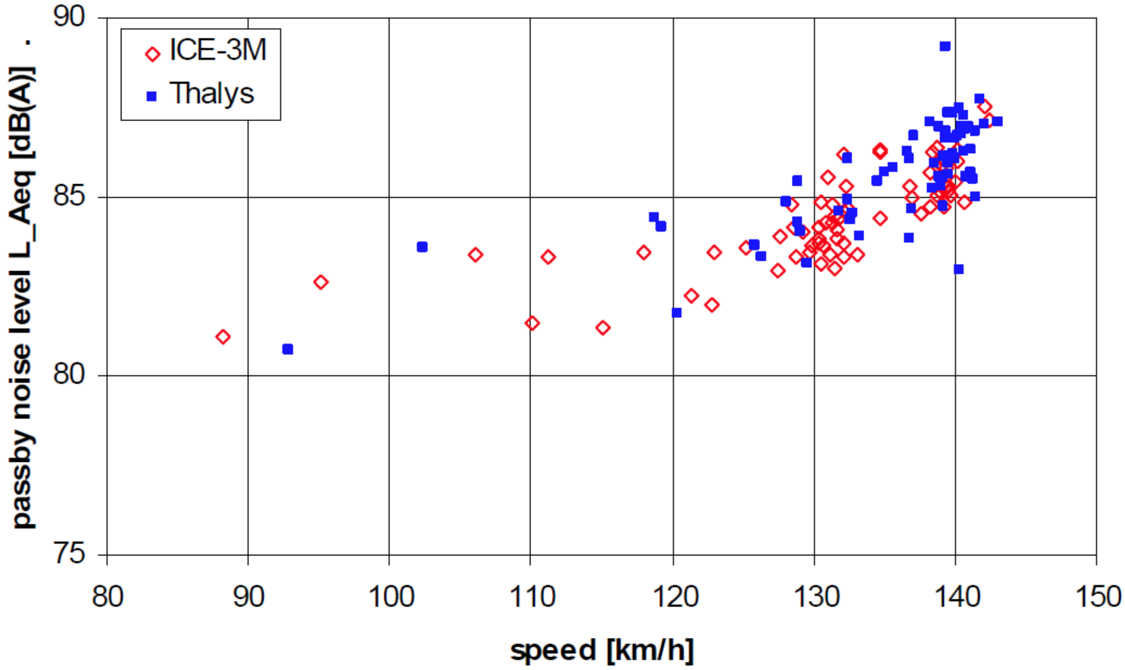


Figure 16: A-Weighted Equivalent Sound Pressure Level of High Speed Trains [101]

The HSL-South

HSL-Zuid (Dutch: Hogesnelheidslijn Zuid, English Translation: High-Speed Line South), is a 125 km-long (78 miles) high-speed railway line in the Netherlands to the Belgian border, with a branch to Breda; see Figure 16 and Figure 17. Together with the Belgian HSL-South 4 it forms the Schiphol–Antwerp high-speed railway. It is a dedicated line for high speed rolling stock, complying with the TSI high speed infrastructure, except for some on- and off ramps around Amsterdam and Rotterdam. It features several tunnels to protect the environment, some elevated sections and several sections that run parallel to existing tracks and/or highways. It has a line speed of 300 km/h (186 mph), is served by 25 kV and has European Train Control Systems (ETCS) as train protection, all per the then-current TSI high speed infrastructure [102]. The line went into service in 2009 after being built between 2000 and 2006.

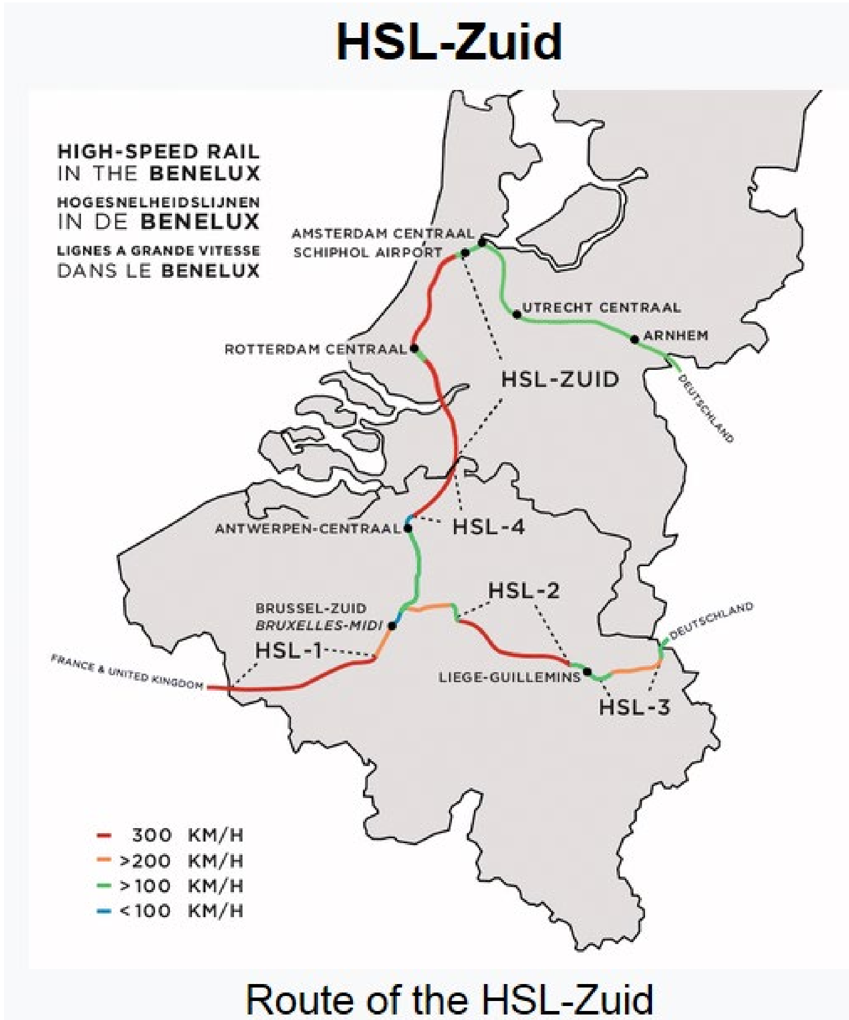


Figure 17: Map of HSL-Zuid (Netherlands) High Speed Rail Line [103]

The noise limits along the HSL-South are defined in the Tracébesluit of 1998, which is the planning document which was decided on by the Government and Parliament [104]. It states that along the HSL a “preferred value” (voorkeurswaarde) of 57 dB(A) as L_{dn} should be regarded as a design requirement, with only limited possibilities to have exceptions with higher limits. This design principle has been adhered by, although there were no specific rules of enforcement defined. Mitigating measures for problem areas included a tunnel, recessed track, and noise barriers. Acoustic grinding would ensure that the slab track would not be noisier than ballast track.

In 2002, in its tender procedure for the railway operator that would bid for the right to operate over the HSL, Infrastructure Interface Requirements had to be defined [105]. One of the aspects defined was the emission levels of rolling stock to be used on the HSL [104]. These values were stricter than those in the then-current draft TSI, in anticipation of gradually lower TSI limits during the tender for operation, and subsequently for rolling stock. It also meant that attenuating measures to mitigate noise exposure (and adhere to the “preferred value”) could be designed using a lower emission value of the rolling stock. The section of the tender document states “Noise emission of rolling stock shall not exceed the values specified in [the] table…for speeds up to service speed." Service speeds not shown in Table 10 were specified to be linearly interpolated. Transient Exposure Level (TEL) [54] is to be measured in accordance with prEN ISO 3095 at 25 m (82 ft.) from the centerline of the track and at a height of 3.5 m (11.5 ft.) above the rail level with full load condition and in the minimal possible operational configuration for normal service [105].

Table 10: Netherlands HSL-Zuid HSR Rolling Stock Maximum Emission Noise Levels [104]

Velocity (k/h)	TEL, dB(A)
300	88
250	85
200	82

The HSL-Zuid rolling stock was designed to meet the defined maximum noise levels, but subsequent in-use testing indicated these maximums had been exceeded, although the train did meet the TSI requirements. No penalties were imposed, however, because unreliability of the train interrupted the legal discussions. In a subsequent tender for rolling stock the stricter Netherlands' requirement was waived because the impact on time and money was too large [106].

Enforcement and Compliance

The HSL-Zuid requirements for noise emission levels was contracted by the operator, NS, to the tender-winning rolling stock manufacturer. The train was designed to comply with this requirement as confirmed by laboratory simulations. However, after being placed in service, the V250 train (manufactured by AnsaldoBreda) was quieter than the then-current TSI requirement, but exceeded the limits as defined by the Infrastructure Interface Requirements. This resulted in legal action between the manufacturer, NS, and the Government of the Netherlands. The manufacturer argued that the limits from the tender were unrealistically low, the State was not inclined to soften the requirement (given also a lot of public outcry about noise along the HSL-Zuid, see Section 3.4) and the operator was caught in the middle. The subsequent failing of that train to become operational interrupted resolution of the issue [107] [108].

Later interviews with potential suppliers of new rolling stock to be used on the HSL-Zuid (albeit at lower speeds) showed that noise emission requirements stricter than the current TSI are very difficult to attain, with a high-risk profile for both time and money. Also, it was argued that the express purpose of the TSI framework is that extra national requirements are prohibited for aspects for which there are TSI limits. Several European agencies agreed with this argument. Ultimately, the stricter limits from the tender were waived (at a cost to the operator) [102] [109].

Prior to 2011 (i.e., the introduction of SWUNG [51]), there was no enforcement mechanism in place for noise immission violations. After 2011, calculations and measurements were made on a regular basis to ensure that the GPPs along the HSL were not exceeded. Given the still fairly low frequency of traffic, the GPPs (i.e., time-dependent values) were, for the most part, within limits. However, there are a few locations where the measurements did not correspond to the calculations. Some noise barriers in practice behaved differently than predicted. This was enhanced by the slab track design of the track, which in practice made reflected noise to predict.

In 2015, € 70 million was made available for remedying those issues. The corrective measures to be taken are currently being evaluated [110] [111].

Public Perceptions HSL-Zuid Rail Noise in the Netherlands

Following the initiation of service on the HSL-South during 2009, negative public perceptions arose regarding train noise immissions, which resulted in formation of community action groups and public protests. Their objections had the following elements [112] [113]:

- The "preferred value" of rolling stock noise emissions was exceeded. Given that there was no enforcement mechanism in place, this led to a lot of criticism.
- The noise barriers did not behave as expected; reflected sound created unpredictable nuisance patterns.
- The rolling stock used while waiting for the delivery of the new high-speed trains was noisier than expected and a lawsuit took place to ban them from service. The lawsuit was not successful; however, the operator still took mitigating measures by improving the brake system to minimize wheel roughness.
- The startle noise of the Thalys trains running at 300 km/h (186 mph) was deemed excessive and also startle noise is not regulated.
- There was a lack of understanding and acceptance of the L_{dn} way of measuring sound immission. For residents, the noise event was a nuisance, not the time in between passages that is also considered with L_{dn}.

There appeared to be a disconnect between regulations and the enforcement mechanisms and the perception of the residents. Due to the complexity of the regulations and noise measurement methods, the discussion became difficult, with the authorities asserting that everything was within limits, and protest groups contesting that claim and mobilizing their local representatives to put pressure on the government to take action [108]. Eventually, the government had to concede that several locations had higher than expected noise levels and proposed mitigating measures in the infrastructure. The government researched several techniques, such as absorbing mats between the rails, rail dampers, and adding absorbing mats to existing noise barriers and small noise barriers between the tracks. The outcome was to implement absorbing mats to existing noise barriers, extend other noise barriers and placing one extra noise barrier. For several reasons (e.g., financial, technical, and contractual), the other measures were considered impractical [114]. With these measures, costing around € 70 million, the protest groups were for the most part appeased [115].

Netherlands High Speed Rail Noise: Lessons Learned

Key lessons learned during implementation of high speed rail projects within the Netherlands include [77] [108] [115] [116]:

Relative to Rolling Stock (Noise Emissions):

- All current rolling stock is designed to comply with TSI noise limits
- Stricter limits imposed by country or State jurisdictions result in economic and implementation time increases

- Compliance to stricter limits in practice is hard to demonstrate due to variations in noise sources (e.g., track roughness), impacts of terrain, and weather conditions on noise measurements
- TSI limits do not address concerns of residents regarding startle noise or curve squeal

Relative to Receivers (Noise Immissions):

- There is a lack of understanding among residents regarding noise metrics, for example, the L_{dn} (day/night) limits and correlation with annoyance levels. Residents are more concerned with conditions that occur during the passby events rather than the time-averaged values over long time periods.
- In general, noise protection through noise production ceilings (i.e., maximum allowable values at reference points) works well
- In practice, noise barriers do not always exhibit the predicted behavior

3.4 Example Country: Germany

The history of the German rail sector started in 1837 with trains operating between Nürnberg and Furth [117]. In 1871, the collection of kingdoms and principalities became one empire, after which the differently owned rail infrastructure was nationalized. Operations were still performed by entities owned by the different States within the country. After World War I, apart from other changes such as a considerable loss of land, all these entities were consolidated into one State-owned company responsible for all aspects of rail transportation within Germany. After World War II, Germany was broken up into two countries, with two rail networks and operators and very limited interaction. In West Germany, this was Deutsche Bundesbahn (DB). This was the time that mass international travel became more prevalent, with significant development in the rail sector [118].

In 1991, service started on the new InterCity Express (ICE) network in West Germany, a network of upgraded existing tracks and some purpose-built high-speed tracks. DB also placed an order for high speed trains at Siemens, with a top speed of 250 km/h (155 mph) and a new, higher service level [118]. Also during the early 1990s, DB joined other EU rail operators in addressing noise emissions [78]. This included development of the Railway Noise Action Plan, which was agreed by the railway umbrella organizations (International Union of Railways [UIC], International Union of Wagon Keepers [UIP], and Community of European Railway [CER]) [78].

In the following years, the network expanded and several new, dedicated high speed tracks were built within Germany. Also, the ICE trainsets were developed further, from both a technical design point (distributed traction) and top-speed target. The current InterCity Express 3 (ICE3) trainsets have a top speed of 330 km/h, or 205 mph. The holding company, DB AG, is responsible for both infrastructure (DB Netz) and operations (DB Fernverker). Maximum train speeds vary across the various routes. Several lines are shared with freight operations, with freight trains using the tracks during the night. Connections to other countries were completed during 2000 in the Netherlands), and 2007 in France [119].

In the meantime, some other developments had influence on the German rail system:

- The integration of the East-German network after reunification

- The mandatory division of infrastructure and operatorship as required by the EU

With Berlin becoming capital of the unified German republic, located in the former East Germany, good connections to the rest of the country were necessary; in 1998 the new Berlin – Hannover high speed line was opened, see Figure 18 [118].

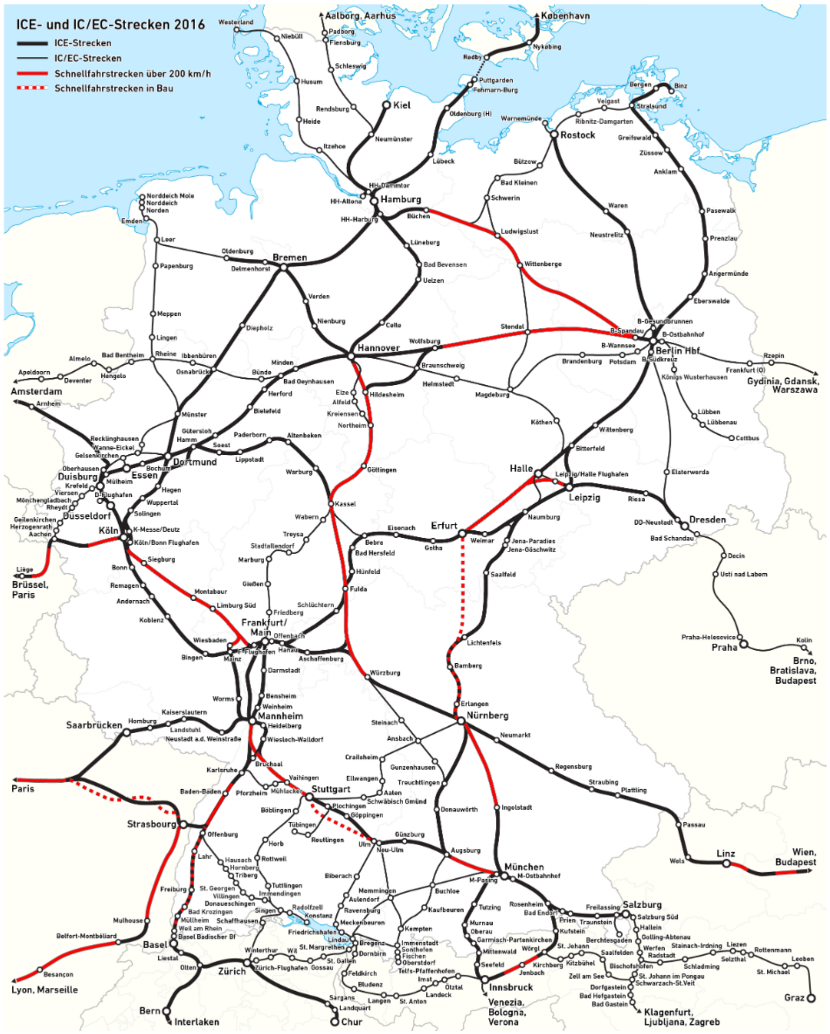


Figure 18: German High-Speed Rail Network[6]

3.4.1 Noise Legislation: Emissions from Rolling Stock

As with the Netherlands and other European countries, the noise emissions of rolling stock are governed by the EU TSI Noise as part of the TSI Framework. There is no record of Germany imposing stricter emission limits on rolling stock, be it high speed or other.

[6] Reference: Maximilian Dörrbecker under CCBY-SA 2.5

3.4.2 Noise Legislation: Immissions

As with the Netherlands, noise immission regulations are source independent and deal principally with identification of authorities have the jurisdiction to assess the noise levels adjacent to the train routes.

According to the EU Environmental Noise Directive, Germany also has the obligation to develop noise maps and noise action plans. The legislation Germany has enacted to this end is the Bundes-Immissionsschutzgesetz (BImSchG), translated as the Federal Immissions Protection Act. It states, in paragraphs 47 a–f that the competent authorities have the obligation to draw up noise maps and make noise action plans, as well as inform the public, thus putting the obligations and intent of the EU Environmental Noise Directive into national law.[7] In it, the competent authority for the drawing up of noise maps along the national rail network is the Eisenbahn Bundesamt (EBA), the Federal Rail Agency. The competent authorities to make noise action plans are according to the law the municipalities or the provincial authorities (Länder) [120].

The results of the noise maps are presented as L_{den} and L_{night} and include a statistical analysis of the number of people impacted. They can be accessed from the EBA website [121]]. The EBA also distributes its findings to the authorities charged with developing the noise action plans, as input for their planning process. The data along major train routes are summarized by Geoportal, Germany [122]. Figure 19 shows an example noise map for track running through Dülmen.

[7] Reference: Geoportal.de image.

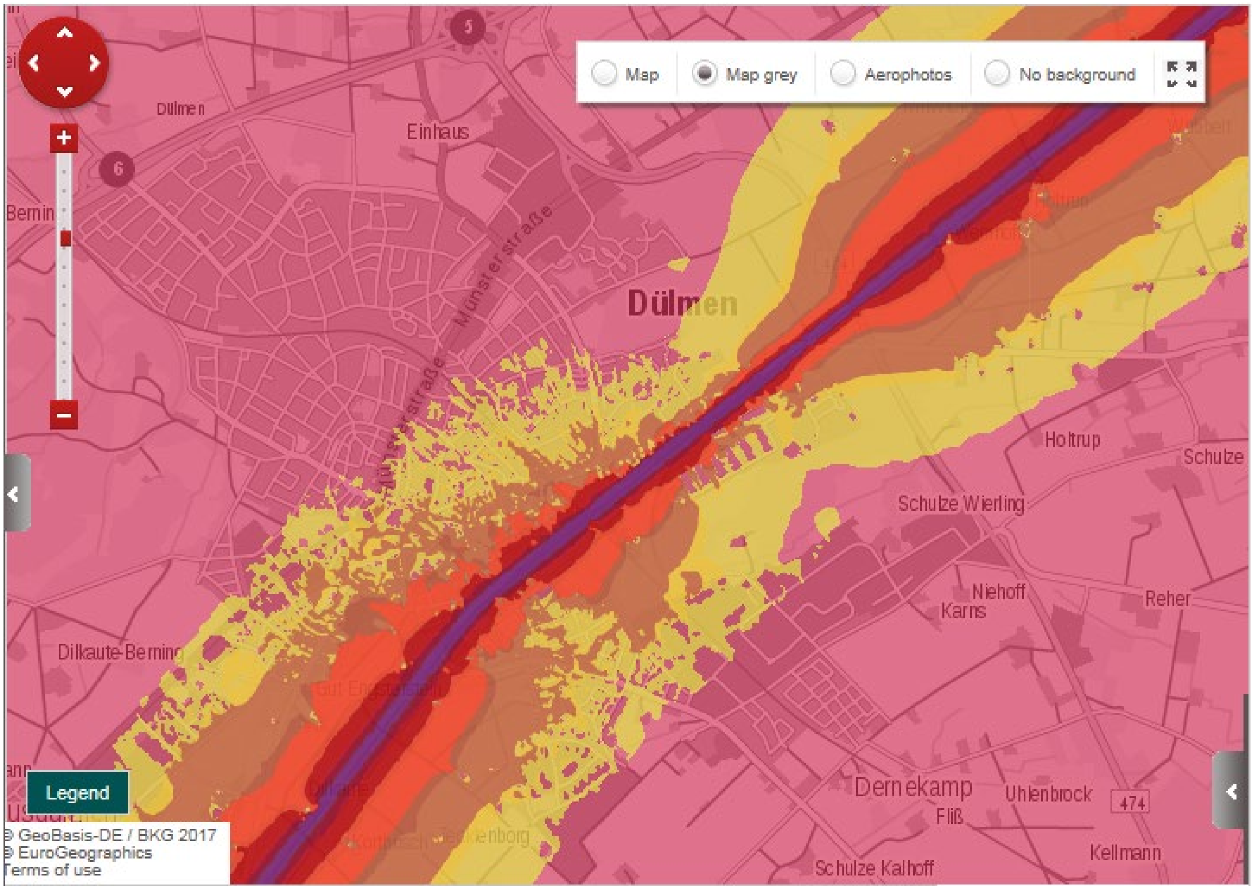


Figure 19: Example Noise Map, Dülmen, Germany (see footnote #7)

There are detailed requirements for the noise maps with regard to calculation methods and criteria for incorporating local circumstances; for instance, there is a factor to be taken into consideration if there are wooded areas between the source and the resident (paragraph 7.6 of Berechnungsverfahren für den Umgebungslärm Schienenwegen (VBUSch)—Calculation method for environmental noise of tracks).[8] These noise maps are made for national tracks on which more than 30,000 train movements per year are realized as well as in agglomerations of more than 100,000 inhabitants [123]. The total length of track along which noise maps have been made is 14,000 km (8,700 miles) [121]. Table 11 shows an example of the summary data collected by EBA [121]:

[8] Reference: Bundesanzeiger

Table 11: Example Noise Exposure Compiled by EBA (Germany)

BL	Reporting Entity Unique Code Kennung der berichtenden Behörde	Numbers of people Exposed to Lden 55-59 outside agglomerations Anzahl Belasteter LDEN >55≤60 (außerhalb Ballungsräume)	Numbers of people Exposed to Lden 60-64 outside agglomerations Anzahl Belasteter LDEN >60≤65 (außerhalb Ballungsräume)	Numbers of people Exposed to Lden 65-69 outside agglomerations Anzahl Belasteter LDEN >65≤70 (außerhalb Ballungsräume)	Numbers of people Exposed to Lden 70-74 outside agglomerations Anzahl Belasteter LDEN >70≤75 (außerhalb Ballungsräume)
BRD	DE_BR	1,774,100	737,700	264,400	110,300
BB	DE_BR	44,800	14,300	6,400	2,700
BE	DE_BR	200	100	100	100
BW	DE_BR	282,800	125,900	42,000	15,300
BY	DE_BR	334,500	137,800	51,100	21,000
HB	DE_BR	0	0	0	0
HE	DE_BR	278,200	113,400	36,100	14,700
HH	DE_BR	400	100	0	100
MV	DE_BR	7,700	2,900	1,400	900
NI	DE_BR	234,300	109,900	34,000	13,300
NW	DE_BR	282,400	112,500	42,800	18,000
RP	DE_BR	118,900	55,300	22,100	11,500
SH	DE_BR	35,500	15,600	7,100	2,700
SL	DE_BR	20,200	6,700	2,800	1,300
SN	DE_BR	49,400	16,300	6,700	2,700
ST	DE_BR	46,600	13,200	5,100	2,500
TH	DE_BR	38,200	13,700	6,700	3,500

Figure 20 shows another noise map, for rail operations near Oberhausen, Germany. The map was generated using software developed to meet the European Noise Directive requirements for Germany [124], where the purple areas near the tracks represent sound pressure levels, L_{den}, greater than 75 dB(A) and yellow represents L_{den} between 55 and 59 dB(A).

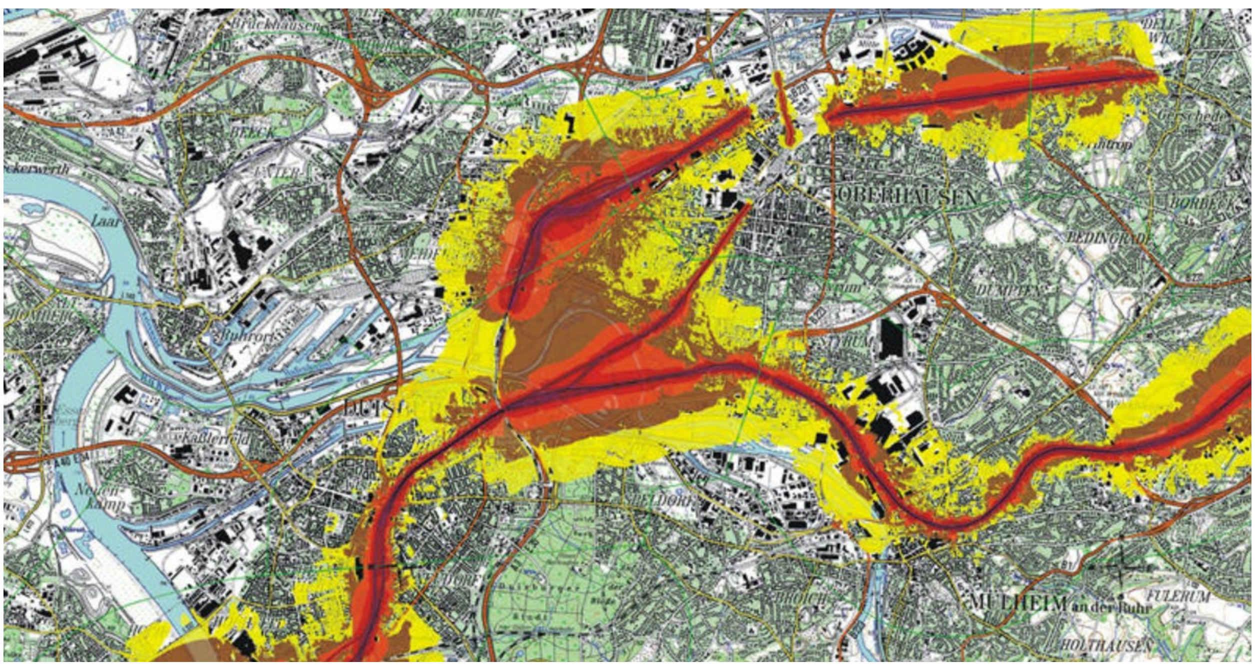


Figure 20: Calculated Rail Noise Levels near Oberhausen, Germany

From the German Federal Immissions Protection Act (BImSchG) also stems the obligation to assess the noise impact of newly planned or significantly altered rail infrastructure. The Verkehrslärmschutzverordnung (Traffic Noise Protection Act – 16. BImSchV) defines maximum noise values and the manner in which these values should be calculated. The technical manual

(Technische Anleitung) for the Traffic Noise Protection Act is known as TA Lärm) [125]. The definition for significantly altered rail infrastructure in this context is as follows: 1) when a new track is added to an existing alignment; or 2) when due to a significant construction change the projected calculated noise level would rise by 3 dB(A) or exceed 70 dB(A) (day) or 60 dB(A) (night). It is important to note that line speed increases due to changes in train control systems, changes of frequency of traffic, or changes in rolling stock are not considered significant construction changes [125] [126].

If projected noise levels of this new or significantly altered rail infrastructure would exceed the following limits, corrective measures would have to be taken [125]:

Table 12: Maximum Noise Levels per German Noise Protection Act

Location	Maximum Daytime Noise Level, dB(A)	Maximum Nighttime Noise Level, dB(A)
Hospitals, Schools, Spas	57	47
Residential	59	49
Cities, Mixed Areas	64	54
Industrial Areas	69	59

Measures to be taken can include acoustic barriers and source noise reduction, but also passive measures at the receiver's end, such as insulating windows and walls. The measures need to be such that when implemented, the maximum limits shown in Table 12 are achieved.

Detailed requirements for calculations are found in Appendix 2 of the Traffic Noise Protection Act. This appendix also defines acoustic characteristics of possible infrastructure elements, such as bridges, tracks, noise barriers, and vegetation. It also includes the acoustic appraisal of characteristics of rolling stock. With all these elements and the frequency of traffic projected a noise level expectation can be assessed [125].

The Traffic Noise Protection Act does not apply to existing rail infrastructure. Since 1999, the German Federal Government has managed a program to alleviate the noise impact on buildings and residents along existing rail infrastructure. This is a voluntary program with a budget of €150 million per year (2016 value—it started with €50 million in 1999) and an expected total expenditure of € 2.5 billion. Together with Deutsche Bahn, 3,700 kilometers of existing tracks had been designated for noise mitigating measures. The total amount of time taken for these measures has not been defined but is dependent on the yearly budget allocation [127].

The regulation requires the worst situations, where noise levels are extremely high and a high number of residents are impacted, to be addressed prior to others. Measures are to be defined that ensure the limits shown in Table 13 are not exceeded. Note that the levels are calculated based on known rolling stock emissions (not measured). The measures that can be taken are either active–at the source, like on-board covers and shields, acoustic grinding of tracks, rail dampers—or passive—at the receiver, like insulating glass and other noise insulation, or a combination of active and passive measures. Generally, decisions are based on cost-benefit analyses. Future operational conditions, such as increase rail traffic, are not taken into account for these calculations. The German traffic department together with the infrastructure provider DB Netz AG is responsible for the execution of this program [127] [128] [129].

Table 13: Deutsche Bahn Immission Noise Mitigation Targets

Location	Maximum Daytime Noise Level, dB(A)	Maximum Nighttime Noise Level, dB(A)
Hospitals, Schools, Spas, Residential Areas	67	57
Cities, Mixed Areas	69	59
Industrial Areas	72	62

Source: BMVI [130] according to explanatory notes to the Federal Budget Plan Epl 12 Chapter 1202 Title 891 05

At the end of 2015, approximately 40 percent (1,500 kilometers) of the 3,700 kilometers of existing tracks eligible for noise mitigation measures were brought into compliance [130] [131].

3.4.3 Public Perceptions High-Speed Rail Noise in Germany

Compared to the Netherlands, German high-speed rail lines occupy more rural locations with fewer segments in high-population density areas. Noise pollution is a theme, but mostly targeted at freight trains and/or metropolitan areas and specific developments, such as the project around Stuttgart, known as Stuttgart21 [132] [133]. For instance, the Rhine valley between Bonn and Koblenz, which is a UN World Heritage Site, used to be a passenger intercity thoroughfare connecting Cologne with Frankfurt. After the so-called Neubaustrecke (i.e., newly built dedicated high-speed track) between Cologne and Frankfurt was built, passenger rail was limited to regional trains connecting the villages along the Rhine. The reduced passenger use of the local line made way for an increase in freight trains, and due to an increase in trade and capacity north and south of the valley, it became a bottle neck with levels of traffic that according to the inhabitants threatened their well-being [134].

3.5 Compare and Contrast Measurement and Compliance

Comparisons of emission and immission regulations within the EU, as represented by Germany and the Netherlands are shown in Table 14. The table includes compliance practices, but omits measurement procedures. Immissions levels are calculated based upon the measured emissions values and are the source of noise maps required by the European Noise Directive. Freight rolling stock is the current primary source of railroad noise and is the key target of EU noise regulations.

Table 14: Comparison of Compliance Practices, Netherlands & Germany

Aspect	Germany	Netherlands	Comments
Rolling Stock (Emission):			
TSI Limits	x	x	
Stricter national limits than TSI		x	Attempted; but since waived as unattainable
Criterion for admittance (acceptance)	x	x	Access to rail
Incentive for improvements	x	x	Mostly targeted at freight
Receivers (Immission):			
High speed rail specific			Source-independent limits
EU limits	x	x	European Noise Directive
Noise maps & action plans	x	x	Required updates every 5 years
Compliance check yearly		x	
New or altered infrastructure	x	x	
Existing infrastructure		x	Germany: only voluntary measure if limit exceeded
Enforcement by infrastructure manager		x	
Enforcement by government	x		

Noise measurement procedures for the EU, as well as several other countries, are defined in the International Standards Organization (ISO) Publication 3095 [40]. The following portions of the report abstract provide a good overview of the defined procedures and applications.

> ISO 3095:2013 specifies measurement methods and conditions to obtain reproducible and comparable exterior noise emission levels and spectra for all kinds of vehicles operating on rails or other types of fixed track, hereinafter conventionally called "unit."
>
> ISO 3095:2013 is applicable to type testing of units. It does not include all the instructions to characterize the noise emission of the other infrastructure related sources (e.g., bridges, crossings, switching, impact noise, curving noise, etc.).
>
> ISO 3095:2013 is not applicable to:
>
> - Noise emission of track maintenance units while working
> - Environmental impact assessment
> - Noise emission assessment
> - Guided buses
> - Warning signal noise
>
> The results may be used, for example:
>
> - To characterize the exterior noise emitted by units

- To compare the noise emission of various units on a particular track section
- To collect basic source data for units

3.6 Compare and Contrast EU Best Practices

Based on the evaluation of noise regulations within the EU, the following list of best practices has been assembled [135]. These are deemed appropriate for countries considering noise regulations for high speed rail.

Rolling Stock (Emissions):

- Apply TSI Noise limits (or equivalent), which provide:
  - Objective and clearly defined limits (pass/fail), subject to acceptable measurement and calculation procedures
  - Large experience base, wide range of application across many countries, and well-known in rail industry
- High speed passenger trains should operate on dedicated infrastructure to maintain track quality [18].
- Incentivize voluntary improvements to facilitate implementation, examples include:
  - For train operators: lower track access charges where applicable, or reduced tariffs
  - For rolling stock manufacturers: flexibility in defining required noise performance (as options in procurement documents), including better-than-regulations require in anticipation of future rule making.

Receivers (Immissions)

- Provide clear and transparent legislation (source independent), with objective, well-defined noise limits supported by acceptable measurement and calculation procedures.
- Provide clear definition of which AHJs are responsible for compliance and enforcement
- Well defined consequences (penalties) for noncompliance
- Identifies procedures and timelines for periodical verification of compliance
- Provides procedures to follow should in-use noise performance differ from calculations and laboratory/development results.

UIC and CER initiated studies during 2007 and 2013 to evaluate the cost effectiveness of rail noise reduction methods and develop sustainable low noise technologies [136] [137]. In addition, the European Parliament has published a report on approaches to reducing railway noise pollution [90]. These are discussed in more detail in Section 6. Although the focus of the studies was reduction of noise from freight trains, some key conclusions from these studies, applicable to high speed rail, are:

- Key source noise (emissions) reduction methods include rail grinding, rail dampers, improved brakes (freight rolling stock), resilient wheels, and wheel dampers (tuned absorbers). For high speed rail, aerodynamic modifications are recommended, including pantograph barriers and shields, inter-car gap fillers, wheel truck (bogie) covers, and attached-flow forebody designs. For high-speed trains, pantographs and the leading wheel truck have been identified as the two primary sources of aerodynamic noise.

- All EU countries included in the study apply noise protection (receiver immissions) measures as defined by the European Noise Directive.
    - In Northern Europe, the preferred approach is to provide noise insulation at receivers.
    - In Southern Europe, the favored method is erection of noise barriers.
    - Central Europe employs a combination of building noise insulation and barriers.

3.6.1 *Summary of EU High Speed Rolling Stock Passby Noise Standards*

The applicable portions of the 2008 and 2014 versions of the EU TSI are summarized in Table 15. It is noted that both versions of the TSI contain emission noise limits that vary with train speed.

Table 15: Summary of TSI Limits on High Speed Train Passby Noise Emissions

TSI Version	Region	Applies to	Speed (km/h)	Noise Source	Noise Limit A weighted sound level, dB(A)	Noise Metric	Measurement Location
TSI HS RST 2008 (superseded by TSI Noise 2014)[1]	EU	High speed rolling stock variable formation	200	Pass by	88	$L_{pAeq,Tp}$	25 m, 3.5 m above top of rail
TSI HS RST 2008 (superseded by TSI Noise 2014)[1]	EU	High speed rolling stock trainsets	250	Pass by	87	$L_{pAeq,Tp}$	25 m, 3.5 m above top of rail
			300	Pass by	91	$L_{pAeq,Tp}$	25 m, 3.5 m above top of rail
			320	Pass by	92	$L_{pAeq,Tp}$	25 m, 3.5 m above top of rail
TSI Noise 2014[2]	EU	Locomotives and on track machines (OTMs) electrical traction	80	Pass by	84	$L_{pAeq,Tp}$	7.5 m, 1.2 m above top of rail; speeds >250 km/h also 3.5 m above top of rail
			250	Pass by	99		
		Electric Multiple Units (EMU's)	80	Pass by	80		
			250	Pass by	95		
		Diesel Multiple Units (DMU's)	80	Pass by	81		
			250	Pass by	96		

[1]High Speed Rolling Stock portion of TSI Noise 2014

[2]Portions of TSI NOI reference TSI HS RST 2008; for example: 7.1.1.6. Transitional measure for noise requirements, however, the EU has verified that TSI HS RST 2008 has been superseded by TSI NOI [138].

Figure 21 shows an e-mail from Hubert LaVogiez of the ERA that provides clarification regarding revised TSI Locomotive & Passenger 2005 and TSI NOI relative to earlier versions of the TSI.

From: LAVOGIEZ Hubert (ERA)
Sent: Friday, December 19, 2014 1:28 PM
To: René Scholtes
Cc: DIMITROVA Desislava (ERA); Ainhoa.SAN-MARTIN@ec.europa.eu; Piotr Rapacz; Amelia.AREIAS@ec.europa.eu; MESTRE Pedro (ERA); MARTOS Oscar (ERA); GIGANTINO Anna; SCHIRMER Andreas (ERA)
Subject: Application of revised TSIs LOC&PAS and Noise - Answer to NSA LU

Dear René,

Following your analysis of TSIs published on 12 / 12 / 2014, we can bring the following information:

The revised TSIs LOC&PAS and Noise have been prepared to allow an adoption, publication and entry into force of the TSI NOISE at a differed date, according to its original planning of development and to its planning of presentation to vote in the RISC.
You can note that the date of adoption of the TSI noise (26/11/2014) is effectively differed compared to the date of adoption of the TSI LOC&PAS (18/11/2014).
The possibility to have both TSIs published at the same date was anyway analysed and we concluded that both texts are suitable in that case for the following reasons:

- The **scope of the revised TSI Noise** as specified in its article 2 mentions the revised TSI LOC&PAS and the TSI WAG; it is clear that this TSI **covers all types of rolling stock**.
  The whereas (2) of this TSI also clearly mentions the merging the noise requirements for high-speed and conventional rolling stock.
  The whereas (10) mentions the need for an amendment of the HS RST TSI 2008; this amendment is specified in article 9 (points related to noise deleted).

- The clause 7.1.1.6 of the revised TSI LOC&PAS "Transitional measure for noise requirements specified in the HS RST TSI 2008" is applicable until a revised **TSI Noise covering all types of rolling stock** is applicable.
  This is the case from 01/01/2015 according to the point above.

We will ensure that the new ERA webpage related to the TSIs applicable from 01 / 01 / 2015 is presented in a way to avoid any misunderstanding regarding their scope of application.
Please take note that this page may be modified in January 2015 (after its first introduction)) for that purpose.

We hope having answered your concern and wish you a merry Christmas.

Best regards

Hubert LAVOGIEZ
ERA RST Sector
Tel 33 3 27 09 65 46

Note: this answer will be also forwarded to member of the XA WP.

Figure 21: E-mail from Hubert LaVogiez of the ERA

Table 16 outlines the applications and jurisdictions of the EU emissions, immissions, and measurement requirements.

Table 16: Summary of EU Codes, Standards, and Regulations

Code / Regulation	Origin	Source: Rolling Stock	Receivers	High Speed Specific	International (EU)	National	Local
Noise Sources: Rolling Stock							
TSI Noise 2014[1]	EU	x		x	x	x	x
TSI HS RST[1] (High Speed Rolling Stock) 2008	EU	x		x	x	x	x
TSI Infrastructure[1] 2008	EU			x	x	x	x
Noise Receivers: Residents							
EU Environmental Noise Directive 2002	EU		x		x	x	x
Verkehrslärmschutzverordnung[2]	DE		x			x	x
Wet Milieubeheer Swung[3]	NL		x			x	x
Measurement Procedures							
EN 3095[4]	EU	x			x	x	x

[1]The EU TSI includes noise regulations for both rolling stock and infrastructure

[2]German traffic noise ordinance (includes rail noise)

[3]Dutch environmental management act, includes noise limits

[4]Measurement procedures, locations, and conditions are defined in EN ISO 3095:2013, as referenced by the emission and immission codes

3.6.2 Standardized Format for Identified Codes, Standards, & Regulations

A standardized format was developed for summarizing identified codes, standards, and regulations. The basic format is shown in Table 17 and contains the following primary sections:

1. Identifying information, including name of the code, standard, regulation or recommended practice, reference number, reference designation, date of issue, authorizing/issuing agency, and geographical coverage (i.e., US and EU)
2. Applicability categories (i.e., infrastructure, rolling stock, emissions, immissions, subsystems, stations, mitigation, verification procedures, and measurement)
3. Description: general description including key sections and requirements
4. Subcategories for noise (i.e., stationary noise, starting noise, passby noise, and driver's cab interior noise) and measurement (i.e., instrumentation, location, procedure, and test conditions)
5. Key insights and best practices: includes key and unique components of the code, standard, regulation or best practice, as well as identified best practices.
6. References: identifies sources and links to code, standard, regulation or recommended practices, and in some cases, key commentary/interpretation documents.

Table 17: Standardized Regulations Summary Form

Name	Name of Code, Standard, Regulation, or Recommended Practice	Code	Reference Number, Reference Designation	Date of Issue	
Authorising / issuing agency				Geographical coverage	

Applicability								
Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
	✓	✓		✓			✓	✓

Description
General Description of the Code, Standard, Regulation or Recommended Practice, including Key Sections and Requirements

Noise Subcategories (Categories for Applicability and Noise Subcategories Vary for Emissions and Immissions Entries)			
Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise
✓	✓	✓	✓
Measurement Subcategories			
Instrumentation	Location	Procedure	Test Conditions

Key take-outs / Best practice
Key Components of the Code, Standard, or Recommended Practice

References
References and Links to Original Documents Employed in Preparing Summary

3.6.3 EU Codes, Standards, Regulations, and Best Practices

Table 18 through Table 26 summarizes EU codes, standards, regulations, and best practices.

Table 18: TSI Noise 2014

Name	TSI Noise 2014	**Code**	TSI NOI	**Date of Issue**	2014
Authorising / issuing agency	European Union – European Railway Agency ERA			**Geographical coverage**	EU

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
	✓	✓		✓			✓	✓

Description

Noise sets noise limitations on rail for:

- Limits for stationary noise
- Limits for starting noise
- Limits for pass-by noise
- Limits for the driver's cab interior noise
- Modules
- EC verification (calculations and normalized) of subsystems: normalized value is used for pass/fail assessment for TSI compliance.
- Test track conditions
- Procedures
- High speed railway

These limits are binding requirements for admitting rolling stock.

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise
✓	✓	✓	✓

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions

Key take-outs / Best practice

Noise is measured at 7.5m from centerline of track at 1.2m above top of rail, and for speeds > 250 km/h the pass-by noise limit is at 95 (dB) normalised to 250 km/h.

References

TSI NOI 2014
Test conditions: EN ISO 3095/2013

Table 19: TSI Locomotive & Passenger 2015

Name	TSI Loc&Pas 2015	**Code**	TSI Loc&Pas	**Date of Issue**	2015
Authorising / issuing agency	European Union – European Railway Agency ERA			**Geographical coverage**	EU

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
	✓			✓				

Description

Reference is made to the TSI Noi 2014 and the TSI HS RTS. The TSI Noise sets noise limitations on rail for:

- Limits for stationary noise
- Limits for starting noise
- Limits for pass-by noise
- Limits for the driver's cab interior noise
- Modules
- EC verification of subsystems
- Test track conditions
- Procedures
- High speed railway

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise
			✓

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions

Key take-outs / Best practice

The maximum noise level allowed in the cab is specified in the TSI Noise.

References

TSI Loc&Pas 2015
TSI Noise 2014

Table 20: TSI for High Speed Rolling Stock

Name	TSI High Speed Rolling Stock	Code	TSI HS RST	Date of Issue	2008
Authorising / issuing agency	European Union – European Railway Agency ERA			Geographical coverage	EU

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
	✓	✓		✓				

Description

General definition of standards for high speed rolling stock. For noise:

- Start up noise
- Stationary noise
- Pass by noise
- Driver's cab noise

This TSI has been repealed by the TSI Loc & Pas 2015 and TSI Noise 2014. However, this has been a design parameter for most existing high speed rolling stock.

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise
✓	✓	✓	✓

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions

Key take-outs / Best practice

Noise limits for speeds from 200 km/h up until 320 km/h. Noise is measured at 25m from centreline of track at 3.5m above top of rail. Limits pass-by noise at 250 km/h is 87 dB(A)

References

TSI HS RST 2008

Table 21: TSI Infrastructure 2008

Name	TSI Infrastructure 2008	**Code**	TSI INF	**Date of Issue**	2008
Authorising / issuing agency	European Union – European Railway Agency ERA			**Geographical coverage**	EU

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
✓	✓			✓				

Description

In a previous version of TSI:

- Calculate with rolling stock noise characteristics in line with TSI High Speed Rolling Stock
- With regard to vibrations: Should be in line with local regulations

In current TSI no noise paragraph

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise

Measurement Subcategories

Current Version of TSI INF does not include rolling stock noise characteristics

Instrumentation	Location	Procedure	Test Conditions

Key take-outs / Best practice

Rationale is that rolling stock adheres to TSI Noise and immission limits are defined by Member States.

References

TSI INF 2008

Table 22: EN ISO 3095 Noise Measurement Procedures

Name	EN ISO 3095	**Code**	EN ISO 3095	**Date of Issue**	2013
Authorising / issuing agency	European Union – European Railway Agency ERA			**Geographical coverage**	EU

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
	✓	✓						✓

Description

Sets:

- Environmental conditions
- Track conditions
- Vehicle conditions
- Measurements positions
- Test procedures

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise
✓	✓	✓	✓

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions
✓		✓	✓

Key take-outs / Best practice

Each measurement position shall be located at a distance of 7,5 m from the centerline of the track at a height of 1,2 m above the upper surface of the rail.

References

EN ISO 3095 2013

Table 23: Netherlands Environmental Management Law (SWUNG)

Name	Wet Milieubeheer – Environment management law Swung I 2012			**Code**	Swung		**Date of Issue**	2012
Authorising / issuing agency	Dutch government						**Geographical coverage**	NL
Applicability								
Infrastructure	**Rolling Stock**	**Emission**	**Immission**	**Subsystems**	**Stations**	**Mitigation**	**EC Verification Procedures**	**Measurement**
✓		✓	✓					

Description
Dutch law governing immission limits as required by EU Environmental Noise Directive. Sets: • Noise production • Noise pollution • Noise production ceiling • Need for mitigating measures • Enforcement mechanism • Infrastructure manager defined as enforcer

Noise Subcategories			
Stationary Noise	**Starting Noise**	**Pass-by Noise**	**Driver's Cab Interior Noise**

Measurement Subcategories			
Instrumentation	**Location**	**Procedure**	**Test Conditions**
	✓	✓	

Key take-outs / Best practice
Yearly compliance check on noise production ceiling by infrastructure manager. Mitigating measures obligatory if limits are exceeded

References
Wetten.nl - Regeling - Wet milieubeheer - hst 11 SWUNG EU Environmental Noise Directive

Table 24: EU Environmental Noise Directive

Name	EU Environmental Noise Directive	**Code**	ERO	**Date of Issue**	2012
Authorising / issuing agency	European Union			**Geographical coverage**	EU

Applicability								
Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
✓			✓					

Description

The Directive does not set limit or target values, nor does it prescribe the measures to be included in the action plans, leaving those issues at the discretion of the competent Member State authorities.
Its targets:

- the determination of exposure to environmental noise
- ensuring that information on environmental noise and its effects is made available to the public
- preventing and reducing environmental noise where necessary and preserving environmental noise quality where it is good

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise

Refers to any noise source

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions

Includes directive for member countries to establish action plans.

Key take-outs / Best practice

The Directive requires Member States to prepare and publish, every 5 years, noise maps and noise management action plans.

References

ec.europa.eu/environment/noise/directive
Directive 2002/49/EC

Table 25: German Traffic Noise Protection Act (see footnote #7)[9]

Name	Verkehrslärmschutzverordnung (Traffic Noise Protection Act)	Code	16 BImSchV	Date of Issue	1990
Authorising / issuing agency	German government			Geographical coverage	Germany

Applicability								
Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
✓			✓					

Description

German law governing immission limits as required by EU Environmental Noise Directive.

For new or altered infrastructure and for the altering of an operation.
Technical guideline concerning the protection against noise.
Enforced by German government as part of planning and admittance process.

Immission levels are calculated based on rolling stock emissions measurements (as required for TSI compliance).

Noise Subcategories			
Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise
Refers to any noise source			

Measurement Subcategories			
Instrumentation	Location	Procedure	Test Conditions
	Immission Levels are Calculated		

Key take-outs / Best practice

Levels are calculated and not measured

References

www.umweltbundesamt.de
https://www.gesetze-im-internet.de/bundesrecht/bimschv_16/gesamt.pdf

[9] Reference: Unwelt Bundesamt

Table 26: German Technical Manual for Noise Protection (see footnote #9)

Name	Technische Anleitung zum Schutz gegen Lärm (Technical Instructions for Noise Protection)	**Code**	TA Lärm	**Date of Issue**	1998
Authorising / issuing agency	German Government			**Geographical coverage**	Germany

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
✓			✓	✓				✓

Description

This regulation defines the following :

- Limits for day and night immissions in existing situations
- Mitigation measures of a certain limit is exceeded on a voluntary level for German government.

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise

Refers to any noise source

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions

Does not include measurement specifications

Key take-outs / Best practice

Clear limits, but no "hard" consequences if levels are exceeded

References

TA Lärm
www.umweltbundesamt.de

4. Asian Codes, Standards, Regulations, and Recommended Practices

High speed rail systems are well established in both China and Japan and operate through urban and rural areas. Information available from these countries can provide insights into public expectations for noise regulations and best practices to ensure noise compliance.

China has the world's longest high-speed rail network with over 9,900 miles (16,000 km) of track. It also has the world's longest rail line from Beijing to Guangzhou at 1,428 miles (2,300 km) with a maximum operating speed of 220 mph (350 km/h) (see Figure 22 and Figure 23) [139] [140].

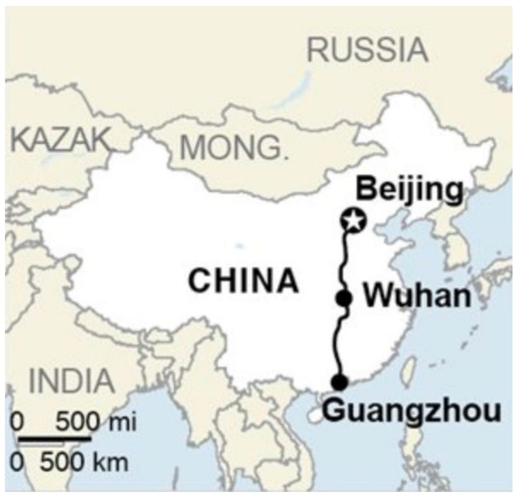


Figure 22: High Speed Rail Line between Beijing and Guangzhou, China[10]

Figure 23: China G802 High Speed Train [139]

[10] Reference: ESRI; Legislative Council of Hong Kong

The Shinkansen (English translation "new trunk line") high speed train in Japan began operation during 1964 and has an average daily passenger ridership of over 424,000 [141]. Maximum operating speed is 285 km/hour (177 mph). During April 2016, the Central Japan Railway Company set a new train world speed record of 375 mph (603 km/h) during test runs for the magnetic-levitation train line planned to operate between Tokyo and Nagoya [142].

The Shinkansen track is continuous welded rail with a combination of ballast and slab track [143]. The minimum radius of curves is 4,000 m (2,485 ft.) [144].

Train aerodynamics and noise issues have been under continuous development since the launch of the first Shinkansen train. This includes reduction of noise sources (emissions) along the lower body, upper body (including the nose), pantographs, and inter-car gaps. Lower body noise sources include rolling noise (i.e., wheel/rail interaction), equipment noise (i.e., running gear), and aerodynamic noise near the wheel trucks. Pantograph noise originates with both aerodynamics and sparking noise [145].

4.1 China High Speed Rail Noise Codes, Standards, Regulations, and Best Practices

Most of China's 70,000 km (43,500 miles) of rail lines are located in the eastern provinces. The main trunk lines are Beijing-Shanghai, Beijing-Guangzhou, Xian-Shanghai, and Shanghai-Zhuzhou. Surveys indicate noise levels for cities with high speed rail lines are higher than those for other Chinese cities [146].

Recent increases in rail traffic within China have resulted in an increase of noise levels adjacent to rail lines (L_{Aeq}) of 2–3 dB(A). This has produced in noise levels that exceed the limits defined in the "Law of Preventing and Eliminating Environmental Noise Pollution of People's Republic of China" [66]. As a result, the railway authority and regional/local governments have adopted additional measures to control railroad noise. Emissions sources for high speed trains have been identified as rolling noise, aerodynamic noise and traction (on-board equipment such as engines, compressors, etc.) noise. The frequency range having the highest sound power levels is in the range of 5,000 to 8,000 Hz [146]. Recent (2014) studies by Southwest Jiaotong University [147] indicate the wheel/rail area is the largest contributor to high speed rail noise (CRH380 high speed train test speeds 271 km/h [168 mph] to 386 km/h [240 mph]), followed by the pantograph and inter-coach gaps.

There are two Chinese noise standards governing rail noise. Both relate to noise immissions. No specific noise emissions (vehicle focus) regulations have been established (see Table 27) [66] [148].

Table 27: Chinese Regulations Applicable to Railway Noise

Agency	Code for National Standards	Title	Description
Ministry of Transportation of PRC	GB 12525-90	Railway noise on the boundary & measurement methods	Specifies the limits and measurement methods of urban railway boundary line evaluation
Ministry of Environmental Protection	GB 3096-2008	Environmental quality standard for noise	Applies to sound environmental quality assessment & management

4.1.1 China: Rail Noise Immissions Regulations

Noise immission levels regulations, GB 3096-2008, Environmental Quality Standards for Noise [66] were initially in place by the China Ministry of Environmental Protection during 1992. They were later revised in 1993 and again in 2008. This standard was originally drafted by the China Environmental Science Research Institute, the Beijing Municipal Environmental Protection Monitoring Centre and Guangzhou City Environmental Monitoring Centre.

The noise limits are defined for different areas within a city (e.g., residential, commercial) and are consistent across all the provinces in China (i.e., do not vary from region to region as occurs within the US and EU). Noise limits across different zones within China are contained within the appendices.

This standard has been defined in consideration of the following standards:

- GB 3785 – Sound level meter power, sound performance & testing methods [149]
- GB/T 15173 – Sound calibrator
- GB/T 15190 – Technical specifications to determine suitable areas for environmental noise
- GB/T 17181 – Technical specification for integrating averaging sound level meters
- GB/T 50280 – Standards for basic terminology of urban town planning

China designated zones with pre-defined day and night limits; noise limits are maximum values for areas adjacent to railway lines.

Table 28: GB 3096-2008, Environmental Quality Standards for Noise

Functional Zone	Receiver		
	L_d, dB(A)	L_n, dB(A)	Description of Activity Category
Zone 0	50	40	Special areas which need quiet environment like rehabilitation sanatorium care area
Zone 1	55	45	Areas which need quiet environment like residential areas, hospitals, education institutions, R&D institutions, office/ commercial areas
Zone 2	60	50	Commercial & financial center, markets or trading centers or a mixture of residential / commercial / industrial areas
Zone 3	55	55	Areas for industrial production, warehousing
Zone 4a	70	55	Highway, tier-1 road, tier-2 road, urban high-speed road, urban main street, urban sub-level street, urban rail transit, the sides of inland waterways
Zone 4b	70	60	Areas on both the side of railway lines

China Ministry of Environmental Protection Regulation GB 3096-2008 relates to measurement of noise at the boundary of railroad property, see Table 28. No specific regulations are imposed relative to high speed rail and noise limits are not related to train speed. Table 29 summarizes the noise limits [148].

Table 29: Noise Limits, China Railway Noise Regulation GB 12525-90

China Railway Noise Immission Limits: Regulation GB 12525-90		
Noise Metric	**Noise Limit, dB(A)**	**Measurement Location**
L_d	70	30 m from track, elevation 1.2 m (98.4 ft. from track, elevation 3.94 ft.)
L_n	60	

4.1.2 China: Rail Noise Measurement Guidelines

Measurement guidelines are defined within Noise Regulation GB 12525-90 [148]. The regulation requires five measurement points to be taken at the border of the railway property with the microphone located 1.2 m (3.94 ft.) above the ground and not less than 1 m (3.28 ft.) from a reflective surface. Measurements are taken at a distance of 30 m (98.4 ft.) from the centerline of the outer track.

Measuring instruments should meet the GB 3785 standards [149] as specified for the Type II sound level meter (i.e., widely used to test the sound level of environment, vehicles or any other noises and is compatible with all the global standards such as IEC 651 & ANSI S1.4)

Measuring conditions should meet the GB 3222 standards—Measurement Methods for Community Noise [150] which states measurements should be taken in the absence of rain or snow. Measurement time to be day or night; 16 hours is the duration for day measurements and 8 hours is the duration for night measurements.

4.1.3 China: Enforcement of Railroad Noise Regulations

Environment-related legislation is promulgated by the Standing Committee of the National People's Congress, which is China's national legislature. The Ministry of Environmental Protection (MEP) was established in 2008 as the successor to the State Environmental Protection Administration Bureau (SEPA). MEP is responsible for overall supervision & administration of environmental protection work nationwide [151] [152].

Enforcement of National Environmental policies and certain specific rule making at local level are vested in local Environmental Protection Bureaus (EPBs) [153].

GB 3096-2008 Law of the People's Republic of China on the Prevention & Control of Environmental Noise Pollution contains several sections applicable to railway noise, including [152]:

Article 34 of the law states that the locomotives passing through urban areas must use sound apparatus (e.g., horn, etc.) according to the regulations; however horn noise is one of the primary public complaints regarding railway noise [146].

Article 39 of this law states that the local municipal bodies should develop plans to mitigate pollution caused by locomotives passing through the urban residential, cultural and educational districts.

Penalties for exceeding the noise regulations of GB 12525-90 and GB 3096-2008 are not explicitly stated. Instead, enforcement and assignment of penalties is relegated to local authorities. For example, relative to GB 12525, if the locomotive noise levels violate the provisions mentioned in Articles 34 and 39, the competent railway department is to penalize the person(s) held responsible. China has imposed fines for non-compliance with high speed rail noise limits. For example, during 2007, the Taiwan High Speed Rail Corporation was fined NT $1.5 million and was given 1 month to bring the trains into compliance [154].

China has found that noise barriers are a cost-effective approach to mitigating rail noise immissions. Research on this topic began during 1985. Currently, barriers have been erected along 4,000 km (2,485 miles) of China's rail routes. Two barrier designs have been developed, one for the 250 km/h (155 mph) high speed passenger train route and one for the 350 km/h (217 mph) route. The classification of over 90 percent of the barriers is "metallic fin-inserted" barriers and range in height from 2.15 to 2.95 m (7.05 ft. to 9.68 ft.). The barriers provided a 5 dB(A) to 6 dB(A) reduction in noise energy levels at train speeds of 350 km/h (217 mph) [155]. Other studies have shown even greater sound attenuation using metal plug board-type sound barriers along the Beijing-Shanghai high speed railway [156]. Sound levels for the CHR380 high speed train operating at 300 km/hr (186 mph) were reduced between 5.6 dB(A) and 11.7 dB(A), with the range of values representing changes in barrier height.

4.1.4 China: Rail Noise Regulation Summaries

Table 30 and Table 31 summarizes the China codes, standards, regulations, and best practices included on the following pages.

Table 30: China Regulation GB 12525-90 Railway Noise Immissions

Name	Railway Noise on the Boundary & Measurement methods	**Code**	GB 12525-90	**Date of Issue**	1991
Authorising / issuing agency	Ministry of Transport of People's Republic of China			**Geographical coverage**	China

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
	✓	✓						✓

Description

Specifies the limits & measurement methods of urban railway noise on the boundary

Key take-outs / Best practice

1. Measurement is done at 30m from the centreline of the track and at an elevation of 1.2m from the ground

Time	Noise level (dB)
L_d	70
L_n	60

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise
✓		✓	

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions

References

China State Environmental Protection Agency, "Railway Noise on the Boundary and Measurement Methods GB 12525-90," China State Environmental Protection Agency, Beijing, China, 1991

Table 31: China Regulation GB 3096-2008 Environmental Quality Standards for Noise

Name	Environmental quality standards for noise	**Code**	GB 3096- 2008	**Date of Issue**	2008
Authorising / issuing agency	Ministry of Environmental Protection			**Geographical coverage**	China

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
			✓					

Description

This standard refers to five categories of sound environmental functions of environmental noise limits & methods of measurements

The regulation applies to all noise sources.
This standard has been defined in consideration of the following China standard GB 3785 – Sound level meter power, sound performance & testing methods

Key take-outs / Best practice

Zone		L_d(dB(A))	L_n(dB(A))
Zone 0		50	40
Zone 1		55	45
Zone 2		60	50
Zone 3		65	55
Zone 4	4a	70	55
	4b	70	60

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise
		✓	

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions
✓			

References

People's Republic of China State Administration of Quality Supervision, Inspection and Quarantine, "Law of the People's Republic of China on Prevention and Control of Pollution from Environmental Noise, GB 3096-2008," National Standards, People's Republic of China (see China.Org), Beijing, China, 2008.

4.2 Japan High Speed Rail Noise Codes, Standards, Regulations, and Best Practices

Exterior noise is one of the largest environmental issues relating the high-speed Shinkansen trains in Japan because they run through residential areas. Noise reduction has been included in train and infrastructure design in Japan since the 1970s during which the original high speed railway noise immission limits were defined [157]. This noise has been divided into two categories: 1) noise along open section of track, and 2) sonic boom at tunnel entrances (i.e., caused by micro-pressure waves. Noise along open sections of track for Shinkansen trains is dominated by aerodynamics and has been found to increase by the 6th power of train speed. Thus, in moving from 172 mph (277 km/h) to 225 mph (362 km/h), the aerodynamic noise increases by a factor of $(225/172)^6 = 5$. Sonic boom at tunnel entrances, on the other hand, increases by the 3rd power of train speed; thus, in moving from 172 mph (277 km/h) to 225 mph (362 km/h), the sonic boom (micro-pressure waves) increases by a factor of 2.2 [158]. Wheel/rail noise and noise related to surfaces adjacent to the vehicle have also been addressed, such as the sound reflection of slab track vs. sound absorption of ballast track and resilient track [145] [157].

The following approaches to reducing Shinkansen noise immissions were implemented over the 50-year history of this system: 20 m (65.6 ft.) wind environmental zone included on both sides of the right-of-way, noise barriers, brake discs (e.g., Shiraishi et al. [2016] in which air through the ventilation duct of the disc brakes was identified as a key contributor to aerodynamic noise), vehicle shape, pantograph shielding (e.g., Mitsumoji et al. [2016], in which noise levels were reduced between 1 dB(A) and 5 dB(A) depending upon the geometry modifications), inter-car gap seals, improved track and wheel surfaces (i.e., wheel and track grinding), improved track foundations, improved noise absorption surfaces adjacent to train, and decrease of speed through densely inhabited districts [141] [145] [157]. The problem of air velocities and pressures on high speed trains passing each other also must be addressed [145].

Beginning in 2005, East Japan Railway Company has been evaluating design changes to the Shinkansen rolling stock using two types of high speed test trains, known as FASTECH360S and FASTECH360Z [160] [161]. The most effective noise reduction measures, termed "countermeasures" are divided into five classifications as shown in Table 32.

Table 32: Primary Noise Reduction Approaches for Shinkansen High Speed Trains [160]

Noise Classification	Noise Reduction Countermeasures
(1) Pantograph Noise	(a) Improved Aerodynamics (b) Pantograph Noise Insulation Plates
(2) Aerodynamic Noise from Train	(a) Bogie (Wheel Truck) Covers (b) Smoothed Door to Driver's Cab (c) Snowplow Cover
(3) Aerodynamic Noise from Upper Parts	(a) Circumferential Bellows (inter-car gap seal) (b) Smoothed Roof without Cables
(4) Noise from Lower Parts	(a) Bogie Covers (b) Sound Absorbing Panels
(5) Structure-Borne Noise	(a) Lighter Axle Load

4.2.1 Japan: Rail Noise Immissions Regulations

Japan has specific noise standards for high speed rail that are aligned with the environmental standards for noise. Like China, Japan's noise regulations are based on immission levels, with no specific rolling stock emissions specifications. The two agencies having jurisdiction are the 1) Ministry of Land, Infrastructure, Transport, and Tourism and 2) Ministry of the Environment. Table 33 summarizes these regulations [67] [68] [69] [71]:

Table 33: Japan Rail Noise Immissions Regulations

Agency	Code for National Standards	Title	Description
Ministry of Land, Infrastructure, Transport & Tourism	Japanese Railway Bureau (2012)	Technical standards on Japanese Railways	Ministerial ordinance to provide technical regulatory standards on railways for both locomotives & Shinkansen (high speed rail)
Ministry of Environment, Govt. of Japan	Law No 91 of 1993, Basic Environmental Law (updated 2000)	Environmental quality standards for Shinkansen railway	This standard covers the impact of Shinkansen (High speed rail) on the environment & what are the regulations associated with it
Ministry of Environment, Govt. of Japan	Environment Agency Notification No. 64, September 30, 1998	Environmental quality standards for noise	This standard defines the regulations for quality standards in noise which are in accordance with the basic environmental law

Japan's Technical Regulatory Standards on Japanese Railways is the primary governing force for noise regulation [70]. A portion of the regulation applicable to high speed trains (i.e., not specifically high-speed trains) are:

1. Prevention of Extreme Noise (Chapter 1 / Section 6): "A railway enterprise shall strive to prevent extreme noise to be generated with the movement of a train [70]."
2. Last revised in 2012, this section of the regulation applies to Shinkansen as well as conventional train operation and references Japan's Environment Standard [68]. Noise levels must be less than 75 dB(A) in specified areas, depending on population density, but this maximum value is set as a "target" rather than an enforceable requirement. As described below, passby noise measurements are to be made at an elevation of 1.2 m (3.94 ft.) at a distance of 25 m (82 ft.) from the track. For new rail construction of conventional rail (non-Shinkansen) projects, measurements are to be made at an elevation of 1.2 m (3.94 ft.) at a distance of 12.5 m (41 ft.) from the track and day limits (Ld) are to be 60 dB(A) max, and night limits (Ln) are to be 55 dB(A) max. Table 34 summarizes this below.
3. Facilities to Abate Extreme Noise (Chapter 3 / Section 5): not specific regarding noise levels, "…shall be equipped with the devices to abate extreme noises generated from the high-speed operation…[70]."
4. Structure for Reducing Severe Noise (Chapter 8 / Section 4): not specific regarding noise levels: "…takes the prevention of substantial noise during the running to the train into consideration…[70]."

The Ministry of the Environment, Government of Japan, "Environmental Quality Standards for Shinkansen Superexpress Railway Noise, Notification No. 91" [67] requires noise levels for high speed trains to produce immissions levels less than those defined in Table 34.

Table 34: Noise Limits for Japan Shinkansen High Speed Rail

Code	Applies to	Noise Source	Area category*	Sound Pressure Level, dB(A)	Noise Measure	Measurement Location
In accordance with Basic Environmental Law (Law 91 of 1993)	Shikansen (High speed rail)	Primary standard	I	70 or less	L_{eq}	25m from the track
			II	75 or less		25m from the track

*Where Area Category I refers to residential zones
Area Category II refers to areas used for commercial and industrial purposes
The noise metric L_{eq} (versus L_d) is calculated using the energy mean of the peak noise levels
Sound pressure limits are not indexed by train speed

The Japanese Environmental Quality Standards also assign zone designations for noise limits as shown in Table 35 [68] [71]:

Table 35: Assigned Zone Designations for Noise Limits

Type of Area	L_d	L_n
AA	50 dB(A) or less	40 dB(A) or less
A & B	55 dB(A) or less	45 dB(A) or less
C	60 dB(A) or less	50 dB(A) or less

Daytime is from 6 a.m. to 10 p.m. & night time is from 10 p.m. to 6 a.m. of the following day
Area category AA is where low noise is essential, such as healthcare & welfare institutions
Area category A is applied exclusively for residences
Area category B is applied primarily for residences
Area category C is applied to areas used for commerce & industry as well as significant number of residences

For areas adjacent to Japan's high-speed train lines, the Shinkansen Superexpress Railway Noise regulations [67] apply and supersede the stricter Environmental Quality standards [68].

4.2.2 Japan: Rail Noise Measurement Guidelines

Methods of measurement of noise, units of measurement, and measuring instruments are defined in the Japan Environmental Quality Standards for Noise [68] and summarized in the Ministry of the Environment Quality of the Environment White Paper (Section 2b, Method of Measurement) [162]. These standards have been divided into three parts: (1) standards on the methods for measurement of noise emitted by machinery, equipment, and other sound sources; (2) standards on the method for measurement of environmental noise; and (3) standards on measurement instruments. Group (1) is further divided into two sub-groups: basic standards and specific standards (test codes adopted for specific sound sources) [163].

The Japanese Agency of Industrial Science and Technology (AIST) typically leaves the preparation of new draft standards and/or the revision of existing standards to organizations with specific knowledge of the affected subject areas. Basic noise standards are typically drafted by the Acoustical Society of Japan (part of the Institute of Noise Control Engineering [INCE]). Ad hoc technical committees are established in the respective societies, and experts prepare draft standards in these committees [70] [163].

Until recently, Japanese national standards have not necessarily been in harmony with corresponding international standards. However, due to requirements imposed by the World Trade Organization (WTO), the Japanese government made a basic policy decision in 1995 that all Japanese Industrial Standards will have complete conformity to international standards, such as those published by ISO, IEC, etc., by the end of March 1998 [163].

The method of measurement of noise, units of measurement, and measuring instrument are defined as follows.

a) The method of measurement shall conform to the noise level measurement method of Japanese Industrial Standard (JIS) Z8731. In principle, mean values shall be employed in evaluating the measurement results.

b) The unit of measurement shall be dB (A).

c) The measuring instrument shall be the indicating noise meter prescribed by JIS C1502 or the precision noise meter prescribed by International Electric Standards Conference (IESC) Pub/179 or equivalent instrument.

These instrument standards and corresponding ISO standards are summarized in Koyasu (2000), and reproduced in Table 36.

Table 36: Japanese Noise Instrument Standards and Corresponding ISO Standards

JIS Number	Measured Quantity	Measurement Environment	Accuracy Grade	Corresponding ISO Standard
Z 8731:1999	Sound Pressure	Free-Field & Hemi-Field	Engineering	ISO 1996-1:2016
Z 8732:xxxx	Sound Pressure	Free-Field & Hemi-Field	Precision	ISO/DIS 3745
Z 8733:xxxx	Sound Pressure	Approximately Hemi Free-Field	Engineering	ISO 3744:94
Z 8734:xxxx	Sound Pressure	Reverberant	Precision	ISO 3741:99
Z 8736-1:99	Sound Intensity	Any	Precision, Engineering, Survey	ISO 9614-1:93
Z 8735-2	Sound Intensity	Any	Engineering, Survey	ISO 9614-2:96

Shinkansen Superexpress Railway Noise [67] requires a power mean of the peak noise level shall be measured at 1.2 m (3.94 ft.) above the ground in the open air along the railway line with the measuring point located at 25 m (82 ft.) from the center line of the near side of the track. This is not applicable in sparsely inhabited forests, agricultural lands, etc.

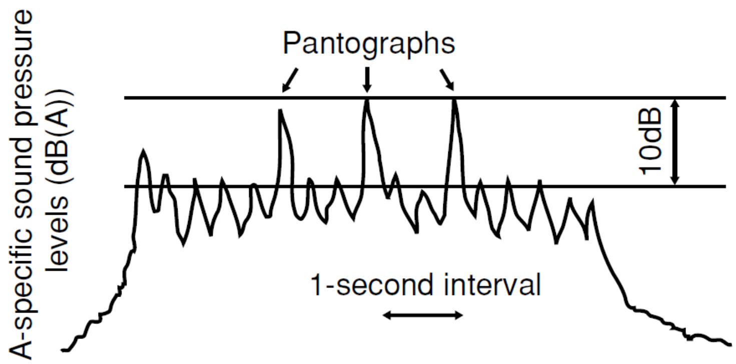


Figure 24: Example Sound Signature for Shinkansen Passby [164]

According to the environmental quality standards for the Shinkansen Superexpress, noise measurements are to be performed as described below [67]:

- Measurement are to be carried out by recording the peak noise level of each of the Shinkansen trains passing in both the directions, in principle for 20 successive trains
- Measurement shall be carried out outdoors and in principle at the height of 1.2 m above the ground. Measurement points shall be selected to represent Shinkansen railway noise levels in the area concerned as well as the points where the noise is posing a problem.
- Any period when there are special weather conditions or when the speed of the trains is lower than normal shall not be considered
- The Shinkansen railway noise shall be evaluated by the energy mean value of the higher half of the measured peak noise levels.
- The measuring instrument used shall be a noise meter that meets the requirements of Article 88 of the measuring law (Law no 207 of 1951), with A-weighted calibration & slow dynamic response. Thus, metric is L_{max} (slow).
- The environmental quality standards shall apply between 6 a.m. to 12 midnight.

4.2.3 Japan: Enforcement of Railroad Regulations

Regarding the Shinkansen Superexpress Railway Noise notification, railway administration and prefectural governments make efforts to maintain the environmental quality standards within the limits and within the target dates for achievement specified for each zone alongside the Shinkansen super express railway, see Figure 24 [164].

In areas where it is difficult to implement standards within target dates, efforts are being made to reduce high speed rail noise such as by soundproofing of houses [164]. For new high speed rail lines, timetables are imposed for achieving noise level compliance [67]. Table 37 summarizes these below.

Table 37: Timetable for Noise Regulation Compliance of Japan New High-Speed Rail Projects

Classification of Zones along the Shinkansen Superexpress railway			Target dates for achievement		
			Existing lines	Lines Under construction	New Lines
Zone a	80 dB(A) or more		Within 3 years	Immediately on start of service	Immediately on start of service
Zone b	Between 75 dB(A) & 80 dB(A)	A	Within 7 years	Within 3 years of start of service	
		B	Within 10 years		
Zone c	More than 70 dB & less than 75 dB		Within 10 years	Within 5 years of start of service	
Area Zone Classifications are assigned based on land use, with Category I representing residential and other quiet areas, and Category II refers to industrial and other high noise areas. Zones a, b, and c refer to areas where HS rail noise levels exceed the limits of Categories I & II; Zone b is divided into two sub classifications with A referring to regions where several Classification I areas exist adjacent to each other and sub classification B to those zone not designated as A.					

The Shinkansen Noise Regulation also states that the implementation policy for noise control is to give highest priority to those areas exhibiting noise levels 80 dB(A) or more (Zone a) in excess of the Category I limit. Not penalties are defined for non-compliance of the Shinkansen noise regulation.

4.2.4 Japan: Rail Noise Regulations Summaries

Table 39 summarizes the Japan Environmental Quality Standards for the Shinkansen high speed.

Table 38: Japan Environmental Quality Standards for Shinkansen High Speed Train[11]

Name	Environmental quality standards for Shinkansen	Code	Law No 91 of the basic environmental law	Date of Issue	1993
Authorising / issuing agency	Ministry of Environment, Govt. of Japan			Geographical coverage	Japan

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
	✓	✓						

Description

Standards for regulating the Environmental conditions of Shinkansen Super express railway are specified by this standard and are in accordance with the law for Environmental quality standards

Key take-outs / Best practice

1. Measurement is done at 25m from the centreline of the track and at an elevation of 1.2m from the ground

Area category	Time	Noise level (dB)
I	L_d	70 or less
II		75 or less

2. Area Category I is residential while II is commercial & industrial

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise
✓		✓	

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions

References

http://www.env.go.jp/en/air/noise/railway.html

[11] Ministry of Environment: Government of Japan. Environmental Quality Standards for Shinkansen Superexpress Railway Noise.

5. US Codes, Standards, Regulations, and Recommended Practices

A history and brief summary of railroad noise regulations within the US are included in Boeker et al. (2009), beginning with the Noise Control Act of 1972 [165] and extending to the current 40 CFR Part 201, Noise Emissions Standards for Transportation Equipment; Interstate Rail Carriers (i.e., overseen by the EPA) [56]; and 49 CFR Part 210, Railroad Noise Emission Compliance Regulations (i.e., overseen by FRA) [55] [57] [58] [59] [60] [61]. It is noted that compliance with railroad noise regulations is evaluated by FRA inspectors, noise professionals working for railroad equipment manufacturers, or by the railroads themselves.

It is noted that both FRA and US Federal Transit Administration are required to comply with the National Environmental Policy Act (NEPA) [166], and both agencies have established noise exposure assessment procedures.

5.1 Compliance with National Environmental Policy Act

On January 1, 1970, the NEPA was signed into law. NEPA requires Federal agencies to assess the environmental effects, including noise, of their proposed actions prior to making decisions [166]. The range of actions covered by NEPA is broad and includes:

- Making decisions on permit applications
- Adopting federal land management actions
- Constructing highways and other publicly-owned facilities

Using the NEPA process, agencies evaluate the environmental and related social and economic effects of their proposed actions. Agencies also provide opportunities for public review and comment on those evaluations.

NEPA requires Federal agencies to incorporate environmental considerations in their planning and decision-making through a systematic interdisciplinary approach. Specifically, all Federal agencies are to prepare detailed statements assessing the environmental impact of and alternatives to major Federal actions significantly affecting the environment. These statements are commonly referred to as EIS and EA.

FRA's procedures for considering environmental impacts under NEPA are defined in the Federal Register (1999) and include compliance with the Noise Control Act, limits on noise emissions, requirements for mitigating impacts of noise, and compliance with applicable Federal, State, and local noise standards.

Impact assessments of planned Federal actions are a requirement under other environmental laws, including NEPA, and there are no statutory or prescriptive linkages to noise emissions (pollution) standards in the NEPA regulation.

It is noted US regulations do not limit "immissions" (sound pressure levels at receivers). Rather, guidance and procedures, as required by NEPA, are used to assess exposure from planned infrastructure projects. Noise immissions from ongoing railroad operations in the US are not directly regulated. Also, the term "immissions" is not commonly used in US. These exposure assessments include land use categories, existing and planned buildings and occupancy categories, and population densities (see Section 5.3).

Federal government preemptions for specific areas of noise regulation can be found in the Title 49 CFR under the EPA Noise Abatement Programs, Parts 201 to 205 and 211, which cover railroads, motor carriers in interstate commerce, construction equipment, and motor vehicles [167]. Communities may enact regulations that are not stricter than the Federal ones so that local enforcement can be carried out. Federal government can enact curfews and restrict vehicle use in established zones such as residential. Any restriction on interstate motor carriers or railroads may not be for the purpose of noise control [168].

Although the establishment of the NEPA was to inform and improve decision making by Federal government agencies, implementation requires interpretation of requirements, agency roles and responsibilities [169]. NEPA reviews of high speed rail projects typically include EIS, which must include noise and vibration assessments. For example, the draft (Tier 1) EIS for the Northeast Corridor (NEC) infrastructure plan was completed during 2015 and contains references to the various compliance requirements including [170]:

- National Environmental Policy Act (42 USC § 4332 et seq.)
- Council on Environmental Quality (CEQ) Regulations for Implementing NEPA (40 CFR Parts 1500–1508)
- Section 106 of the National Historic Preservation Act (54 USC § 306101 et seq.)
- Section 4(f) of the U.S. Department of Transportation Act (49 USC § 303)
- FRA Procedures for Considering Environmental Impacts (64 FR 28545), which includes FRA's Noise and Vibration Impact Assessment Methodology [23]

5.2 US Rail Noise Regulations

The following sections of the CFR relate to railroad noise:

- 40 CFR Part 201–Noise Emission Standards for Transportation Equipment; Interstate Rail Carriers
- 49 CFR Part 210–Railroad Noise Emission Compliance Regulations
- 49 CFR Part 222–Use of Locomotive Horns at Public Highway-Rail Grade Crossings
- 49 CFR Part 227–Occupational Noise Exposure
- 49 CFR Part 228–Hours of Service of Railroad Employees; Recordkeeping and Reporting; Sleeping Quarters
- 49 CFR § 229.121–Locomotive cab noise
- 49 CFR § 229.129–Locomotive horn

Table 39 through Table 41 summarizes the US railroad noise regulations.

Table 39: Summary of US Federal Railroad Noise Regulations

Agency	Code of Federal Regulations (CFR)	Title	Description
EPA	40 CFR Part 201	Noise Emission Standards for Transportation Equipment; Interstate Rail Carriers	Covers standards for locomotive operation under stationary and moving conditions, rail car operations, retarders, car coupling operations and load cell test stand Specifies quantities measured, instrumentation, test conditions and procedures
FRA	49 CFR Part 210	Railroad Noise Emission Compliance Regulations	Contains enforcement provisions including: • Authorization for inspection and testing • Measurement criteria and procedures • New locomotive certifications • Operation standards • Penalties and waivers
FRA	49 CFR Part 222	Use of Locomotive Horns at Public Highway-rail Grade Crossings	Regulates standards for sounding horns when locomotives approach and pass through public highway rail grade crossings. Also provides standards for creation and maintenance of quiet zones.
FRA	49 CFR Part 227	Occupational Noise Exposure	Establishes noise exposure standards for railroad employees
FRA	49 CFR Part 228	Hours of Service of Railroad Employees (Sleeping Quarters)	Regulates noise environment in railroad employee sleeping quarters. Establishes the maximum noise level which will be regarded as the level permitting "an opportunity to rest."
FRA	49 CFR Part 229	Railroad Locomotive Safety Standards (Locomotive Horns and Locomotive Cab Interior Noise)	The provisions of 49 CFR Part 229.121 related to Part 227, require railroads to obtain and maintain locomotives that meet specified standards for limiting in-cab noise. 49 CFR Part 229.129 requires locomotives to be equipped with an audible warning device, sets min/max sound levels for locomotive and wayside horns and describes the measurement instruments and test site requirements

Table 40: Noise Levels, US Federal Railroad Noise Regulations, Locomotives

Code of Federal Regulation	Region	Applies to	Speed	Noise Source	Noise standard A weighted sound level, dB(A)	Noise Measure	Measurement Location
40 CFR 201	US	All locomotives manufactured on or before 31 Dec 1979	Regulations are independent of train speed	Stationary, Idle Throttle Setting	73	L_{max} (slow)	30 m (100 ft)
				Stationary, All Other Throttle Settings	93	L_{max} (slow)	30 m (100 ft)
				Moving	96	L_{max} (fast)	30 m (100 ft)
40 CFR 201	US	All Locomotives Manufactured After 31 December 1979		Stationary, Idle Throttle Setting	70	L_{max} (slow)	30 m (100 ft)
				Stationary, All Other Throttle Settings	87	L_{max} (slow)	30 m (100 ft)
				Moving	90	L_{max} (fast)	30 m (100 ft)
40 CFR 201	US	Additional Requirement for Switcher Locomotives Manufactured on or Before 31 December 1979 Operating in Yards Where Stationary Switcher and other Locomotive Noise Exceeds the Receiving Property Limit of 65 dB [L_{90} (fast)]		Stationary, Idle Throttle Setting	70	L_{max} (slow)	30 m (100 ft)
				Stationary, All Other Throttle Setting	87	L_{max} (slow)	30 m (100 ft)
				Moving	90	L_{max} (fast)	30 m (100 ft)

Table 41: Noise Levels, U.S. Federal Railroad Noise Regulations, Rail Cars, Other Equipment

Code of Federal Regulation	Region	Applies to	Speed	Noise Source	Noise standard A weighted sound level dB(A)	Noise Measure	Measurement Location
40 CFR 201	US	Rail Cars	<=45 mph		88	L_{max} (fast)	30 m (100 ft)
			>45 mph		93	L_{max} (fast)	30 m (100 ft)
40 CFR 201	US	Other Yard Equipment & Facilities	Regulations are independent of train speed	Retarders	83	$L_{adjavemax}$ (fast)	Receiving Property
				Car Coupling Operations	92	$L_{adjavemax}$ (fast)	Receiving Property
40 CFR 201	US	Locomotive Load Cell Test Stands, Where the Noise from Locomotive Load Cell Operations Exceeds the Receiving Property Limits of 65 dB [L_{90} (fast)]		Primary Standard	78	L_{max} (slow)	30 m (100 ft)
				Secondary Standard if 30m Measurement Not Feasible	65	L_{90} (fast)	Receiving property located more than 120 m from Load Cell

Does not apply to:

- Sound emitted by a warning device, such as a horn, whistle or bell when operated for the purpose of safety
- Special purpose equipment which may be located on or operated from railcars
- Street, suburban or interurban electric railways unless operated as a part of a general railroad system of transportation

During 2012, FRA published an update to its impact assessment manual for noise and vibration originating with high speed ground transportation equipment [23]. The report includes procedures for predicting and assessing noise and vibration for both traditional steel-wheel on steel-rail and magnetically levitated (maglev) systems for train speeds of 90 mph (145 km/h) to 250 mph (402 km/h). Data on noise emissions from high-speed trainsets in the United States, Europe, and Asia are included that provide opportunities for comparisons to the current rail noise regulations contained in this report. It is noted that direct comparisons are difficult to make due to the variations in measurement procedures and associated metrics. FRA has initiated a research project to develop methods to facilitate comparisons of regulations employed within the US, EU, China, and Japan, as well as an assessment of the compliance of current commercially available train set source noise levels relative to the identified regulations [171].

United States Department of Labor, Occupational Safety and Health Administration (OSHA) noise regulations also apply to railroad workers [171]. The applicable portion of the regulation is Title 29 CFR § 1910.95, Occupational noise exposure. Table 42 shows permissible noise exposures, measured at the employee location, and included in the OSHA regulation:

Table 42: US OSHA Permissible Noise Exposures [171]

Duration (hours/day)	Sound Level, dB(A)
8	90
6	92
4	95
3	97
2	100
1½	102
1	105
1/2	110
1/4	115

Within 49 CFR, standards-specific noise measurement guidelines are provided for both line-haul and yard operations. High speed operations are addressed in 49 CFR Part 227 (Occupational Noise Exposure—applying to railroads, and contractors to railroads) where the term *Railroad* includes the following statement in § 227.5(2), Definitions [58]:

> [Railroad means] high speed ground transportation systems that connect metropolitan areas, without regard to whether those systems use new technologies not associated with traditional railroads.

Thus, US railroad noise regulation also includes references to noise exposure of railroad employees associated with high speed rail systems.

5.3 US: Rail Noise Measurement Guidelines

US railroad noise measurements and procedures for noise emissions are defined in the FRA publication Handbook for Railroad Noise Measurement and Analysis [28], based on 40 CFR §§ 201.21, 201.22, 201.23, 201.24, and 201.25—Interstate Rail Carriers Operations Standards, Measurement Criteria [56]. Because no high-speed rail system was in operation within the US when the Handbook was written in 2009, the following statement is included in the introduction: "This Handbook does not cover the measurement or assessment of transit rail or high-speed rail noise." Thus, current US railroad noise measurement regulations were developed based on conventional passenger and freight operations.

Figure 25 through Figure 27 illustrates the specifications of 40 CFR Part 201 that includes specifications for microphone placement relative to the track, measurement site boundaries for railroad horn measurements, and measurement site boundaries for railroad sideline measurements [28]. The regulations also specify the measurement site must be free of large, reflecting objects such as buildings, hills, sign posts, bridges, parked vehicles, and railroad cars and locomotives (other than the one being tested).

For passby measurements, at least 80 percent of one rail along the test track must be visible from the microphone location, and no single obstruction should obscure more than 5 percent of the test track.

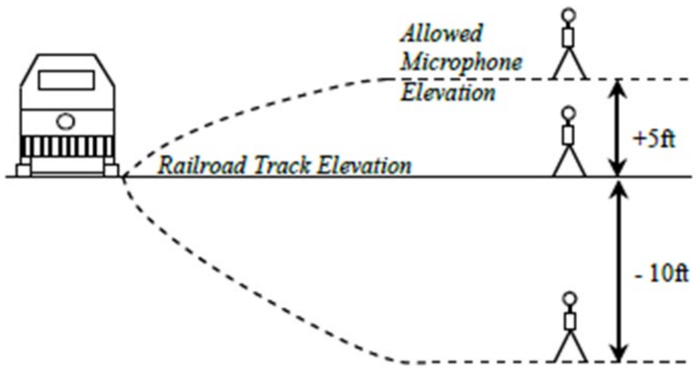


Figure 25: Microphone Elevation for Railroad Sideline Measurements [28]

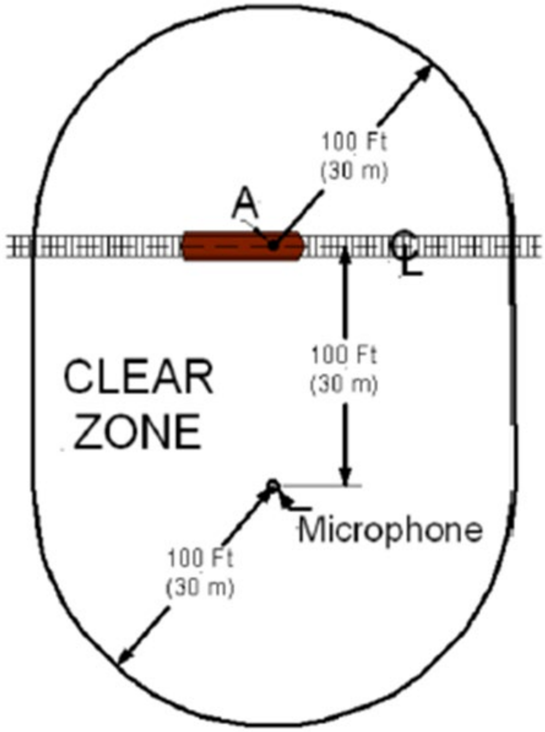


Figure 26: Site Boundaries for Railroad Sideline Measurements [28]

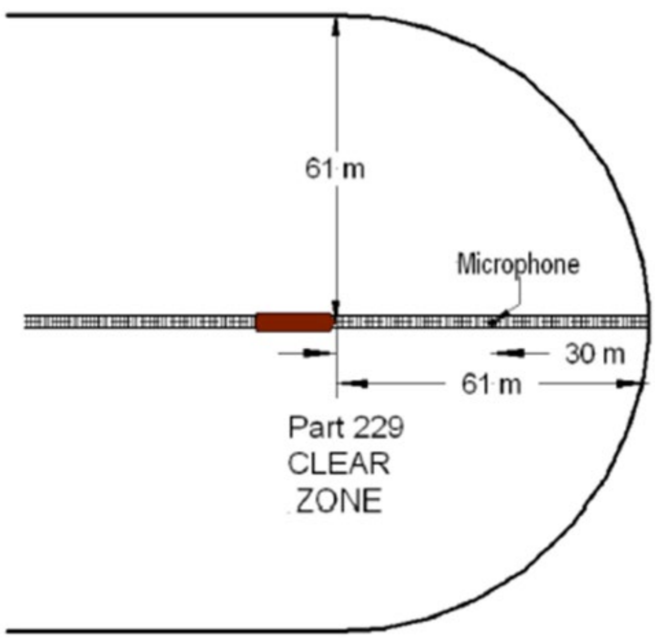


Figure 27: Site Boundaries for Railroad Horn Measurements [28]

Example noise measurements relating to trains operating within the NEC (Amtrak) can be found in Wood (2011).

5.3.1 Instrumentation for Compliance Testing

Instrumentation for compliance testing is defined in the following: CFR Part 201 [56], Part 210 [55], and the FRA Handbook of Railroad Noise Measurement and Analysis [28].

Sound Level Meter**:** Must meet all the requirements of American National Standards Institute S1.4-1971 1 for a Type 1 (or S1A) instrument [172] must be used with the “fast” or “slow” meter response characteristic. In the event that a Type 1 (or S1A) instrument is not available for determining noncompliance with this regulation, the measurements may be made with a Type 2 (or S2A), but with certain adjustments to the measured levels to account for possible measurement instrument errors pertaining to specific measurements and sources [173].

A measurement tolerance of 2 dB(A) for a given measurement is allowed to take into account the effects of variation in instrument tolerance, measurement site topography, atmospheric conditions, reflections and rounding off.

Microphone Windscreen and Acoustic Calibrator: As recommended by either the manufacturer of the sound level meter or the microphone. The type 1 or 2 performance must be maintained for frequencies below 10,000 Hz. A calibrator which meets ANSI Type 1 requirements, that is not pressure sensitive and that yields a 94 dB, A-weighted sound pressure level at 1 kHz, is suitable for use in FRA noise measurements.

Other Instruments: Other measurement devices such as meteorological instruments (e.g., wind speed, and temperature), accessories (e.g., tripod, measuring tape, camera, etc.) are also needed while testing for compliance.

5.4 US State and Local Noise Regulations

States and local governments issue compliance requirements that are typically general in nature (not source specific). NEPA regulations require consideration of state and local laws to reduce duplication between NEPA and comparable state and local requirements and to disclose any inconsistency of a proposed action with any approved state or local plan and laws [40 CFR 1506.2]. In general, Federal law for interstate carriers overrides local and State law. Precedence has been set by the FRA Train Horn and Quiet Zone regulation, which preempts any state or local laws regarding the use of train horns at public crossings [57] [174].

An evaluation of immission levels across selected cities and States shows that there is considerable variation in local codes [175]. The differences in local noise immission levels (generally defined as the sound input to the receiving individual or measured at the established property line), metrics and descriptors need to be considered for high speed rail projects and regulations. Both noise thresholds and noise descriptors vary across different cities and States.

In general, local immission levels (noise limits) are defined based on time of day and type of receiver (e.g., residential, industrial, etc.). In some cases, permitted limits also depend on the source of noise. Noise regulations for locations evaluated during the current study do not have consistent descriptors (metrics) or maximum allowable limits. Table 43 shows the permitted immissions levels, dB(A), at residential property line from industrial sources, Dallas, TX, has the most stringent noise limits [175] [176] [177] [178] [179] [180] [181]. For this analysis, noise originating at railroad sources is assumed to fall in the industrial source category. Connecticut considers all transportation noise sources to be an industrial [182].

Table 43: Selected US Local and State Immission Levels

City, State	Residential (Night)	Residential (Day)	Noise Descriptor
Raleigh, NC	55	62.5	L_{10} (Tenth Percentile Sound Level)
Greenville, NC	75	75	$L_{max (slow)}$
Dallas, TX	49-59	56-66	L_{max}
Houston, TX	58	65	$L_{max (slow)}$
Miami, FL	55	60	L_{dn} (average over 24 hr period)
New York City, NY	50	60	L_{eq} (1 hour)
Sacramento, CA	50 - 70	55 - 75	L_{eq} (1 hour)
CT	54-59	64-69	Not Specified
IL	51	61	Not Specified
MI	57	57	L_{eq} (1 hour)
Lincoln, NE	50 +	60 +	L_{eq} (1 min)

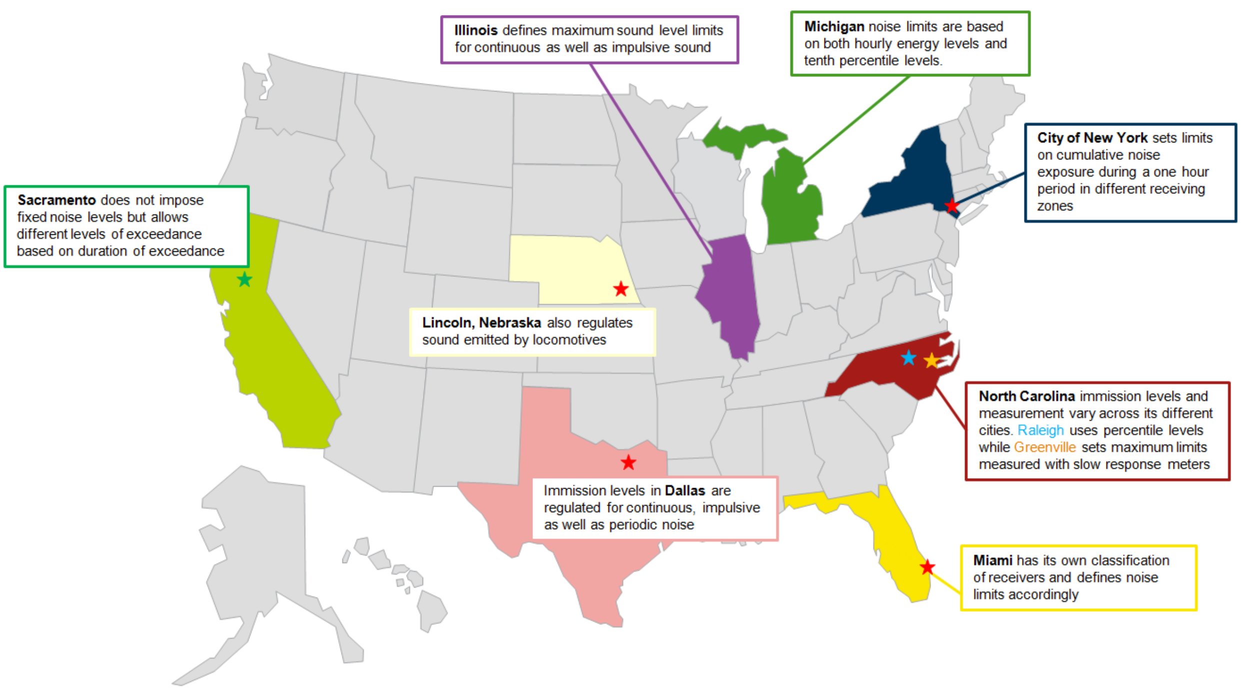


Figure 28: Comparisons of Selected US State and Local Noise Regulations

Figure 28 shows examples of variations in State and local noise regulations that include:

- Sacramento, CA, does not impose fixed noise levels, but allows different levels of exceedance based on duration of exceedance.

- Illinois defines maximum sound level limits for continuous as well as impulsive sound.
- Lincoln, NE, specifically regulates sound emitted by locomotives.
- Immission levels in Dallas are regulated for continuous, impulsive as well as periodic noise.
- Michigan noise limits are based on both hourly energy levels and tenth percentile levels.
- The City of New York sets limits on cumulative noise exposure during a 1-hour period in different receiving zones.
- North Carolina immission levels and measurement vary across its different cities. Raleigh uses percentile levels while Greenville sets maximum limits measured with slow response meters.
- Miami, FL, has its own classification of receivers and defines noise limits accordingly.

5.5 US: Rail Noise Regulation Summaries

Table 43 through Table 59 includes relevant sections of the US CFR related to railroad noise. The summaries follow the standardized template employed to allow ready comparison of the identified codes, standards, regulations and recommended practices for the EU, Asia, and US.

The summary template found in Figure 29 includes the key information for each identified code, standard, regulation, or recommended practice.

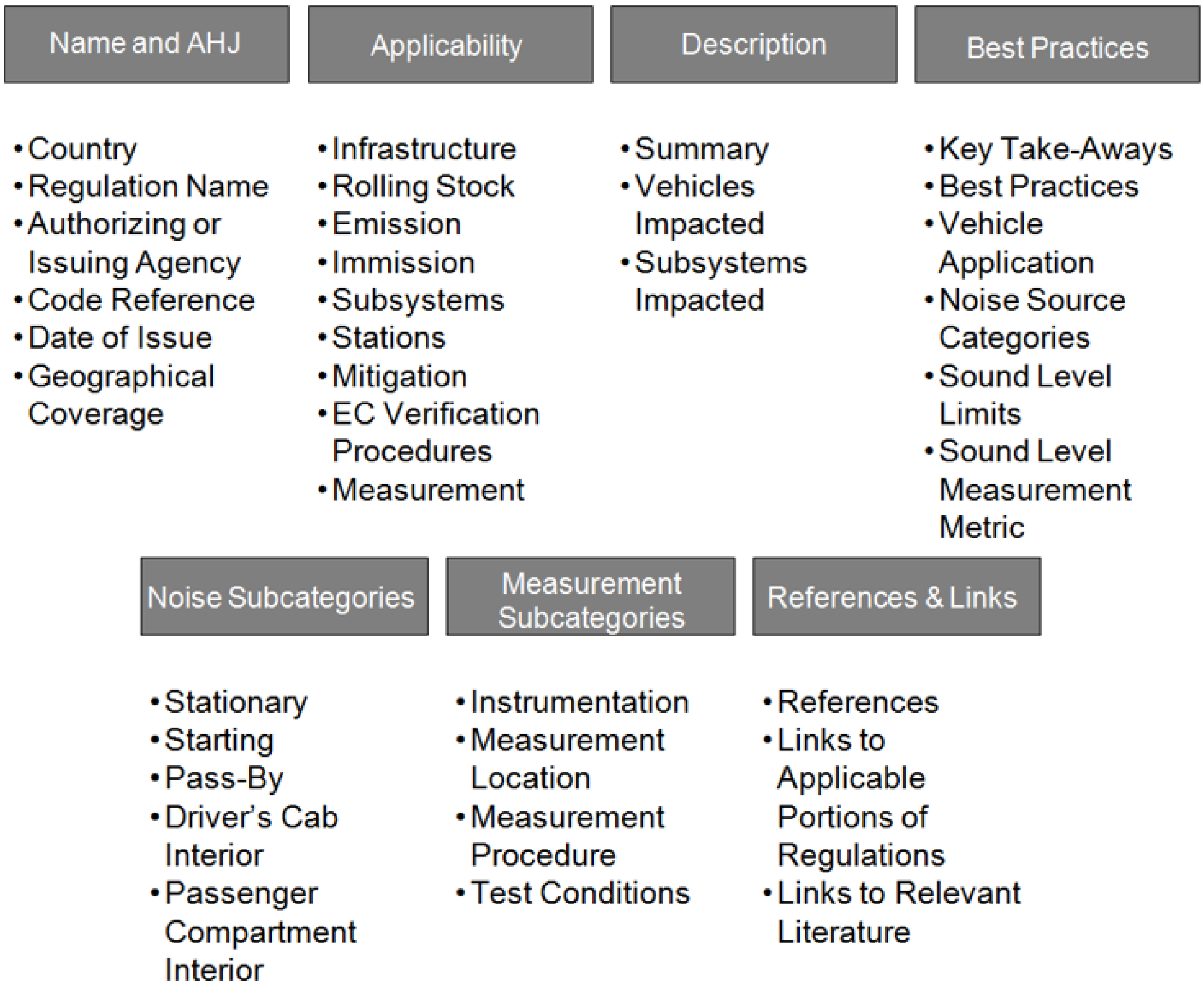


Figure 29: A Comparison of the Identified Codes, Standards, Regulations and Recommended Practices for EU, Asia, and US

Table 44: US Interstate Rail Carriers Noise Regulations [56]

Name	Interstate Rail Carrier Operations Standards	**Code**	40 CFR Part 201.11	**Date of Issue**	1980
Authorising / issuing agency	Environmental Protection Agency			**Geographical coverage**	US

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
	✓	✓						

Description

Regulates noise levels produced by locomotives under stationary conditions based on:

- Date of manufacture
- Throttle setting

Key take-outs / Best practice

Applies to	Noise Source	Sound level (dB) L_{max} (slow)
All locomotives manufactured on or before 31 Dec 1979	Idle Throttle Setting	73
	Other Settings	93
All Locomotives Manufactured After 31 December 1979	Idle Throttle Setting	70
	Other Settings	87
Switcher Locomotives Manufactured on or Before 31 December 1979	Idle Throttle Setting	70
	Other Setting	87

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise
✓			

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions

References

http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title40/40cfr201_main_02.tpl

Table 45: U.S. Interstate Rail Carriers Noise Regulations [56]

Name	Interstate Rail Carrier Operations Standards	**Code**	40 CFR Part 201.12	**Date of Issue**	1980
Authorising / issuing agency	Environmental Protection Agency			**Geographical coverage**	US

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
	✓	✓						

Description

Regulates noise levels produced by locomotives under moving conditions based on:

- Date of manufacture
- Throttle setting

Key take-outs / Best practice

Applies to	Sound level (dB)
All locomotives manufactured on or before 31 Dec 1979	96
All Locomotives Manufactured After 31 December 1979	90
Switcher Locomotives Manufactured on or Before 31 December 1979	90

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise
		✓	

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions

References

http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title40/40cfr201_main_02.tpl

Table 46: U.S. Interstate Rail Carriers Noise Regulations [56]

Name	Interstate Rail Carrier Operations Standards	**Code**	40 CFR Part 201.13	**Date of Issue**	1980
Authorising / issuing agency	Environmental Protection Agency			**Geographical coverage**	US

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
	✓	✓						

Description

Regulates noise levels produced by rail car operation based on speed

Key take-outs / Best practice

Speed	Sound level (dB)
Less than 72 kph or 45 mph	88
Greater than 72 kph or 45 mph	93

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise
		✓	

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions

References

http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title40/40cfr201_main_02.tpl

Table 47: U.S. Interstate Rail Carriers Noise Regulations [56]

Name	Interstate Rail Carrier Operations Standards	**Code**	40 CFR Part 201.14 - 15	**Date of Issue**	1980
Authorising / issuing agency	Environmental Protection Agency			**Geographical coverage**	US

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
	✓	✓						

Description

Regulates noise levels produced by retarders and car coupling operations

Key take-outs / Best practice

Source	Sound level (dB)
Retarder	83
Car Coupling	92

Car coupling will be found in compliance with this standard and the carrier will be considered in compliance, if the railroad demonstrates that the standard is exceeded at the receiving property measurement locations when cars representative of those found to exceed the standard are coupled at similar locations at coupling speeds of 8 mph or less.

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise
		✓	

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions

References

http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title40/40cfr201_main_02.tpl

Table 48: U.S. Interstate Rail Carriers Noise Regulations [56]

Name	Interstate Rail Carrier Operations Standards	**Code**	40 CFR Part 201.16	**Date of Issue**	1980
Authorising / issuing agency	Environmental Protection Agency			**Geographical coverage**	US

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
	✓	✓						

Description

Regulates noise levels produced by locomotive load cell test stands

Key take-outs / Best practice

Locomotive load cell test stands noise level must not exceed an A-weighted sound level of 78 dB when measured with slow meter response

All locomotive load cell test stands in a particular railroad facility are in compliance with this standard if the A-weighted sound level from the load cell does not exceed 65 dB at any receiving property measurement location near that particular railyard facility and when measured with fast meter response

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise
		✓	

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions

References

http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title40/40cfr201_main_02.tpl

Table 49: U.S. Interstate Rail Carriers Noise Regulations [56]

Name	Measurement Criteria	**Code**	40 CFR Part 201.21 - 22	**Date of Issue**	1980
Authorising / issuing agency	Environmental Protection Agency			**Geographical coverage**	US

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
								✓

Description

Describes quantities measured under test conditions and the required measurement instrumentation

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions
✓			

Key take-outs / Best practice

A-weighted sound levels for "fast" or "slow" meter response as defined in the American National Standard S1.41971

A sound level meter or alternate sound level measurement system that meets, as a minimum, all the requirements of American National Standard S1.419711 for a Type 1 (or S1A) instrument must be used with the "fast" or "slow" meter response characteristic. In the event that a Type 1 instrument is not available, the measurements may be made with a Type 2 but with the measured levels reduced by certain amount to account for possible instrument errors

References

http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title40/40cfr201_main_02.tpl
American National Standard S1.41971

Table 50: U.S. Interstate Rail Carriers Noise Regulations [56]

Name	Measurement Criteria	**Code**	40 CFR Part 201.23	**Date of Issue**	1980
Authorising / issuing agency	Environmental Protection Agency			**Geographical coverage**	US

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
								✓

Description

Describes test site, weather conditions and background noise criteria for measurement at a 30 meter (100 feet) distance of the noise from locomotive and rail car operations and locomotive load cell test stands

Key take-outs / Best practice

- Open space free of large, sound reflecting objects
- Top of at least one rail shall be visible
- Ground cover between vehicle and microphone shall be limited such that 80 % of the top of at least one rail along the entire test section of track be visible from a position 1.2 meters above the ground
- Ground elevation at the microphone location shall be within plus 1.5 meters or minus 3.0 meters of the elevation of the top of the rail
- Track shall exhibit less than a 2 degree curve
- Measurements shall not be made during precipitation
- Wind velocity shall be 12 mph or less. Gust wind of 20 mph is allowed

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions
	✓		✓

References

http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title40/40cfr201_main_02.tpl

Table 51: U.S. Interstate Rail Carriers Noise Regulations [56]

Name	Measurement Criteria	**Code**	40 CFR Part 201.24	**Date of Issue**	1980
Authorising / issuing agency	Environmental Protection Agency			**Geographical coverage**	US

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
								✓

Description

Procedures for measurement at a 30 meter (100 feet) distance of the noise from locomotive and rail car operations and locomotive load cell test stands

Key take-outs / Best practice

- Microphone shall be positioned 1.2 m above the ground
- For stationary locomotive and locomotive load cell test stand tests, the microphone shall be positioned on a line perpendicular to the track at a point 30 meters (100 feet) from the track centerline
- For rail car passby tests, the microphone shall be positioned on a line perpendicular to the track 30 meters (100 feet) from the track centerline
- Measurements shall be made when the locomotives have passed a distance 152.4 meters (500 feet) or 10 rail cars
- Brake squeal should not be present and tracks well maintained

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions
		✓	

References

http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title40/40cfr201_main_02.tpl

Table 52: U.S. Interstate Rail Carriers Noise Regulations [56] (1 of 2)

Name	Measurement Criteria	**Code**	40 CFR Part 201.25	**Date of Issue**	1980
Authorising / issuing agency	Environmental Protection Agency			**Geographical coverage**	US

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
								✓

Description

Measurement location and weather conditions for measurement on receiving property of the noise of retarders, car coupling, locomotive load cell test stands, and stationary locomotives

Key take-outs / Best practice

- Measurement locations on receiving property must be selected such that no substantially vertical plane surface, other than a residential or commercial unit wall or facility boundary noise barrier, that exceeds 1.2 meters (4 feet) in height is located within 10 meters (33.3 feet) of the microphone and that no exterior wall of a residential or commercial structure is located within 2.0 meters (6.6 feet) of the microphone. If the residential structure is a farm home, measurements must be made 2.0 to 10.0 meters (6.6 to 33.3 feet) from any exterior wall
- Average wind velocity should be 12 mph or less and max gust 20 mph
- No measurement may be taken when precipitation

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions
	✓		✓

References

http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title40/40cfr201_main_02.tpl

Table 53: U.S. Interstate Rail Carriers Noise Regulations [56] (2 of 2)

Name	Measurement Criteria	**Code**	40 CFR Part 201.25	**Date of Issue**	1980
Authorising / issuing agency	Environmental Protection Agency			**Geographical coverage**	US

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
								✓

Description

Procedures for the measurement on receiving property of retarder and car coupling noise

Key take-outs / Best practice

Retarder:
- Microphone must be located on receiving 1.2 - 1.5 m above ground

Car Coupling:
- Microphone must be located on receiving property and at a distance of at least 30 meters (100 feet) from the centerline of the nearest track

Both:
- At least 30 consecutive sounds must be measured. The measurement period must be between 60 and 240 minutes
- The energy average level for retarder sounds must be calculated and adjusted to get maximum A-weighted sound levels

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions
		✓	

References

http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title40/40cfr201_main_02.tpl

Table 54: Railroad Noise Emission Regulations [55]

Name	General Provisions	**Code**	49 CFR Part 210	**Date of Issue**	1983
Authorising / issuing agency	Environmental Protection Agency/Federal Railroad Administration			**Geographical coverage**	US

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation & Enforcement	EC Verification Procedures	Measurement
						✓		

Description

Prescribes minimum compliance regulations for enforcement of the Railroad Noise Emission Standards established by the Environmental Protection Agency in 40 CFR part 201.

Key take-outs / Best practice

- Railroads are responsible for taking corrective action on non compliant railroad equipment
- Any person who operates railroad equipment subject to the Standards in violation of any requirement of this part or of the Standards is liable to penalty
- Any person may petition the Administrator for a waiver of compliance with any requirement in this part

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions

References

http://www.ecfr.gov/cgi-bin/text-idx?SID=24ae0e7b83fc70b7d0b9b07facacecfc&mc=true&node=pt49.4.210&rgn=div5

Table 55: Railroad Noise Emission Regulations [55]

Name	Inspection and Testing	**Code**	49 CFR Part 210	**Date of Issue**	1983
Authorising / issuing agency	Environmental Protection Agency/Federal Railroad Administration			**Geographical coverage**	US

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation & Enforcement	EC Verification Procedures	Measurement
						✓		

Description

Prescribes minimum compliance regulations for enforcement of the Railroad Noise Emission Standards established by the Environmental Protection Agency in 40 CFR part 201.

Key take-outs / Best practice

- An FRA inspector is authorized to perform any prescribed noise test without prior notice for the purpose of determining whether railroad equipment is in compliance with the Standards and comply with 40 CFR Part 201.25: measurement locations, lack of noise barriers, wind velocity restrictions, precipitation restrictions, microphone placement, distance to track, number of pass-by measurements, retarder sound adjustment procedure.
- The sound level measurement system shall be checked not less than once each year by its manufacturer

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions

References

http://www.ecfr.gov/cgi-bin/text-idx?SID=24ae0e7b83fc70b7d0b9b07facacecfc&mc=true&node=pt49.4.210&rgn=div5

Table 56: Railroad Locomotive Safety Standards [61]

Name	RAILROAD LOCOMOTIVE SAFETY STANDARDS	**Code**	49 CFR Part 229.129	**Date of Issue**	1980
Authorising / issuing agency	Federal Railroad Administration			**Geographical coverage**	US

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
		✓		✓				

Description

Requires locomotives to be equipped with a warning device. Specifies a minimum and maximum sound levels that the warning device must produce.

Outlines the measurement procedures, instrumentation and test conditions required to determine compliance

Key take-outs / Best practice

- Each lead locomotive shall be equipped with a locomotive horn that produces a minimum sound level of 96 dB(A) and a maximum sound level of 110 dB(A) at 100 feet forward of the locomotive in its direction of travel.

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions
✓	✓	✓	✓

References

http://www.ecfr.gov/cgi-bin/text-idx?SID=24ae0e7b83fc70b7d0b9b07facacecfc&mc=true&node=pt49.4.210&rgn=div5

Table 57: Railroad Safety Standards [57]

Name	Use of Locomotive Horns at Public Highway-rail Grade Crossings	**Code**	49 CFR Part 222	**Date of Issue**	2005
Authorising / issuing agency	Federal Railroad Administration			**Geographical coverage**	US

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation & Enforcement	EC Verification Procedures	Measurement
						✓		

Description

This part prescribes standards for sounding locomotive horns when locomotives approach and pass through public highway rail grade crossings. This part also provides standards for the creation and maintenance of quiet zones within which locomotive horns need not be sounded. The provisions of this part are separate and severable from one another. If any provision is stayed or determined to be invalid, it is the intent of FRA that the remaining provisions shall continue in effect.

Key take-outs / Best practice

- Clearly defines when and how locomotive horns must be used.
- Penalties for non-compliance
- Issuance of this part pre-empts any state laws, rule, regulation or order governing the sounding of locomotive horns (with certain exceptions)

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions

References

http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title49/49cfr222_main_02.tpl

Table 58: Railroad Safety Standards [59]

Name	Hours of Service of Railroad Employees	**Code**	49 CFR Part 228.309(h)	**Date of Issue**	1978
Authorising / issuing agency	Federal Railroad Administration			**Geographical coverage**	US

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
			✓					

Description

Regulates noise environment in railroad employee sleeping quarters. Prescribes reporting and recordkeeping requirements with respect to the hours of service of certain railroad employees and certain employees of railroad contractors and subcontractors; and establishes standards and procedures concerning the construction or reconstruction of employee sleeping quarters.

Key take-outs / Best practice

- Establishes the maximum noise level which will be regarded as the level permitting "an opportunity to rest."
- The interior noise should not exceed an Leq(8) value of 55 dB(A)
- This regulation is taken into consideration during the construction (or reconstruction) of railroad employee sleeping quarters on railroad property.

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions

References

https://www.gpo.gov/fdsys/pkg/CFR-2010-title49-vol4/pdf/CFR-2010-title49-vol4-part228.pdf

Table 59: Railroad Safety Standards [58]

Name	Occupational Noise Exposure	**Code**	49 CFR Part 227	**Date of Issue**	2007
Authorising / issuing agency	Federal Railroad Administration			**Geographical coverage**	US

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
			✓					

Description

This part establishes noise exposure standards for railroad employees who regularly encounter their predominant occupational noise exposure in the locomotive cab.

Key take-outs / Best practice

- Limits employee noise exposure to an 8-hour time-weighted average (TWA) of 90 dB(A)
- Requires railroads to develop and implement a noise monitoring program and administer an effective hearing conservation program for those employees who are exposed to noise at or above an 8-hour TWA of 85 dB(A).

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise
			✓

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions

References

http://www.ecfr.gov/cgi-bin/text-idx?SID=16d7ab1fcdfa781ffbfddc28cc00a4ce&node=pt49.4.228&rgn=div5

Table 60: Railroad Safety Standards [60]

Name	Locomotive cab noise.	Code	49 CFR Part 229.121	Date of Issue	1980
Authorising / issuing agency	Federal Railroad Administration			Geographical coverage	US

Applicability

Infrastructure	Rolling Stock	Emission	Immission	Subsystems	Stations	Mitigation	EC Verification Procedures	Measurement
			✓					

Description

Regulates noise limits inside locomotive cab based on different periods of exposure. Specifies instrumentation, procedure and test conditions for determination of compliance

Noise Subcategories

Stationary Noise	Starting Noise	Pass-by Noise	Driver's Cab Interior Noise
			✓

Measurement Subcategories

Instrumentation	Location	Procedure	Test Conditions
✓		✓	✓

Key take-outs / Best practice

- Locomotives manufactured after October 29, 2007, must have cab noise levels that average less than or equal to 85 dB(A), with an upper 99% confidence limit of 87 dB(A).
- A railroad shall not make any alterations that cause the average sound level for that locomotive design or model to exceed:
  (i) 82 dB(A) if the average sound level for a locomotive design or model is less than 82 dB(A); or
  (ii) 85 dB(A) if the average sound level for a locomotive design or model is 82 dB(A) to 85 dB(A),
- Repairs to correct excessive cab noise levels must be completed before the next periodic inspection as required by § 229.23 and documented

References

https://www.law.cornell.edu/cfr/text/49/229.121

5.5.1 US Local and State Noise Immissions Regulations

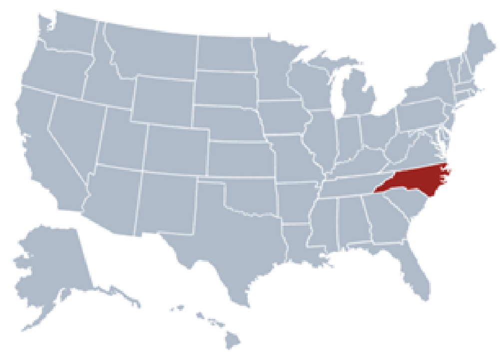
As noted in Section 5.3, US Enforcement of Railroad Noise Regulations, a survey of local and State noise immissions regulations was conducted, although these standards are not enforceable on US railroads. This was not meant to be an exhaustive search of all noise regulations, cut rather an effort to define the range of local standards for noise levels. Noise regulations for locations evaluated during the current study do not have consistent descriptors (metrics) or maximum allowable limits. Figure 30 through Figure 41 summarizes the permitted immissions levels, dB(A), at residential property lines from industrial sources, included in the following States and cities:

- Raleigh and Greenville, NC [176]
- Dallas, TX [175]
- Miami, FL [178]
- New York City, NY
- Connecticut [182]
- Illinois [180]
- Michigan [181]
- Sacramento, CA [179]

Raleigh land-use maximum noise levels dB(A)
(L10, 100 meas slow @ 10 sec increments)

Source	Receiver		
	Residential	Business	Industrial
Residential	45 (Night) 55 (Day)		
Business	50 (Night) 57.5 (Day)	55 (Night) 60 (Day)	
Industrial	55 (Night) 62.5 (Day)	60 (Night) 65 (Day)	65 (Night) 70 (Day)

North Carolina immission levels and measurement vary across its different cities with some being stricter than others



Greenville land-use maximum noise levels dB(A)
(Measurement Lmax,slow) *

Source	Receiver		
	Residential	Business	Industrial
Residential	55 (Night) 60 (Day)		
Business	60 (Night) 65 (Day)	60 (Night) 65 (Day)	
Industrial	75	75	75

* Some exceptions apply on weekends and holidays

Figure 30: Local and State Noise Immission Regulations: North Carolina[12]

[12] Reference: Article IV. Noise Regulation

Noise Limits dB(A)at receiver property line in Dallas

Receiver	Limit
Residential	56
Office / Retail	63
LC/HC/I-1/I-2 district	65
I-3	70

Immission levels in Dallas are regulated for continuous, impulsive, as well as periodic noise

Noise is present at nighttime . . . . Subtract 7db

Noise is impulsive (meter reading changes at a rate greater than 10 decibels per second). . . . . Subtract 7db

Noise has an "On Time" of no more than:	And an "Off Time" between successive "On Times" of at least:		
0.5 Minutes	1/2	Hour/	
5.0 Minutes	1	Hour/	Add 10 Decibels to permitted level
10.0 Minutes	2	Hours/	
20.0 Minutes	4	Hours/	

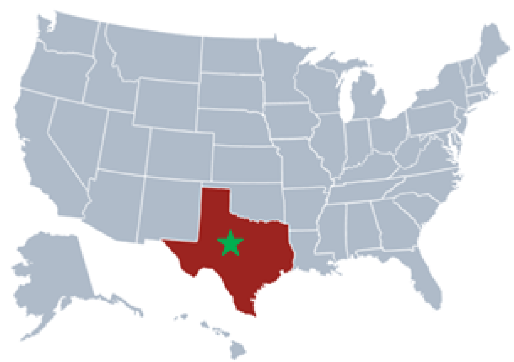


Figure 31: Local and State Noise Immissions Regulations: Dallas, TX[13]

[13] Reference: Dallas City Attorney. Article VI, Environmental Performance Standards

Noise limits at property line in Miami

Receiver	Between 10 p.m. and 7 a.m.	Between 7 a.m. and 10 p.m.
Single-family	5 dBA above ambient or maximum of 55 dBA	10 dBA above ambient or maximum of 60 dBA
Multifamily, institutional, parks and noise-sensitive zones	5 dBA above ambient or maximum of 60 dBA	10 dBA above ambient or maximum of 65 dBA
Retail commercial (offices, retail, restaurants and movies)	5 dBA above ambient or maximum of 65 dBA	10 dBA above ambient or maximum of 65 dBA
Wholesale commercial and industrial	5 dBA above ambient or maximum of 70 dBA	10 dBA above ambient or maximum of 75 dBA

Miami noise ordinances permit sound levels that are within max threshold or not more than 5 to 10 dB(A) above ambient

Figure 32: Local and State Noise Immissions Regulations: Miami, FL [178]

Noise limits at property line in New York city (Leq in dB(A) measured during any one hour period)

Receiver	Between 10 p.m. and 7 a.m.	Between 7 a.m. and 10 p.m.
Noise quality zone N-1 (Low density residential RL; land use zones R-1 to R-3)	50	60
Noise quality zone N-2 (High density residential RH; land-use zones R-4 to R-10)	55	65
Noise quality zone N-3 (All Commercial and manufacturing land-use zones)	70	70

The City of New York sets limits on cumulative noise exposure during a one hour period in different receiving zones

Figure 33: Local and State Noise Immissons Regulations: New York City [175]

- The State of Connecticut divides noise sources and receivers into 3 categories: Residential, Industrial and Commercial
- Noise limits at residential property are further separately based on time of day

Connecticut land-use maximum noise levels dB(A)

Source	Receiver			
	Residential (Day)	Residential (Night)	Commercial	Industrial
Residential	55	45	55	62
Commercial	55	45	62	62
Industrial	61	51	66	70

Allowable exceedance:
- 3 dB if the exceedance occurs for 15 minutes or less
- 6 dB if 7 ½ minutes or less
- 8 dB if 3 minutes or less

The state of Connecticut assigns dB(A) limits based on source/receiver categories and allows exceedance based on noise duration

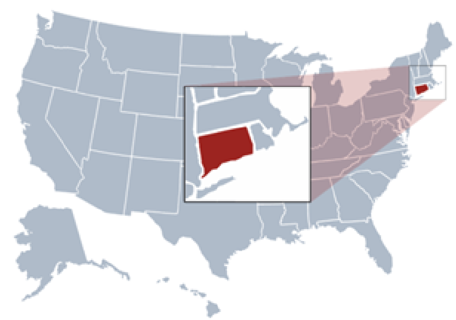
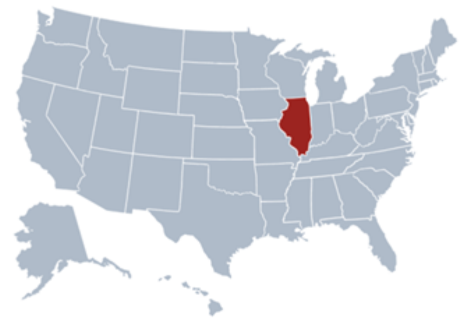


Figure 34: Local and State Noise Immissions Regulations: Connecticut [175]

- Impulsive sound are measured with the fast response A-weighting
- Limit for impulsive sound are 8 dB lower on an average than the land-use levels

The State of Illinois noise ordinance includes land-use noise limits as well as thresholds for highly impulsive sounds



Illinois land-use maximum noise levels dB(A)

Source	Receiver		
	Residential (Day)	Residential (Night)	Commercial
Residential	55	44	55
Commercial	55	44	62
Industrial	61	51	66

Illinois noise limits dB(A) for impulsive sound

Source	Receiver		
	Class A (Daytime)	Class A (Nighttime)	Class B
Class A	47	37	47
Class B	47	37	54
Class C	53	43	58

Figure 35: Local and State Noise Immissions Regulations: Illinois [175]

Either $L_{eq(h)}$ or $L_{10(h)}$ may be used for the project but not both

Michigan has assigned both hourly energy levels and tenth percentile levels that are independent of noise source

Michigan land-use maximum noise levels dB(A)

Activity Category	Receiver		
	Leq(h)	L10(h)	Description of Activity Category
A	57 (Exterior)	60 (Exterior)	Lands of which serenity are of extraordinary significance, serve an important public need, and where preservation of those quantities is essential to serve the intended purpose
B	67 (Exterior)	70 (Exterior)	Picnic areas, recreation areas, playgrounds, active sports areas, parks, residences, hotels, schools, churches, libraries and hospitals
C	72 (Exterior)	75 (Exterior)	Developed lands not included in Category A or B
D	-	-	Undeveloped lands
E	52 (Interior)	55 (Interior)	Residences, hotels, schools, churches, libraries and hospitals

Figure 36: Local and State Noise Immissions Regulations: Michigan [175]

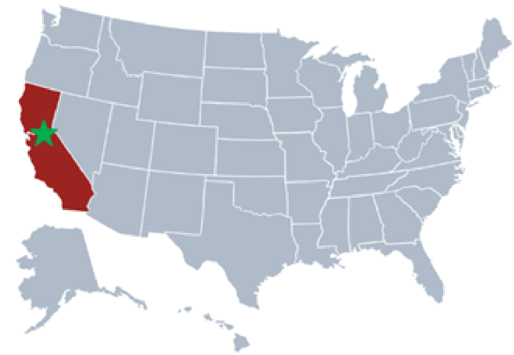
$L_{eq(h)}$ is used to determine the exceedance over the prescribed limits

Noise limits at residential property dB(A)	Day	Night
	55	50

Sacramento does not impose fixed noise levels but allows different levels of exceedance based on duration of exceedance

Allowable exceedance in dB(A) based on duration of exceedance

Cumulative Duration of the Intrusive Sound	Allowable exceedance
30 mins per hour	0
15 mins per hour	+5
5 mins per hour	+10
1 min per hour	+15
Never to exceed	+20

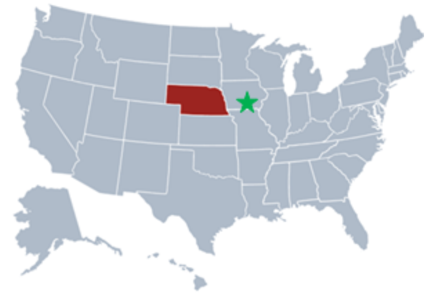


Certain exceptions apply to these noise regulations

Figure 37: Local and State Noise Immissions Regulations: Sacramento, CA[14] [175]

[14] Reference: City of Sacramento, CA, Noise Ordinances. Chapter 8.68 Noise Control.

- Separate maximum sound limits for noise sensitive and residential zones
- Maximum sound level limits for impulsive and continuous sounds
- Regulates the sound emitted by locomotives both under stationary and moving conditions



Noise limits at residential property dB(A) measured as 1 minute Leq

	Day	Night
	60	50

Peak dB(A) limits at residential and noise sensitive zones

Number of Peaks per hour	Day Limit	Night Limit
1	85	75
2	79	69
4	73	63
8	67	57
16+	61	51

The City of Lincoln has a number of less common, but useful, provisions in their noise ordinance

Maximum Continuous Sound level dB(A)

Duration	Limit
24 hrs	90
12 hrs	93
6 hrs	96
3 hrs	99
1.5 hrs	102
45 mins	105
22 mins	108

Figure 38: Local and State Noise Immissions Regulations: Lincoln, NE [175]

5.6 Impact of Current US Noise Regulations on High Speed Rail

Comparisons have been made between measured noise emissions limits of currently available high-speed trainsets and existing US noise regulations, specifically the noise limits defined in 40 CFR 201 and 49 CFR Part 210. The purpose of this exercise was to evaluate potential conflict with the existing regulations if current technology trainsets are placed in operation at speeds in excess of 200 mph (322 km/h).

WSP Parsons Brinckerhoff has prepared a memo on this topic and excerpts have been incorporated into this section [183]. The CaHSRA anticipates putting trainsets into operation having the capability of traveling at speeds of 220 mph (354 km/h) in revenue service. To determine whether these trainsets will exceed the current US railroad noise regulations, passby noise measurements for high speed trains currently in operation within the EU and Asia (referred to "HS Train Model x" in Table 61) were obtained and corrected for differences in the measurement locations (relative to the train). Table 61 summarizes the results below:

Table 61: Measured/Modeled High Speed Train Set Passby Noise Levels

Noise Standard	HS Train Model 1	HS Train Model 2	HS Train Model 3	HS Train Model 4	HS Train Model 5	HS Train Model 6	HS Train Model 7
Passby Noise per EU TSI	97 dB(A)	95 dB(A)	94.1 dB(A)	96.1 dB(A)	> 92.6 dB(A)	96.6 dB(A)	92 dB(A)
Corrected to US Regulation 40 CFR § 201.12(b) Measurement	95.4 dB(A)	93.4 dB(A)	92.5 dB(A)	94.5 dB(A)	>91 dB(A)	95 dB(A)	90.4 dB(A)

*Train Speed: 218 mph (350 km/h)

*From analysis conducted by Banko and Chirco [183]

*Some values approximated from available published reports

These calculations indicate that currently available high-speed train sets operating at 218 mph (350 km/h) will exceed the 40 CFR § 201.12(b) maximum passby noise limit of 90 dB(A). These noise levels will vary depending upon the wheel and rail surface conditions, the type of track being used (e.g., ballast, slab, and acoustic absorbing), and train speed. It has been suggested that Federal noise regulations be reconsidered for high speed trains with preference for standards that are indexed to train speed and include detailed specifications for testing (i.e., track and wheel roughness conditions).

6. Compare and Contrast Regulations, Measurement Approaches, and Compliance

To facilitate interpretation and assessment of the information presented in Sections 2 through 5 (information categories include: identified codes, standards, regulations, recommended practices, measurement approaches, and compliance enforcement and associated penalties), comparison tables were assembled for each category from which differences were identified. Discussions of these differences were included during the stakeholder outreach interviews discussed in Section 7.

6.1 Agencies Having Jurisdiction

Based on research on US, EU, and Asian high-speed rail noise codes, standards, and regulations, it has been determined that emissions are overseen by country (or union of countries) agencies and immissions are overseen by State, provincial or local agencies. Table 62 provides a general overview of organization roles related to both emissions and immissions.

Table 62: Government Agencies Responsible for Noise Regulations and Compliance

	Emissions High Speed Rail Source Noise	Immissions Receivers, Perceived Noise
Overseeing Agency	Country, Union, Federal	State/Province, Local
Enforcement Agency	Country, Union, Federal	State/Province, Local
Compliance Responsibility	Vehicle Manufacturer	Railroad, Transportation System Operator
Measurement Procedures	Technical/Professional Organization	Technical/Professional Organization

In addition, the agencies having jurisdiction have been identified for development and enforcement of railroad noise regulations as summarized in Table 63:

Table 63: AHJs for Countries Included in Study

Location	Emissions	Immissions
European Union	European Commission, European Railway Agency, Technical Standards for Interoperability Individual member country regulations (e.g. Italy)	• Infrastructure Manager • Country and Regional Noise Maps and Noise Management Action Plans (required by EU)
United States	US Environmental Protection Agency US Department of Transportation, Federal Railroad Administration	• US Department of Labor, Occupational Safety and Health Administration • Individual States • Local & Regional Agencies (cities, counties)
China	Ministry of Transportation of PRC	Ministry of Environmental Protection
Japan	Ministry of Land, Infrastructure, Transport & Tourism	Ministry of Environment, Government of Japan

6.2 Rolling Stock Noise Regulations Comparisons

It is challenging to make direct comparisons of railroad noise regulations for rolling stock due to:

1. Sound pressure measurement methods vary by jurisdiction.

2. Specifications for locations of sound measurements relative to the train vary by jurisdiction.
3. Some jurisdictions (e.g., China and Japan) specify immissions levels only and thus allow stationary barriers or other noise attenuation methods to be present during the measurements.
4. Some noise measurement methods account for variations in train speed while others do not.
5. Noise measurement equipment and procedures vary by jurisdiction.

Table 64 summarizes noise regulations applying to rolling stock for the US, EU, China, and Japan.

- EU and US rolling stock regulations are based on single passby events
- Asian regulations are based on a defined number of passby events.

Table 64: Rolling Stock Noise Regulations Comparisons

For Moving Trains		Applicable Rolling Stock	Sound Pressure Measurement Method	Train Speed (km/h)	Maximum Allowable Sound Pressure, dB(A)	Measurement Location	
Location	Reference					Elevation (m)	Distance from Track Centerline (m)
US	40 CFR Part 201.12	Locomotives	L_{max}(fast)	all	90	1.2 (above top or rail)	30
	40 CFR Part 201.13	Rail Cars	L_{max}(fast)	>45	93		
EU	TSI Noise 2014	Locomotives	$L_{pAeq,Tp}$	80	84	1.2 (above top or rail)	7.5
				250	99		
		EMUs		80	80		
				250	95		
		DMUs		80	81		
				250	96		
China	GB 12525-90	All Rolling Stock	L_d	all	70	1.2 (above top or rail)	30
			L_n		60		
Japan	Environmental Law 91 of 1993	High Speed Rail	L_{pASmax}	all	75*	1.2 above ground	25
		General Rail	L_d	all	60*		12.5
			L_n		55*		

*Sound pressure level at receiver allows use of barriers and other noise path attenuation methods.

Comparisons between $L_{max\ fast}$ and $L_{pAeq,Tp}$ can be performed by calculating the sound exposure level (SEL) for each using a procedure defined by Hanson et al. (2012) in Appendix C of the report.

6.3 Comparisons of Measurement Methods, Compliance, and Best Practices

Table 65 through Table 76 include comparisons of the regulated rail noise measurement procedures and equipment specifications, compliance enforcement, penalties for noncompliance, as well as strategies and techniques for achieving compliance for the US, EU, China, and Japan.

Table 65: Rail Noise Measurement Procedures and Measurement Equipment Comparisons

Location	Sound Measurement	
	Procedures	**Equipment**
US	40 CFR Part 210: Railroad Noise Emission Compliance Regulations	Sound Level Meter: ANSI S 1.4-1971, Meter Type 1 (S1A) or Type 2 (S2A)
		Microphone Windscreen and Acoustic Calibrator: ANSI Type 1 or 2.
EU	EN ISO 3095:2013: Acoustics - Railway Applications - Measurement of Noise Emitted by Railbound Vehicles	EN 60942, Electroacoustics — Sound calibrators (IEC 60942:2003)
		EN 61260, Electroacoustics — Octave-band and fractional-octave-band filters (IEC 61260:1995)
	Member Country Noise Management Action Plans as required by the EU Environmental Noise Directive	EN 61672-1, Electroacoustics — Sound level meters — Part 1: Specifications (IEC 61672-1:2002)
		EN 61672-2, Electroacoustics — Sound level meters — Part 2: Pattern evaluation tests (IEC 61672-2:2003)
		EN ISO 266, Acoustics — Preferred frequencies (ISO 266:1997)
China	GB/T 15190 – Technical specifications to determine suitable areas for environmental noise	GB 3785 – Sound level meter power, sound performance & testing methods
	GB/T 17181 – Technical specification for integrating averaging sound level meters	
	GB/T 50280 – Standards for basic terminology of urban town planning	GB/T 15173 – Sound Calibrator
Japan	ISO 11201:95 Acoustics - Noise Emitted by Machinery and Equipment (Free Field over a Reflecting Plane) and ISO 11202:95 Acoustics - Noise Emitted by Machinery and Equipment (Environmental Corrections)	International Electric Standards Conference (IESC) Publication 179

Table 66 includes comparisons of measurement procedures and equipment as specified in the identified regulations. Acoustics experts interviewed during the industry outreach portion of the study agreed that the identified procedures and equipment were adequate to support the corresponding regulations.

Table 66: Rail Noise Regulations Enforcement Comparisons

Location	Compliance Requirements	Enforcement
US	40 CFR Part 210: Railroad Noise Emission Compliance Regulations, 49 CFR Part 227 Occupational Noise Exposure	Enforcement of FRA noise regulations is the responsibility of regional offices. This includes quiet zone development (https://www.fra.dot.gov/Page/P0244). Noise related issues are addressed by industrial hygienists assigned to each region. Discussions with industrial hygienests indicates noise complaints related to rolling stock are rare (most noise complaints are related to horn noise) and none had any recollection of fines being imposed.
EU	EU Commission Regulation 1304 (2014): Technical Specification for Interoperability (TSI) Relating to the Subsystem "Rolling Stock - Noise"	The TSI states: 'Operation of the trans-European high-speed rail system must remain within the statutory noise nuisance limits.' Failure to meet rolling stock emissions noise requirements will result in the non-certification by the European Rail Agency, ERA (failure to meet criterion for admittance - acceptance).
	EU Directive 2002/49/EC Relating to the Assessment and Management of Environmental Noise	According to The Second Implementation Review of the Environmental Noise Directive, Workshop Paper 1, Emerging Findings (2015), the first implementation review report highlighted that most Member States (21) had noise limit values which were legally enforced and whose transgression should in theory have led to measures to control noise and/or insulate exposed populations, and/or in some countries the imposition of penalties on those responsible for the source. In practice, Strategic Noise Maps revealed that their transgression neither led to measures being implemented nor any specific action being taken, although they did inform Noise Action Plans in those countries. The Round 2 Implementation Review responses indicated that no change in enforcement of noise limit values (LVs) have been made. However, among the 75% of Member States that have noise limits, less than 25% were able to confirm categorically that these LVs were (fully) enforced.
China	Defined in People's Republic of China Ministry of Environmental Protection Regulation GB 3096 - 2008, Environmental Quality Standards for Noise (China References 5 and 6).	China has imposed fines for non compliance with high speed rail noise limits. For example, during 2007, the Taiwan High Speed Rail Corporation was fined NT$1.5 million and was given one month to bring the trains into compliance (*The China Post* , 16 September 2016, THSRC Facing Fines for Noise Pollution, http://www.chinapost.com.tw/news/2007/01/16/100104/THSRC-facing.htm)
Japan	Japan Ministry of the Environment, Environmental Quality Standards for Shinkansen, Law No. 91.	According to Tatsuo Maeda, Protecting the Trackside Environment (*Japan Railway & Transport Review,* Vol. 22, December 1999), the Shinkansen trains have all met the required noise levels of 70 dB(A) max in residential areas and 75 dB(A) max in commercial, industrial, and rural areas as of 1999, so no penalties for non-compliance have been required (peak noise levels of 20 Shinkansen trains, 300 km/hr, 1.2 m above tracks, 25 m from track centerline.

Table 67: Rail Noise Regulations Compliance and Penalties Comparisons

Location	Compliance and Penalties	
	Compliance Requirements	Penalties for Non-Compliance (and/or Incentives to Comply)
US	40 CFR Part 210: Railroad Noise Emission Compliance Regulations, 49 CFR Part 227 Occupational Noise Exposure	**§ 210.11 Waivers:** (a) Any person may petition the Administrator for a waiver of compliance with any requirement in this part. A waiver of compliance with any requirement prescribed in the Standards may not be granted under this provision; **§ 210.13 Penalty:** Any person who operates railroad equipment subject to the Standards in violation of any requirement of this part or of the Standards is liable to penalty as prescribed in Section 11 of the Noise Control Act of 1972 (42 U.S.C. 4910), as amended. SEC. 11 [42 U.S.C. 4910] Enforcement of the Noise Conrol Act of 1972: "Any person who willfully or knowingly violates ... this Act shall be punished by a fine of not more than $25,000 per day of violation, or by imprisonment for not more than one year, or by both. If the conviction is for a violation committed after a first conviction of such person under this subsection, punishment shall be by a fine of not more than $50,000 per day of violation, or by imprisonment for not more than two years, or by both." In addition, there are civil penalties: "Any person who violates ... this Act shall be subject to a civil penalty not to exceed $10,000 per day of such violation."
EU	EU Commission Regulation 1304 (2014): Technical Specification for Interoperability (TSI) Relating to the Subsystem "Rolling Stock - Noise"	Failure to meet rolling stock emissions noise requirements will result in the non-certification by the European Rail Agency, ERA (failure to meet criterion for admittance - acceptance). According to *Railway Noise in Europe,* published by the International Union of Railways (UIC, 2016), ERA, on behalf of the European Commission, sets noise emissions limits for railway vehicles being approved for the European market. According to European Parliament Structural and Cohesion Policies Report, *Reducing Railway Noise Pollution* (2012), the following incentives are offered for achieving noise reductions prior to legislated mandates: reduced rail access charges and public subsidies for development and purchase of low-noise equipment.
	EU Directive 2002/49/EC Relating to the Assessment and Management of Environmental Noise	The EU Environmental Noise Directive does not set limits but imposes process requirements for each country. National laws impose immission limits based on time of day, location and use-designation of nearby buildings. These limits are source-independent and not specifically related to high speed rail. Slight differences in implementation and enforcement exist between countries.
China	Defined in People's Republic of China Ministry of Environmental Protection Regulation GB 3096 - 2008, Environmental Quality Standards for Noise (China References 5 and 6).	**Article 4:** The State Council and local people's governments at various levels shall incorporate prevention and control of environmental noise pollution into their environmental protection plans and adopt economic and technological policies and measures to protect the acoustic environment. **Article 16:** Units that produce environmental noise pollution shall take measures to control it and pay fees for excessive emission of such pollution according to the regulations of the State. The fees collected from excessive emission of pollution must be used for prevention and control of pollution and may not be appropriated for any other use. **Article 17:** Any enterprise or institution that produces serious environmental noise pollution in an area where noise-sensitive structures are concentrated shall be ordered to control the pollution within a time limit. The unit that is ordered to control the pollution within a time limit must accomplish the task on schedule.
Japan	Japan Ministry of the Environment, Environmental Quality Standards for Shinkansen, Law No. 91.	The Environmental Quality Standards for high speed train noise must be achieved. There is no monitary penalty for non-compliance. Instead, the required noise levels of 70 dB(A) max in residential areas and 75 dB(A) max in commercial, industrial, must be met or the trains are not allowed to operate. Typically, time periods that vary from 1 to 3 years are allowed to achieve compliance if violations are found.

Table 68: Rail Noise Compliance Approaches at Noise Source (1 of 3) [12] [23] [28]

Location	Compliance Requirements	At the Noise Source		
		Modification	Application	Examples
US	40 CFR Part 210: Railroad Noise Emission Compliance Regulations, 49 CFR Part 227 Occupational Noise Exposure	**Vehicle Modifications:**	Mechanical Equipment	bearings, propulsion equipment (motors, generators), sound insulation, mufflers, speed restriction zones
			Ancillary Equipment	HVAC/ventilation systems, equipment cooling
			Aerodynamics	vehicle body design, skirts, inter-car gasp seals, wheel truck covers, locomotive nose, smooth exterior surfaces, pantograph design
			Underbody and Wheels	damped wheels, resilient wheels, wheel flat removal, under-car noise absorption, spin-slide control
		Rail & Wheel Modifications:	Wheel/Rail Interface	rail grinding, increased turn radii, rail lubrication, rail gap reductions

Table 69: Rail Noise Compliance Approaches at Noise Source (2 of 3) [78][90] [184] [185] [186]

Location	Compliance Requirements	At the Noise Source		
		Modification	Application	Examples
EU	EU Commission Regulation 1304 (2014): Technical Specification for Interoperability (TSI) Relating to the Subsystem "Rolling Stock - Noise"	**Vehicle Modifications:**	Mechanical Equipment	propulsion equipment (motors, generators), sound insulation, mufflers, bearings, speed restrictions deemed not viable (UIC 2008)
			Ancillary Equipment	HVAC/ventilation systems, equipment cooling
			Aerodynamics	vehicle body design, skirts, inter-car gasp seals, wheel truck shrouds, locomotive nose, smooth exterior surfaces, pantograph design, pantograph fairings and shields
	EU Directive 2002/49/EC Relating to the Assessment and Management of Environmental Noise		Underbody and Wheels	improved composite disc brakes, wheel flat removal, under-car noise absorption, wheel geometry to reduce radiated noise, incorporation of dampers and absorbers into wheel design, resilient wheels
		Rail & Wheel Modifications:	Wheel/Rail Interface	rail grinding including acoustic grinding, reductions in rail surface corrugation and roughness, tuned rail dampers (elastomers), friction modifiers (rail lubrication), wheel geometry modifications to reduce vibrations, rail pad stiffness to reduce vibrations

Table 70: Rail Noise Compliance Approaches at Noise Source (3 of 3) [156] [158] [164] [187] [188]

Location	Compliance Requirements	At the Noise Source		
		Modification	**Application**	**Examples**
China and Japan	Defined in People's Republic of China Ministry of Environmental Protection Regulation GB 3096 - 2008, Environmental Quality Standards for Noise. Japan Ministry of the Environment, Environmental Quality Standards for Shinkansen, Law No. 91.	**Vehicle Modifications:**	Mechanical Equipment	reducing weight of rolling stock, reducing gear noise, improved bearings, optimize axle arrangement, reduce wheel flats, optimize suspension system, bogie covers, bolsterless bogies
			Ancillary Equipment	lower noise air conditioning equipment and ventilation air inlets and exhausts
			Aerodynamics	reducing the number of pantographs, vehicle body design, wheel shrouds, locomotive nose (including micropressure waves at tunnels), pantograph design, fairings, and shields, smooth gap covers, smooth exterior surfaces and window structures, pantograph noise insulation plate, sound absorbing panels installed on train underbody and skirts
			Underbody and Wheels	under-car noise absorption, improved disk brakes, wheel dampers and absorbers
		Rail & Wheel Modifications:	Wheel/Rail Interface	rail grinding, increased turn radii, rail lubrication, rail gap reductions, increase track rigidity, use of floating slab track

Table 71: Rail Noise Compliance Approaches Along Noise Path (1 of 3) [12] [23] [28]

Location	Compliance Requirements	Along the Source-to-Receiver Propagation Path		
		Modification	Application	Examples
US	In the US, there are no federal noise immissions requirements. Thus, path mitigations are applicable only to noise reductions required under environmental impact assessments such as under NEPA.	**Sound Barriers**	Barrier Location and Design	Near passing vehicle (height, absorption & reflection properties, barrier gaps)
				At edge of right-of-way
			Sound Path	Alternation of horizontal and vertical alignments (e.g. trenches), acquisition of buffer zones (increasing distance from source to receiver)
		Reflective Surfaces	Ballast and track support	At-grade ballast, elevated track ballast (increase absorption of ballast surface)
				Resilient track support (absorbs noise and vibration)

Table 72: Rail Noise Compliance Approaches Along Noise Path (2 of 3) [78] [90] [184] [185] [186]

Location	Compliance Requirements	Along the Source-to-Receiver Propagation Path		
		Modification	Application	Examples
EU	EU Directive 2002/49/EC Relating to the Assessment and Management of Environmental Noise	**Sound Barriers**	Barrier Location and Design	Barriers placed within shadow zone (to block line of sight from noise source to receiver), sound adsorption material placed on side of barrier facing noise source
				Barrier angled to reflect noise skyward
			Sound Path	Placing track in trenches, increasing distance from source to receiver
		Reflective Surfaces	Ballast and Track Support	At-grade ballast, resilient padding for slab track, damping matrials distributed between ballast-less tracks
				Resilient track supports and baseplates (absorbs noise and vibration)

Table 73: Rail Noise Compliance Approaches along Noise Path (3 of 3) [156] [158] [164] [187] [188]

Location	Compliance Requirements	Along the Source-to-Receiver Propagation Path		
		Modification	Application	Examples
China and Japan	Defined in People's Republic of China Ministry of Environmental Protection Regulation GB 3096 - 2008, Environmental Quality Standards for Noise. Japan Ministry of the Environment, Environmental Quality Standards for Shinkansen, Law No. 91.	**Sound Barriers**	Barrier Design	Barriers with noise absorbing surfaces located as near tracks as pratical, tunnel hoods, sound absorbing pads below rails, bridge beam supports to reduce structure-induced noise.
		Reflective Surfaces	Ballast and track support	Spacers and grooved mats below slap tracks, damping materials at upper surface of slab tracks, lower elastic coefficient of track pads

Table 74: Rail Noise Compliance Approaches at the Receiver (1 of 3) [12] [23] [28] [189 [190]

Location	Compliance Requirements	At the Receiver	
		Modification, Application	Examples
US	In the US, there are no federal noise immissions requirements. Thus, path mitigations are applicable only to noise reductions required under environmental impact assessments such as under NEPA.	**Sound Barriers**	Flat surface and acoustical absorption designs: most effective when located near source or receiver; design process includes determination of height, absorption & reflection properties, and barrier gaps.
		Building Modifications	Low acoustical transmission windows and walls, caulk and seal gaps; HVAC system improvements.

Table 75: Rail Noise Compliance Approaches at the Receiver (2 of 3) [78] [91] [184] [185] [186]

Location	Compliance Requirements	At the Receiver	
		Modification,	Examples
EU	EU Directive 2002/49/EC Relating to the Assessment and Management of Environmental Noise	**Sound Barriers**	Near-receiver sound barriers and noise absorbers.
		Building Modifications	Façade insulation: low acoustical transmission glazing and walls, low-noise air conditions systems, low noise ventilation inlets and exhausts, design for low re-radiation of noise due to ground vibrations, locate bedrooms opposite side of dwelling from noise source, no vents or other openings in wall facing noise source

Table 76: Rail Noise Compliance Approaches at the Receiver (3 of 3) [156] [158] [164] [187] [188]

Location	Compliance Requirements	At the Receiver	
		Modification, Application	**Examples**
China and Japan	Defined in People's Republic of China Ministry of Environmental Protection Regulation GB 3096 - 2008, Environmental Quality Standards for Noise. Japan Ministry of the Environment, Environmental Quality Standards for Shinkansen, Law No. 91.	**Sound Barriers**	Improved building foundation design to incorporate vibration and sound isolation, vibration-breaking trenches, sound barriers on property boundary facing noise source, install barriers on top of berms to improve design and increase barrier height
		Building Modifications	vibration-absorbing/isolating structures to reduce radiated noise, sandwich walls of hard and soft matrials to improve noise attenuation, eliminate openings and seams, windows with 3" air gap, minimize window area on surface facing noise source

6.4 Accuracy of Sound Pressure Measurements

Sound level meters are divided into two classes. The accuracy of Class 1 meters is ±0.3 dB and the accuracy of Class 2 meters is ±0.5 dB [191]. It is recommended that accuracy levels be taken into account regarding high speed train noise regulations. Meters should meet the standard IEC 60942 and should be calibrated to the recommended schedule [192].

Based on industry stakeholder interviews (Section 7), it has been determined that currently available sound pressure level meters are adequate for measurement of noise originating with high speed trains. However, there is concern regarding the uncertainty of the measurements based on a number of factors, including ambient conditions, track/wheel roughness, speed, rolling stock type, wagon type, and degree of on-board noise mitigation measures employed [193]. Uncertainty related to measurement of $L_{Aeq(period)}$ and L_{Amax} is the subject of a draft ISO Standard ISO/DIS 1996-2 [194]. The preferred confidence level for acoustics measurements is 95 percent [195]. The 95 percent confidence level translates ±2 standard deviations [193], which is also referred to a coverage factor of 2.0. This can be compared to a coverage factor of 1.3 corresponding to a probability of 80 percent. Uncertainty is the measure of dispersion or variance that may be expected with a claimed performance value, often represented by the term U_{95}. The subscript '95' means a 95 percent confidence interval. It represents the estimated range in which the true value lies for 95 out of 100 repeated events, e.g., a U_{95} of 5 dB indicates that the true value is expected to be within ±5 dB of the estimates provided for 95 percent of all observations [193].

Additional sources of the uncertainty include: speed variations, differences in rolling stock (i.e., due to manufacturing tolerances, age of vehicle and associated changes to suspensions, wheel surface roughness, bearings, etc.), track surface roughness, track alignment/curvature, track structure decay rates, and intermittent effects such as level of wheel hunting and flanging.

Tests performed by Weber and Zoontjens (2016) in Australia for both passenger and freight trains included extensive measurements of passby noise levels (L_{AE}) and provide an indication of accuracies associated with these types of measurements. It is not stated in the referenced research results what the range of train speeds were, so results related to high speed trains may be different, but the study is interesting in that a large sample of passby events were obtained and compared. Statistical analyses were performed for each set of data to obtain the standard deviation for each passby event and for multiple data sets collected over periods ranging from 1 week to over 6 months. The maximum range in log-averaged measured noise levels was analyzed for single data sets as well as 5, 10, 15, 20, and 60 data sets for each site. Tests conducted on passenger trains using ISO standard-compliant instruments and procedures, showed standard deviations in L_{AE} of approximately 5 dB which led to the statement: "For the measurements in this study, there is a 95 percent confidence that the calculated noise levels are within ±3 dB of the true $L_{Aeq(period)}$ noise levels when at least 20 train passbys of each type under the same operating conditions are measured. For the L_{Amax} assessment parameter, the uncertainty increases to approximately ±5 dB for the same number of train passbys." Thus, regulations should take measurement uncertainty into account when defining maximum allowable noise levels.

6.5 Impact of Distance from Source on Noise Levels

For new high-speed rail projects, it is important to understand the impact of receiver distance from the noise source. Although not cost effective or politically feasible in some highly populated areas, locating tracks away from established residential and other noise sensitive areas is worth consideration.

The maximum sound level of a passing train varies with distance in the free field according to Xiaoan and Hua (2003), as shown in the equation below.

$$\text{when } d \leqslant 150\,\text{m} \quad \text{then } L_d = L_{d_0} - 10\,\text{lg}\left(\frac{d}{d_0}\right)$$

$$\text{when } d > 150\,\text{m} \quad \text{then } L_d = L_{d_0} - 20\,\text{lg}\left(\frac{d}{d_0}\right)$$

Where d is the distance to the noise source, L_{d0} is the sound level at the baseline distance and L_d is the sound level at a distance greater than the baseline distance.

This means that when the distance from the train is doubled, the maximum sound level of the passing train reduces by 3–6 dB(A), which was confirmed by Lu et al. (2014). Figure 39, reproduced from Elliott, provides an indication of sound pressure levels variation with distance from the source for a range of high speed trains [196].

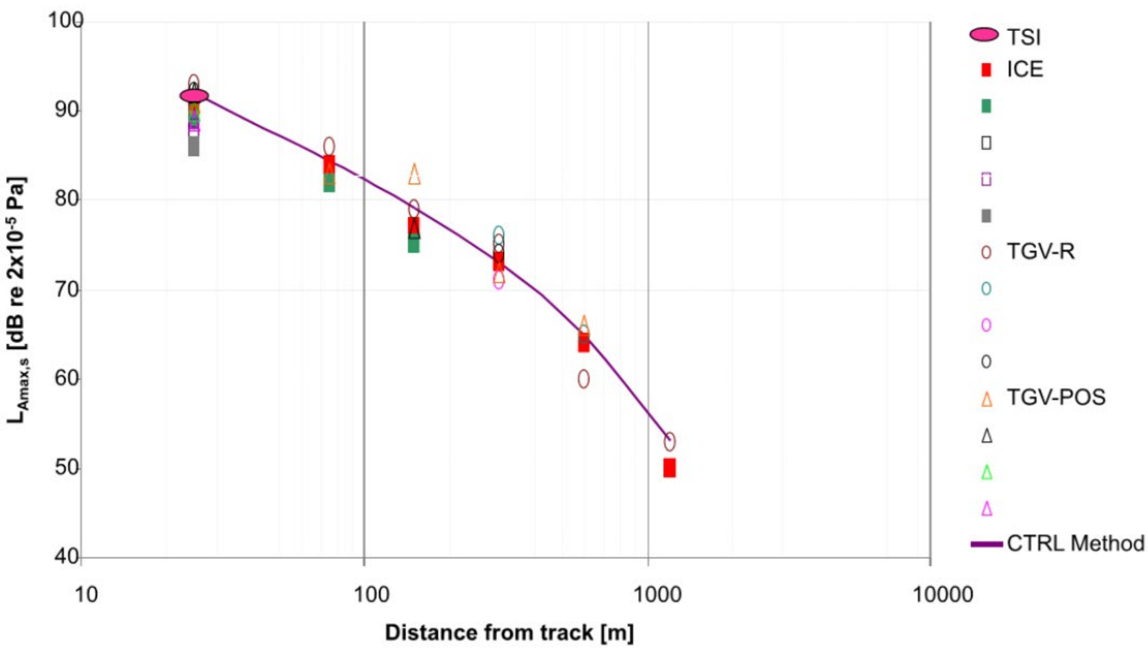


Figure 39: Noise Level Variation with Distance from High Speed Trains[15] [196]

[15] Reference: ICE = Inter City Express Trains, TGV (French high speed train), CTRL Channel Tunnel Rail Link noise calculation method.

6.6 Emission Noise Source Variation with Train Speed

Studies regarding the impact of train speed on noise emissions indicate that different parts for the train have varying aerodynamic noise characteristics that follow separate power laws [197]. The relationship between sound pressure levels at various train speeds is described by the following equation:

$$\text{Sound Pressure Level (dB)} \propto 10\log(\text{train speed}^{\alpha})$$

where α is the power law coefficient. Table 77 shows the power law coefficients for entire trains as well as individual train components and provides direction for addressing noise reduction studies as train speeds continue to increase.

Table 77: Emission Noise Source Power Law Constants, High Speed Trains [197]

Train System		Power Law Constant, α	Comments
TGV	*Locomotive*	3	up to 300 km/h
		7-7.5	above 350 km/h
	Coach	3	up to 300 km/h
		6	above 350 km/h
TGV-A		4.3	average for train
ICE		6.8	average for train
TR-70 Maglev		6	flow separation
		8-9	turbulent boundary layer
TGV-A	*Wheel*	2.9	middle coach position
		3.2	front locomotive position
		3	rear locomotive position
	Pantograph	5.7	rear locomotive position
	Cooling Fan	4.7	front locomotive position
		4.6	rear locomotive position
	Window	5.1	front locomotive position
	Inter-Car Gap	4.2	between coaches
	Bogie	6.1	wheel truck
	Turbulent Boundary Layer	4.3	per square meter

The use of sound pressure maps is also instrumental in identifying emissions noise sources for high speed trains. Arrays of microphones and sophisticated data analysis procedures are able to provide iso-contour lines of constant sound pressure levels overlaid on images of the train cars; see, for example, Gautier et al. (2008).

Figure 40, taken from Poisson et al. (2008), shows how passby noise levels (i.e., measured at 25 m) for the French TGV Duplex vary with speed. It is noted that the test is conducted along a section of track that complies with TSI specifications for allowable acoustic roughness and dynamic properties [200]. The increase in passby noise levels measured for the train traveling at 250 km/h (155 mph) and the same train traveling at 350 km/h (217 mph) is 8 dB(A). Variations of train speeds for other trains operating on tracks in several EU countries is shown in Table 78, also taken from Poisson et al. (2008). The table entries indicate variations in passby noise levels up to 2 dB(A) for the same train operating on two different sections of track.

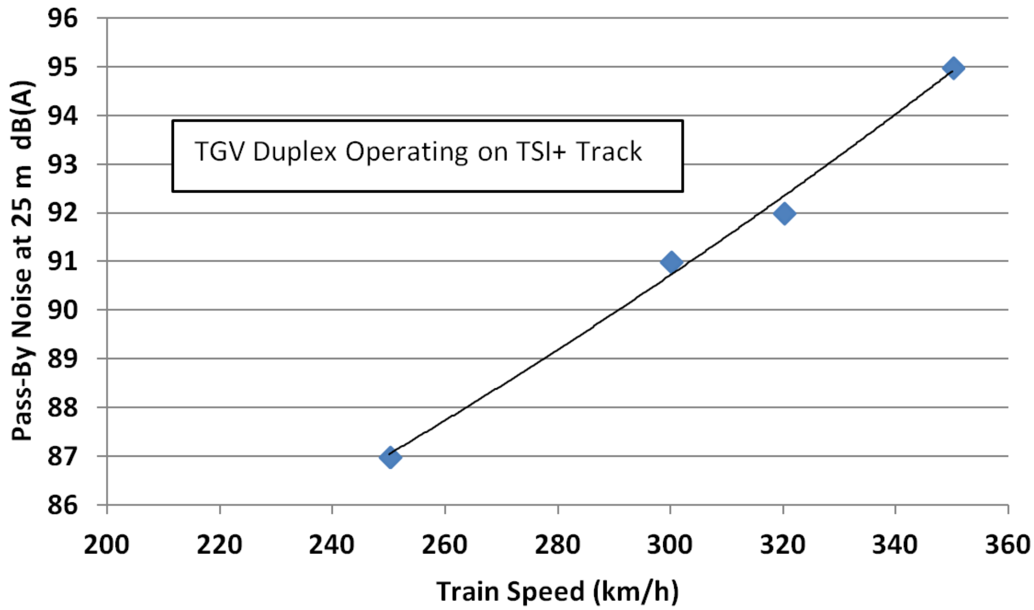


Figure 40: Variation of Passby Noise Levels, dB(A) for High Speed Train [199]

Table 78: Variation in Passby Noise Levels dB(A) for High Speed Trains[16]

Train	Test Site	Pass-By Noise Levels ($L_{pAeqp,Tp}$) dB(A) for Indicated Train Speed				
		250 km/h	300 km/h	320 km/h	330 km/h	350 km/h
TGV Thalys	Belgium	88.5	92	93		
	France	85.5	90	92		
	Germany	85.5				
TGV Duplex	France	87	91	92		95
TGV Atlantique	France		90.5			94.7
TGV Reseau	France	89	91.5		94	97
ICE3	France	87.5	90	91.5		
	Germany	85.5	89	92		
AVE	Spain	86	90	91		
ETR480	Italy	90.5				
ETR500	Italy	88	90.5			
TSI Limits on TSI+ Track			92	94		

[16] All trains operating on TSI-compliant track except TGV Thalys (Belgium) [199]

6.7 Emission Noise Source Variation with Track Surface Roughness

Variations in measured passby noise levels for high speed trains operating on TSI-compliant sections of track, as discussed in Section 6.6, are on the order of 2 dB(A). Other research has indicated variations in rolling noise (wheel/rail surface roughness effects), that can range to 9 dB(A) [201]. The standard deviation of these measurements was 7 dB(A). Thus, legislation regarding rolling stock emissions levels must include specifications for track roughness to provide valid measurements for compliance assessment.

The EU Technical Specifications for Interoperability define track surface roughness and dynamics characteristics for passby noise measurements [200]. The "rail acoustic roughness" of the test track is considered suitable for comparable measurements if the one-third octave band roughness spectra assessed according to EN15610 (European Standard for Rail Roughness Measurement Related to Rolling Noise Generation) [202] throughout the test, fulfill the following upper limit: the wavelength bandwidth is to be at least 0.003 m to 0.10 m (0.3 cm to 10.0 cm) [0.010 ft. to 0.328 ft. (0.118 inches to 3.94 inches)] corresponding to Figure 41.

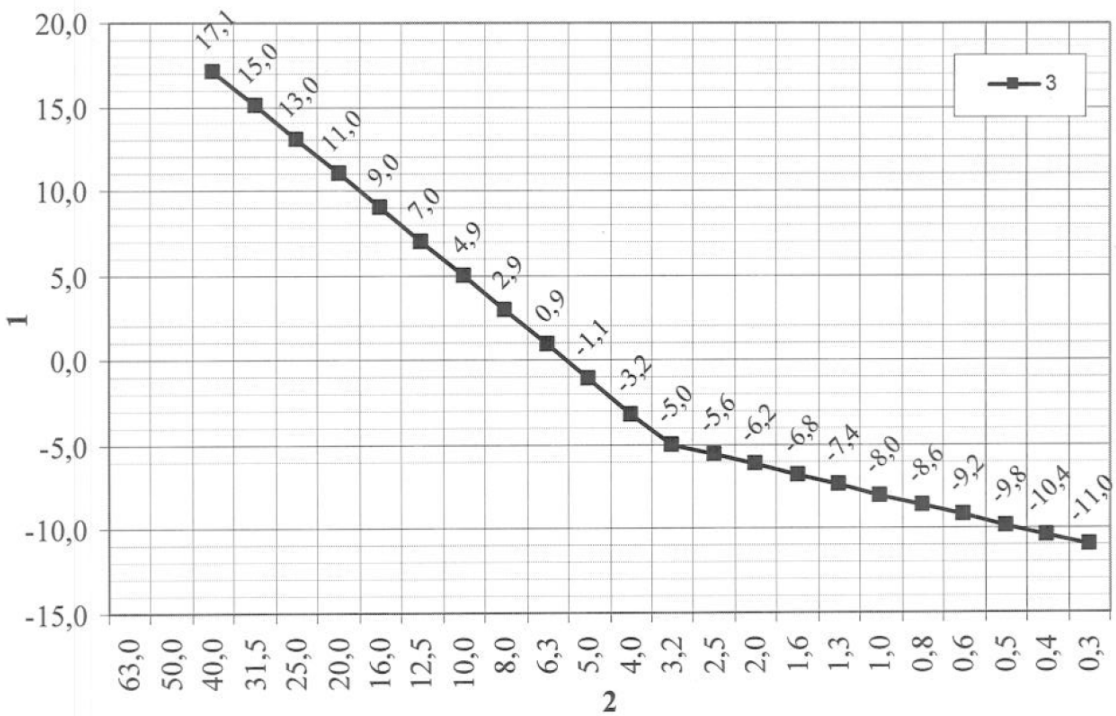


Figure 41: Upper Limit Curve for TSI-Compliant Acoustic Rail Roughness[17]

The dynamic properties of the test track are considered suitable for acceptable noise measurements if the one-third octave band track decay rates spectra measured according to EN15461 (European Standard for Characterization of the Dynamic Properties of Track Selections for Passby Noise Measurements) [203] throughout the test section fulfill the limits shown in Figure 42.

[17] where **1** is the 1/3 octave band roughness level, dB(A) Reference: TSI Noise Regulations [200]
2 is the wavelength (cm)
3 is the 1/3 octave band roughness level, dB(A)

There are three dedicated test facilities ("rings") in Europe with TSI noise compliant track. They are located in the Czech Republic, Germany, and France. In addition, there are sections of 'normal operations' lines with sections that are maintained to meet the TSI requirements and are located in Germany, Switzerland, and the Netherlands. Not all the compliant track sections can be used at all required test speeds. For freight wagons with speeds up to a maximum of 120 km/h it is not difficult to find acceptable track sections to perform the noise measurements. For example, freight wagons are required to be tested at the dedicated facilities to check brake performance and other operational parameters, so the TSI NOI measurements can be included without a significant increase in test costs. However, trains operating at speeds above 200 km/h cannot be tested on the dedicated test facilities, and in these cases, it becomes difficult and expensive for train manufacturers to find a suitable test track. For example, recent tests of trains in the Netherlands at 250 km/h required special conditioning of a part of the track on which the train was going to operate. The track modifications were expensive as was certification of the test procedures and results (the tests had to be repeated because the initial track modifications did not meet the TSI criteria). Fortunately, the latest TSI NOI gives the option to test on rougher/less damped sections of track. If noise limits measured on these noncompliant sections of track are below the TSI-limit values the train can still be approved as being compliant (homologated). However, this has the disadvantage that the test results cannot be used as a reference for homologation of subtypes or comparable train types [204].

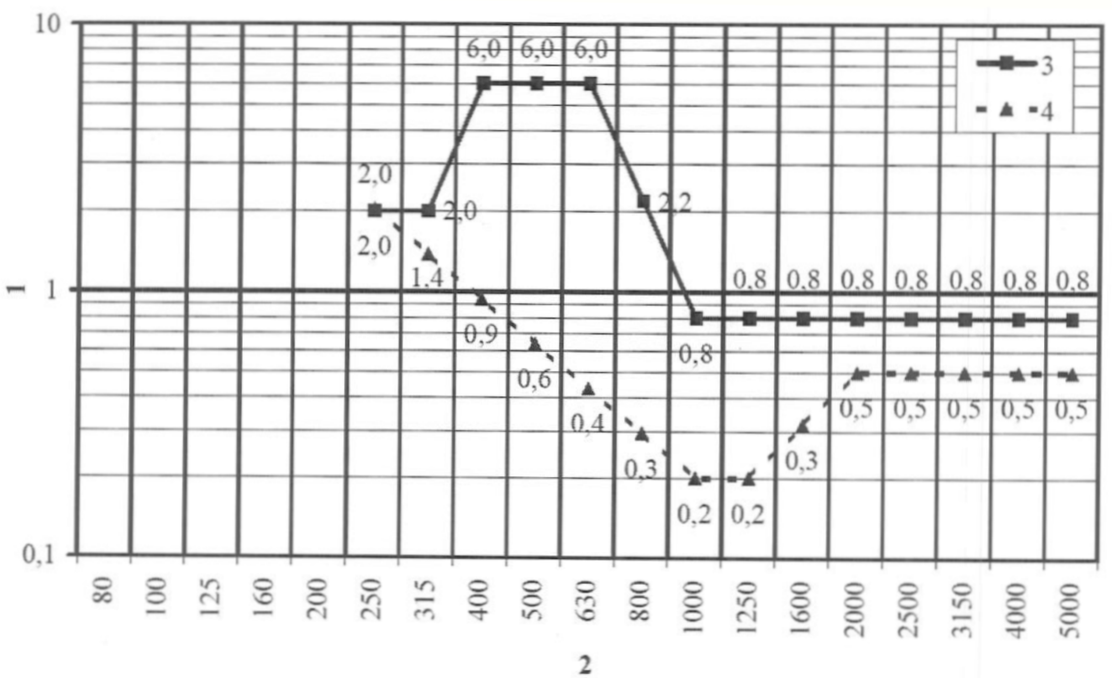


Figure 42: Lower Limit Curves for TSI-Compliant Track Decay Rates[18]

[18] where **1** is the track decay rate, dB/m Reference: TSI Noise Regulations [200]
2 is the frequency, Hz
3 is the track decay rate in the vertical direction
4 is the track decay rate in the lateral direction

6.8 Source Noise Power Quantification for High Speed Rolling Stock

Gautier et al. (2008), have evaluated the noise sources for the SNCF TGV high speed train in an effort to identify and quantify contributors to passby noise as a function of train speed [198]. The results of measurements made using an acoustic microphone array for a passing TGV A trainset, known as the DEUFRAKO project [205], are shown in Table 79. It is interesting to note that some of the noise sources increase for all increases in train speed, particularly those related to aerodynamic noise and rolling noise, such as coach wheels, pantograph, forebody (front window/roof interface), intercar gap and wheel truck (bogie). The power car wheels (both front and rear) exhibit increases in noise levels between 100 km/h (62 mph) and 300 km/h (186 mph) and then decrease between 300 km/h (186 mph) and 350 km/h (217 mph). The rank of the noise sources in order of relative contribution total train noise levels is: 1) pantograph, 2) power car wheels, 3) forebody, front window/roof interface, 4) cooling fans, 5) coach wheels, 6) intercar gap, and 7) wheel truck (bogie) aerodynamic noise.

Table 79: Component Source Noise Power Quantification, TGV-A[19] [198]

Measured/Calculated Source Noise Levels dB(A), at 5 m from Track Centerline				
Component	**100 km/h**	**200 km/h**	**300 km/h**	**350 km/h**
Wheels, Coach	82.4	89.7	97.2	98.1
Wheels, Forward Power Car	82.9	89.4	102.5	100.4
Wheel, Rear Power Car	81.7	89.6	102.7	98.0
Pantograph	82.1	91.3	103.5	104.3
Cooling Fan Front	78.9	87.9	101.3	104.0
Cooling Fan, Rear	78.3	79.6	102.1	100.5
Front Window/Roof	77.9	88.5	102.2	104.9
Inter-Car Gap	81.7	87.1	92.0	98.1
Bogie (Aerodynamic Noise)	76.8	78.6	90.1	93.3

6.9 Rolling Stock Source Noise Reduction Potential

Research into rolling stock source noise, noise path attenuation methods, and receiver noise insulation has been underway for decades and many effective design modifications have already been implemented. The reduction potential for key noise sources are shown in Table 80 and range from 0.5 dB(A) to 10 dB(A) per source. The potential for additional rolling stock noise reduction ranges from 5 dB(A) to over to over 10 dB(A) based on implementation of multiple noise reduction modifications. Note that noise reduction modifications have already been incorporated into many of these components on current high-speed rail rolling stock and thus cost effective additional noise reductions may be limited. Also note that potential noise reductions are shown in units of decibels and thus the impact of combination modifications will be the logarithmic sum of the individual changes.

[19] Determination method: summing acoustical energy received on a zone surround the assumed position of the source.

Table 80: Reduction Potential for Rolling Stock Noise Sources

Component	Potential for Noise Reduction, dB(A)	References
Wheels (rolling noise)	4 to 10	[206]
Pantograph	1 to 3	[159] [145] [207]
Cooling Fans	3 to 6	[208]
Forebody (window/roof interface)	3 to 7	[207]
Intercar gaps	2 to 7	[209]
Wheel Truck (bogie) aerodynamic noise	0.5 to 1.0	[207]

6.10 Promising Developments in Acoustic Technology

The field of acoustics is progressing at a rapid rate due to new modeling and analysis tools. Some key developments that may be candidates for high speed rail noise reduction applications include:

1. Active Noise Control (ANC): this technology employs secondary noise sources to suppress primary noise sources [210]
2. Adaptable Acoustic Liners: this technology employs low-profile, tunable acoustic liners adjusted to absorb sound at frequencies characteristic of the noise source [211]
3. Design of structures to reduce sound transmission through the application of structural acoustic prediction modeling [212]
4. Multiple Scattering Screens: this approach to noise control employs "sonic crystal" materials arranged to control specific noise sources, based on the source frequencies [213]
5. Advanced Barrier Structures: these include integrated resonators that interact to attenuate targeted frequencies [214]
6. Advanced Computational Models for Creating Sound Filters: these models have been used to develop three-dimensional cavities and passages that increase targeted frequencies [215]
7. Development of Acoustic Metamaterials: these materials include engineered microstructures that manipulate sound waves to amplify or attenuate target frequencies [215]

6.11 Cost Benefits of Railway Noise Mitigation

During 2013, Union International des Chemis de fer, the UIC, conducted an economic study of current rail noise mitigation methods, based on a life cycle cost (LCC) approach. The results were calculated in several ways, including an investment payback in units of number of persons per year removed from noise exposure L_{den} above 60 dB(A). Approaches included vehicle related measures, track related measures, sound path interrupters, and receiver modifications. The results indicate that source noise reductions are the most cost-effective approaches for freight trains [139].

Oertli (2000) developed a method to calculate the network-wide costs for candidate noise control approaches, relative to Swiss train immissions levels. The study concluded that optimal use of available funds (i.e., based on number of residents impacted and costs) was: 65 percent on rolling stock improvements, 30 percent on noise control barriers, and 5 percent on insulating windows at receiver locations.

6.12 Effectiveness of Noise Barriers

Noise barriers have been employed for decades within the US, with the largest deployment along interstate highways. The U.S. Department of Transportation (DOT) performed statistical analyses of these barriers based on construction materials and noise attenuation characteristics [189]. Barrier design considerations are provided in the DOT Federal Highway Administration's (FHWA) Noise Barrier Design Handbook (2011). Some of the key acoustical considerations noted in the handbook include:

1. Barrier panel materials should weigh 20 kg/m2 or more for a transmission loss of at least 20 dB(A).
2. Barrier height and length should be defined so only a small portion of sound diffracts around the edges.
3. A berm requires more surface area, but provides 1 dB(A) to 3 dB(A) additional attenuation versus a wall.
4. Sound reflected between parallel barriers may cause degradations in each barrier's performance from 2 dB(A) to 6 dB(A), but in most situations, the degradation is lower.
5. The cost of constructing special barrier shapes typically outweighs the cost of simply increasing the barrier's height to accomplish the same acoustic benefit.

Noise reduction performance of a barrier is a function of [190]:

- Noise reduction is a function of:
  - Barrier height
  - Barrier length
  - Type of barrier (wall or earth berm)
  - Offset distance of barrier from the track
  - Distance from the barrier back to the receivers
  - Proximity of the receiver to the end of the barrier
  - Vertical relationship of the track surface, barrier top elevation, and receiver elevation
  - Type of intervening ground
  - Presence of intervening rows of buildings and their density and height
  - Width of the tracks (number of tracks)
  - Percentage of car types in the mix of traffic
  - Traffic speed

As barrier height increases, noise reduction increases (i.e., to a point), the number of benefited receptors increases (i.e., to a point, depending on the number of receivers and orientation of receivers), and barrier reasonableness (e.g., cost and impact) increases. As barrier length increases, noise reduction increases (i.e., to a point) for some receivers near the end of the barrier, the number of benefited receivers increases (i.e., to a point, depending on the number of receivers and orientation of receivers), and barrier reasonableness increases. As the offset distance of barrier from the track increases, noise reduction first decreases and then, as the barrier gets closer to the receiver, increases. As the distance from the receiver to the barrier increases, noise reduction generally decreases, and barrier reasonableness decreases [216].

Several industry stakeholders interviewed during the project outreach task (see Section 7 of this report) expressed concern regarding the use of barriers and trenches to address noise from high speed trains. Any noise mitigation systems that also block the views of train passengers may raise objections if the barriers are employed over a significant portion of the route. It was suggested that employing opaque barriers in densely populated areas might be acceptable and transparent barriers, if cost effective, in suburban and rural areas, where required.

Based on FHWA data, concrete is the current material of choice for noise barriers [189], as shown in Figure 43.

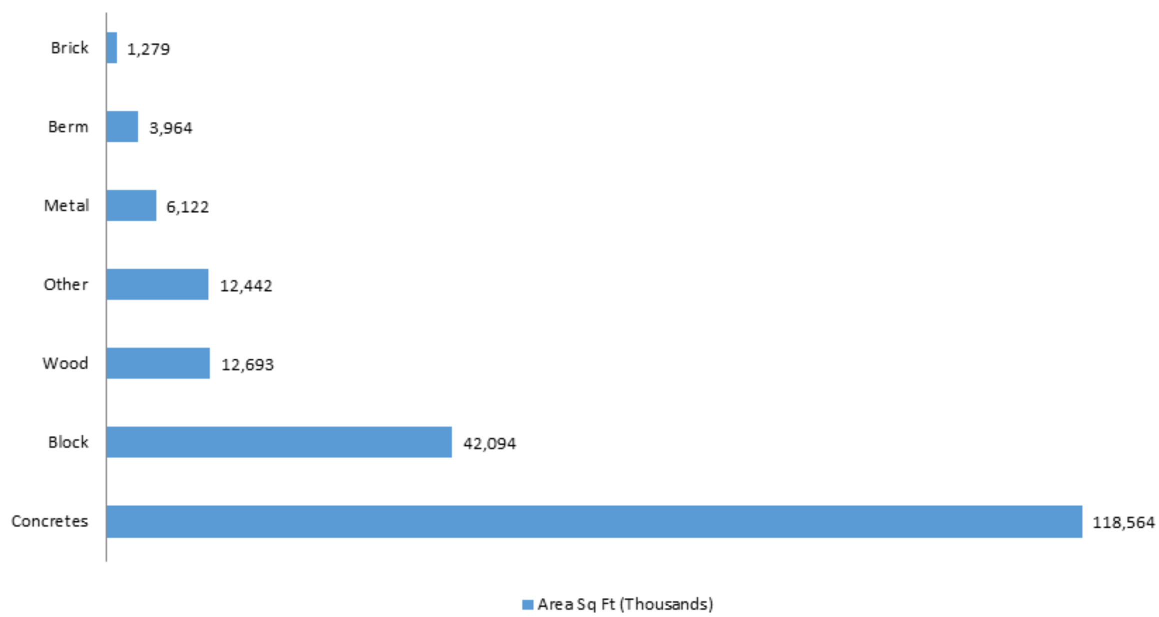


Figure 43: US Single-Material Noise Barriers by Material Type[20] [189]

[20] Based on noise barriers constructed within the US, 1963–2013

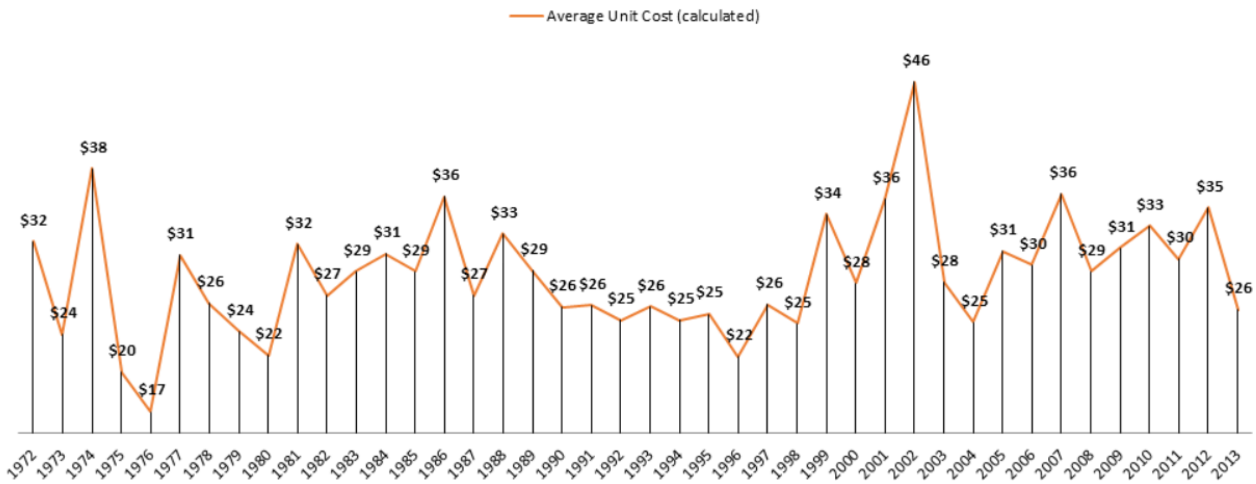


Figure 44: US Noise Barriers; Average Cost per Square Foot (see footnote #20) [189]

Barrier prices are tied to materials costs. In the early 2000s, for example Figure 44 shows a significant spike in building construction in China and the US caused a significant increase in cement prices along with the lack of available cargo ships to bring in imported cement [217].

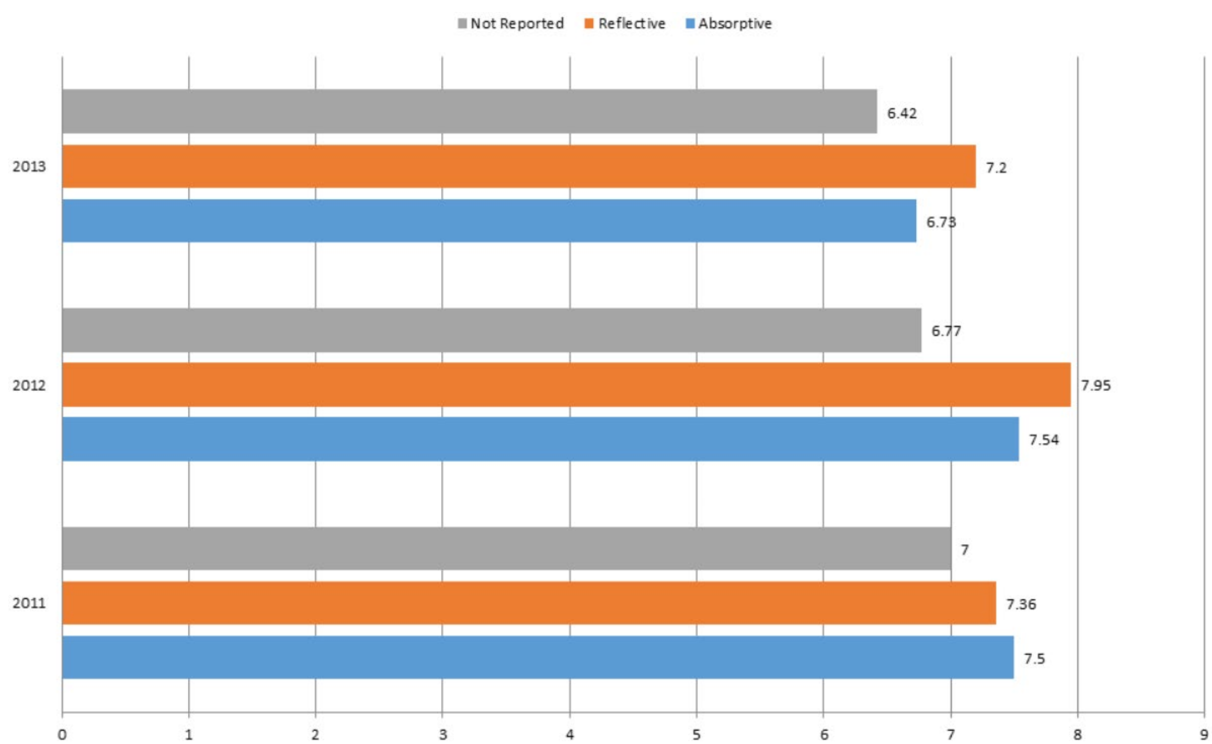


Figure 45: US Noise Reduction in dB(A) by Barrier Surface Treatment (see footnote #20) [189]

Based on noise barriers constructed within the US, 1963–2013 [217], noise reduction through surface treatment methods shown in Figure 45 can reduced noise by as much as almost 8 dB(A).

In summary, research on transportation noise barriers has shown that sound levels adjacent to roadways and railroad tracks can be reduced between 5 dB(A) and 12 dB(A) using a variety of materials, with concrete being the most cost effective [190] [219].

During the stakeholder interviews (see Section 7), it was noted that China and Japan do not specify emissions for high speed rolling stock, but instead define the noise levels (immissions) at the boundaries of the railroad property. Thus, the train, track, track support, and noise path interrupters are regarded as a system. There is support for using adopting this approach for noise associated with US high speed rail regulations.

6.13 Effectiveness of Sound Insulation on Receiver Noise

The effectiveness of various approaches to reducing noise at the receiver through the use of sound insulation methods is shown in Table 81 based on information provided by FHWA [220]:

Table 81: Effectiveness of Receiver Noise Reduction Methods

Noise Reduction Modification	Noise Reduction, dB(A)
Increase Wall Mass and Stiffness	1 to 6
Use of Cavity Partitions	1 to 5
Increase Spacing between Studs	2 to 5
Use Resilient Materials	2 to 5
Acoustical Blankets (use of sound adsorbing materials in air spaces)	3 to 10
Insulated Windows, Increasing Glass Thickness	10 to 25

Construction techniques and materials selection can reduce receiver immissions (interior) noise levels between 1 dB(A) and 25 dB(A).

6.14 Comparison of Noise Measurement Indicators (Metrics)

Pronello and Camusso (2012) have compiled a list of strengths and weaknesses for the various metrics used to measure railroad noise levels. Table 82 shows a modified version of their comparison table.

Table 82: Strengths and Weaknesses of Noise Indicators (Metrics) [48]

Metric	Strengths	Weaknesses
L_{eq}	• It is easy to calculate • It gives a synthetic evaluation of noise • It is suitable for automatic measures • It is correlated with long term effect of noise	• It does not evaluate noise variations • It is influenced by the highest values of noise • It shows low correlation with annoyance
L_{max}, L_{min}	• It is easy to calculate • It evaluates instantaneous effects	• Difficult to assign to a specific source if the measurement is not assisted by an operator • It shows low correlation with annoyance
L_{xx}	• They represent noise distribution • They give information on soundscape	• It shows low correlation with annoyance
SEL	• It is easy to calculate • It allows to calculate L_{eq} summing single SELs • It allows comparing different noise events (two trains, buses, etc.)	• In automatic measure it is difficult to select the event on which calculate the SEL • It shows low correlation with annoyance
L_{dn}	• It weighs differently the noise according to day and night period • There is a good correlation between noise level and annoyance of very disturbed people • It is quite easy to calculate, also in case of automatic measurements • It can be represented through maps	• It is unable to describe annoyance for all the levels of disturbance • It does not take into account all the acoustical differences of the sources
L_{den}	• It weighs differently the noise according to three periods: day, evening, and night • It allows the comparison among different infrastructures • It is easy to understand from general public • It can be represented through noise maps	• It needs continuous monitoring for long periods (even one week) • It needs average yearly data to take into account the meteorological conditions • It is not suitable to describe the disturbance during the night-time
L_{night}	• It is easy to calculate • It allows a better representation of the impact in function of the perceived disturbance • It can be represented through noise maps	• Some studies show that other information as the number of events and their noisiness could be used to describe night-time disturbance
TEL	• It is related to the single noise event, described by SEL and to $L_{eq,T}$	• It takes into account only the passing vehicles and not station operations • It doesn't give any information on the global impact of the infrastructure • It shows low correlation with annoyance
L_r	• It takes into account both the passing vehicles and some specific station operations • It can be represented through maps	• Some parameters used to calculate L_r come from a qualitative approach, with the corrective terms difficult to define • It shows low correlation with annoyance

7. Results of Stakeholder Interviews

To develop insights that are relevant for the U.S. rail industry and to obtain objective assessments of the results of the current study, Ricardo Strategic Consulting arranged periodic reviews and discussions with representatives of project partners Amtrak and CaHSRA (and CaHSRA contractor Parsons Brinckerhoff). Summary reports were prepared prior to each meeting that included comments provided by other industry contacts as well as results of literature research. The direction of the study and content was based on feedback from the project partners and industry stakeholders.

Ricardo's experience with global surveys of regulations and standards (see [221]) has shown there can be significant regional variations in practices. Performing outreach to select industry stakeholders was determined to be beneficial in understanding the different perspectives and impacts of the regulations. In addition to ad hoc discussions with researchers and authors identified during the literature search, Ricardo conducted formal interviews with eight industry stakeholders to support the program. Based on research completed during the study, the following topics and associated question categories were developed for the stakeholder interviews:

Rolling Stock

- Impact of Noise Regulations on Vehicle Design
- Impact of Noise Regulations on Vehicle Costs
- Identification of Cost Effective Approaches

Noise Attenuation

- Source (Rolling Stock) vs. Wayside Approaches
- Ranking of Approaches by Noise Attenuation Effectiveness
- Identification of Cost Effective Approaches

Noise Measurement Procedures

- Equipment and Regulation Requirements
- Procedures and Regulation Requirements
- Identification of Industry Standards

Compliance, Enforcement and Penalties

- How are Regulations Enforced and by What Organization?
- Variations in Enforcement Procedures vs. Location
- What Penalties are Imposed for Non-compliance?

Public Concerns

- Has there been Public Resistance to Existing Regulations?
- Which Organizations are Supporting/Organizing this Resistance?
- Has Public Resistance Resulted in Changes to the Regulations?

Interviews were arranged with representatives of four stakeholder categories:

1) Rail operators
2) Developers of measurement methods and equipment
3) Vehicle manufacturers
4) Government (legislative) and non-government organizations

The Ricardo standardized interview process was used to ensure that consistent quantitative and qualitative data was collected. Specific questions related to each of the selected topics and question categories were prepared prior to the interview. Figure 46 shows the process in the schematic below:

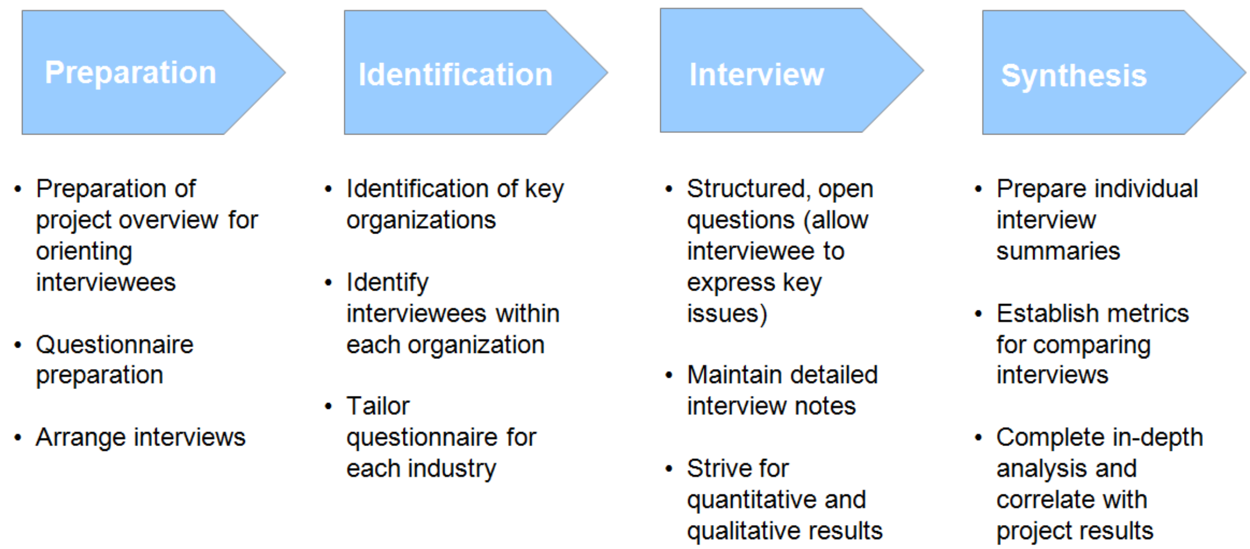


Figure 46: Ricardo Standardized Interview Process

Interviewees could remain anonymous to allow them the opportunity to be candid in their responses. All but three of the interviewees elected to remain anonymous, so it was decided to not release any of their identities. Instead, the research team provided general discussions of the eight interviewees in Table 83:

Table 83: Stakeholder Outreach; List of Interviewees

Interview Number	Location and Category	Organization & Interview Date	Associated References	Interviewee Title and Association with High Speed Rail Noise
1	European Union: Rail Operator	EU Rail Industry Organization September 14, 2016	[1] [80] [222]	Sustainable Development Manager, Project Leader, EU Railway Noise Studies
2	United States: Legislative Support	Acoustics Consultancy September 22, 2016	[23] [223]	Principal Associate; author of numerous reports on railroad noise and vibration issues
3	United States: Rail Operator	Engineering Consultancy Under Contract with Rail Operator September 16, 2016	[11] [147] [224]	Vice President, author of numerous papers and reports on high speed rail operations, including technical

Interview Number	Location and Category	Organization & Interview Date	Associated References	Interviewee Title and Association with High Speed Rail Noise
				memoranda related to on-going high-speed rail projects
4	Japan: Rail Operator	High Speed Rail Operator January 16, 2017	[2] [147] [225]	Executive Director, author of numerous papers on high speed train noise, expert on Japan Rail noise issues, Director, of international high-speed rail organization
5	Europe, Australia, North America: Acoustics Consultancy	Acoustics Consultancy October 25, 2016	[226] [227]	Principal, Acoustics Consultant; author of many papers on railroad noise issues and modeling, including noise control measures, including reviews of rail noise policies
6	United States: Federal Railroad Administration	FRA Regional Office September 16, 2016	[228]	Industrial Hygienist involved in enforcement of railroad noise regulations
7	Germany and France: Trainset OEM	OEM Engineering Team, Acoustics November 22, 2016	[229] [230]	Chief Engineer for OEM that manufacturers high speed train sets, author/co-author of many train noise papers and acoustics R&D manager
8	United States: Acoustics Experts	Acoustics Consultancy September 15, 2016	[231] [234]	Vice President involved in noise impact studies, including modeling and analysis; expert in local noise regulations and railroad operations within quiet zones

7.1 Specific Questions Posed during Stakeholder Interviews

The authors limited the number of questions to eight to restrict the duration of the interview to the agreed 60 minutes. The specific questions varied by stakeholder category:

Rolling Stock

1. How do current noise regulations impact high speed train set design?
2. How are rolling stock noise emission regulations enforced in the various countries? Which countries present the biggest challenges to manufacturers?
3. Are current train sets capable of meeting noise regulations in all target markets? If not, which regulations are not being met and what plans are in place to address noncompliance?
4. How do noise regulations impact train set costs?
5. What are the contributions of mechanical, track, and aerodynamic noise sources to total vehicle noise as a function of speed?
6. Are there any issues related to noise instrumentation or procedures, such as accuracy and repeatability?

7. What design changes have proven to be the most cost-effective at reducing train set noise?
8. What do you envisage for the future in terms of noise regulations and design changes that will comply with the new regulations?

Noise Attenuation

1. Is it more effective to reduce noise at the source (e.g., rolling stock) compared to wayside barriers or insulation of structures?
2. Have you completed any analyses of the relative effectiveness of noise attenuation methods? If so, how do the various identified attenuation methods rank?
3. What are the most cost effective noise attenuation approaches?
4. What variations in noise attenuation approaches have you seen in the various countries where your organization has practiced?
5. How are rolling stock noise emission regulations enforced in the various countries? What penalties are imposed for non-compliance?
6. Has there been public resistance to high speed rail noise regulations? If so, has the resistance resulted in changes to the regulations?
7. What do you envisage for the future in terms of noise regulations and design changes that will comply with the new regulations?

Noise Measurement Procedures

1. What are the key differences in sound pressure measurement procedures, particularly those related to high speed trains: US: 40 CFR Part 210, EU: EN ISO 3095 (rolling stock) and Environmental Noise Directive (receivers), China: technical specifications GB/T 15190, 17181, and 50280, and Japan: ISO 11201:95 and ISO 11202:95? Are any key regulations missing from this list?
2. Do the measurement procedures allow for variations in accuracy? If so what allowances are included?
3. Are there significant differences between ISO standards and EN standards?
4. Are the sound meters specified in ANSI S 1.4 (Type 1 or Type 2) significantly difference than those defined in EN 61672 (Parts 1 and 2) or China GB3/85 or IESC Publication 179?
5. Are you aware of any comparative studies for the various sound measurement procedures and equipment?
6. Do you know if any plans are in place to unify the various sound pressure level measurement regulations?
7. How do noise level compliance requirements and enforcement actions influence measurement procedures?

Compliance, Enforcement, Penalties

1. Can you elaborate on how noise regulation enforcement varies between the US, EU, China and Japan?
2. What organizations are responsible for enforcement and for imposing penalties?
3. What penalties are imposed for non-compliance (i.e., for both equipment operators: noise levels generated by the rolling stock and receivers: noise levels arriving at locations adjacent to the tracks)?
4. Are violators provided a time period during which noise pressure levels can be brought into compliance?
5. Are any plans in place to change allowable noise pressure levels from high speed trains? If so, which changes are anticipated and what is the timeframe for their implementation?
6. Are noise barriers required as part of the regulations? Are barrier specifications and placement defined in the regulations?
7. How successful have the regulations been in reducing noise from high speed trains?

Public Concerns

1. Has there been any public resistance to existing train noise regulations? If possible, can you make comparisons between public resistance movements in the EU, US, and Asia?
2. What organizations are supporting this resistance?
3. Have the resistance organizations provided targets for acceptable high speed train sound pressure levels?
4. Has public resistance resulted in any changes to the regulations?
5. Have the resistance organizations indicated a preference for methods used to attenuate noise (e.g., at the source, barriers, or at the receiver location)?
6. Has public resistance resulted in the delay or cancelation of high speed rail projects?
7. What tactics have been employed to address public resistance to high speed rail?

7.2 Stakeholder Outreach: Key Interviewee Comments

The responses obtained during the stakeholder outreach interviews are summarized in the report sections below. Key comments are divided in five categories: (1) rolling stock, (2) noise attenuation, (3) noise measurement procedures, (4) compliance, enforcement, penalties, and (5) public concerns. Interview numbers, referencing Table 83, are included for each comment (shown in parentheses at the end of the comment). In some cases, additional literature references are provided for those comments that required additional clarification.

7.2.1 Rolling Stock

Impact of Noise Regulations on Vehicle Design

Regulations prevent bad design but do not drive improvements (1)

Placing limits on rolling stock noise must include allowance for track conditions. Poor track surface roughness can significantly increase rolling stock noise levels, so legislation must take this into consideration, as is done with the TSI (1) [11].

It is important to understand current and future noise requirements at the beginning of the design process so acoustics can be integrated in a cost-effective manner. For high speed rail rolling stock, fuel economy, noise and durability are key design parameters (1, 7).

Many noise reduction improvements incorporated by vehicle manufacturers are masked by noise originating with poor track quality. The EU TSI references ISO minimum track quality, but it is not possible to compare measurements made on two different tracks (1, 7) [229].

Track quality must be considered for proposed regulations. It is not possible to set noise targets without also specify track quality for the noise tests (1, 3, 7) [230].

It would be beneficial to design trains and barriers as systems, but this is not currently being done in Europe and no plans are in place to modify the current TSI to require new train/barrier designs (1, 7) [231].

It is not current noise regulations, but rather contractual requirements imposed by clients that is driving new train designs. In Australia, Switzerland, and Sweden, operators set targets that are more stringent that the TSI (7) [2] [3].

Noise due to aerodynamic sources becomes the primary contributor at speeds above 330 km /hr (205 mph). Thus, for high speed rail, key train set component and operational changes affecting noise must be identified and linked to the design process (e.g., ballast vs. slab track impacts underside design, or two types of pantographs for dedicated passenger and shared passenger/freight lines) (1, 3) [147].

Japanese research identified the following approaches to reducing noise of high speed trains to be effective in meeting noise regulations. All result in vehicle cost increases (4) [158] [235]:

A. Pantograph noise reduction: 1) utilizing a special high voltage bus line to connect multiple pantographs electrically. These bus lines reduce spark noise that results from arcing by reducing contact. They also allow for a smaller number of pantographs on the train set. 2) Utilizing single-arm low-noise pantographs.

B. At speeds over 300 km/h (186 mile/h), noise related to the pantographs forms the greatest part of the total. So, the cars of the Shinkansen E5 Series, with a top speed of 320 km/h (200 mph) have been adjusted as follows: 1) utilization of a new-type low-noise pantograph) that cantilevers the main arm. 2) Utilization of pantograph-insulation plates, 3) Utilization of a multi-segment slider unit on the pantograph. The slider improves current collecting performance connecting to the overhead contact line, reduces spark noise due to contact loss, and enables current collecting by only one pantograph per train set. 4) Providing sound-absorbing panels on the lower part of each car: a side-skirt part including bogie slide covers. 5) Equipping cars with circumferential diaphragms to fill the inter-car gaps.

C. Rolling noise reduction: utilizing a wheel tread cleaning device that also polishes the wheel tread surface. Tread brakes, in which cast iron brake blocks act on the wheel tread lead to high levels of roughness on running surfaces, and thus higher levels of rolling noise, due to formation of local hot spots [236]. Tread cleaning devices and disc reduce this increase in wheel roughness and thus reduce rolling noise.

D. Japanese high speed rail noise limits are not coupled to train speed: the regulation sets maximum sound pressure levels based on the designation of high speed rail or general rail only, with noise limits established for land use categories (residential vs. commercial/industrial). Rail operators have not voiced opposition to this approach to the regulations (4) [225].

Impact of Noise Regulations on Vehicle Costs

ERA is of consensus that TSI noise limits cannot be lowered due to uncertainties in track conditions and surrounding topology (1).

In Europe, several countries, including Germany, the Netherlands, and Switzerland are evaluating Noise Differentiated Track Access Charges to provide incentives for reducing train emissions (1, 3; Ricardo research) [226].

Based on discussions with TSI lobby groups within the EU, it is expected that near-future noise targets (passby) for high speed trains may decrease on the order of 1 dB(A) or less (7).

High speed rolling stock manufacturers have challenged researchers to separate wheel/track noise from other noise sources. This would allow definition of the noise targets for the remaining train components, which would be easier to regulate. But current research and development indicates that accurately identifying and quantifying the various noise sources will be difficult (1, 3).

Some regulators are of the opinion that decreasing the maximum allowable TSI noise limits would force new train designs, but manufacturers and operators believe that this would increase costs and eliminate new train designs (1, 7) [229].

Japanese high-speed rail rolling stock developers conducted studies to determine where noise is generated and how much noise each source contributes to the total noise output. The developers measured wayside noise using a linear microphone array and have estimated the proportion that each source contributes to the total noise. They determined that pantograph noise (including spark noise from arcing due to contact loss, and aerodynamic sound from pantographs and adjacent areas) contributes greatly to the overall noise of trains in route sections that have noise barrier installation. As a result, the current key focus is to reduce pantograph noise (4) [158].

Identification of Cost Effective Approaches

Stricter noise regulations will increase costs and push traffic to roads (1).

The Netherlands is installing barriers and rail dampers and will be treating buildings adjacent to railroad lines and have introduced maximum noise values that cannot be exceeded (e.g., a discussion with Ricardo Rail, Netherlands).

Main challenge for train set designers is to reduce noise levels but keep costs in line. Studies indicate it is more cost-effective to reduce noise at the source than along the path or at the receivers. Cost effective designs address the main noise sources, not the entire vehicle (7) [229].

Low weight noise reduction approaches are sought. Adding weight increases rolling noise as well as interior noise. Weight effects bearings and wheel/rail interaction. Low noise wheels have proven effective at reducing interior and exterior noise (7).

Rolling stock manufacturers and operators must know the operating environment (i.e., track quality) before setting noise targets. The impact of noise reduction modification can have a significant impact on cost because of associated product development. There are diminishing returns in noise reduction for money spent once certain threshold levels are achieved (7).

Recent testing indicates rolling noise is the predominant contributor below train speeds of 330 km/hour (205 mph) for some designs and below 340 km/hour (211 mph) for other designs. Beyond that, aerodynamic noise is the main contributor (7; Ricardo research).

From an emissions standpoint, the most effective approach to reducing high speed train noise is to improve wheel quality; the main feature affecting the wheel roughness is the braking system. Tread brakes, in which cast iron brake blocks act on the wheel tread lead to high levels of roughness on running surfaces, and thus higher levels of rolling noise, due to formation of local hot spots [236]. Disc brakes markedly reduce this increase in wheel roughness. The noise level difference between vehicles equipped with disc brakes vs. tread brakes is on the order of 10 dB(A); this is greater than impact of aerodynamics. The second most cost-effective approach is optimizing the wheel flange shape and use of wheel dampers. Pantograph modifications have a positive impact on peak noise levels, but lower impacts on average noise levels. Skirts to cover wheels reduce aerodynamic noise, but are difficult to implement because of maintenance and wheel access issues (7) [224].

7.2.2 Noise Attenuation

Source (Rolling Stock) vs. Wayside and Receiver Approaches

Train noise models require source characterization tests that are not described in current international standards to produce accurate results (7) [229].

The EU Environmental Noise Directive requires member states to prepare noise maps and noise management action plans; noise attenuation requirements are then imposed by state and local governments (1) [234].

Current high speed rail vehicles offered by the major manufacturers meet noise regulations now in effect, but do not meet all contractual requirements. For example, HS2 (UK) has very complicated and strict noise requirements that will require new vehicle designs (7) [1].

Noise of pantograph: new high-speed lines in Europe are seeking combination solutions for noise reduction that includes both source noise reduction and use of barriers. For these systems, the pantograph becomes a key source of noise (e.g., in Japan); so, operators are setting goals for pantograph noise, but this is difficult to measure and predict. Better methods of measuring individual noise components are needed (7, 1) [159].

It is suggested that future regulations allow for both vehicle emissions reductions as well as noise path barrier designs in combination, rather than the current approach applied in the EU and US of specifying only passby noise levels for rolling stock. Designing rolling stock noise attenuation systems in conjunction with wayside barriers can be very effective in reducing immission levels and thus coordination of environmental noise regulations (immissions) with rolling stock (emissions) requirements is encouraged. This will lead to innovation in the design of both train and barriers. In the US, FRA regulations focus on the train set alone; should other methods be allowed to reduce noise at receptors (3) [11]?

Ranking of Approaches by Noise Attenuation Effectiveness

One option to quantify contributions of various high speed rail noise sources is to employ acoustic simulation. Simulations agree with real world data to within 1 dB(A) but depend on good input data. A lot of complaints have been received for parked trains with motors and heating, ventilation, and air conditioning (HVAC) operating. Thus, clients request noise level specifications for trains in parking mode. Noise of pantograph: new lines want to develop a system: design track with noise barriers, then pantograph becomes main source of noise (e.g., in Japan); so, operators are setting goals for pantograph noise, but this is difficult to measure and predict. Useless if cannot measure or predict (2, 4, 7) [229].

Height of the pantograph significantly impacts aerodynamic noise for high speed trains. It is noted that height clearances in Japan allow lower pantographs than would be required in the US (additional height of pantograph arm required to allow for freight operations on same track). The Japanese Shinkansen trains operate on a dedicated high-speed passenger train infrastructure. Thus, it is likely not possible to use the low-noise Japanese pantograph design in US. This is an example of the broader topic of operational requirements that dictate different approaches to reducing noise (3) [2].

Identification of Cost Effective Approaches

Resilient fasteners are a cost-effective approach to reducing sound pressure levels by nearly 10 dB(A) (8).

Noise attenuation programs have been offered to existing properties located near railroad tracks, based on L_{Aeq} criteria (5) [80] [222].

Current research indicates track roughness is a key contributor to high speed rail noise. Track grinding and use of rail dampers have proven to be cost effective approaches in Europe (Ricardo Rail research) (7) [230].

In Japan, aerodynamic modifications, such as pantograph covers, have proven cost effective for reducing noise of high speed trains (4) [159].

Operators are receiving a lot of complaints for parked trains with motors and HVAC equipment operating. Thus, railway operators are requesting from manufacturers noise level specifications for trains in parking mode (7) [227] [228].

Effectiveness of sound walls (barriers) is very site-specific and is most cost effective in densely populated areas. Most high speed rail projects pass through areas that vary significantly in population density so cost-effective solutions vary from area to area. Barriers are more effective for noise sources originating near lower part of train, versus sources located higher on the train, such as pantograph noise. Japanese researchers have done the most work in reducing aerodynamic noise originating at the pantograph; the Shinkansen high speed trains have sound levels about 10 dB(A) lower than European high speed trains due to noise controls incorporated into the rolling stock design coupled with sound absorbing noise path and reflection systems (2)

[190] [223]. Because the Shinkansen trains operate on a dedicated track, many of the low-noise design features may not be exportable to other high speed trains.

Testing of source and wayside noise attenuation systems may prove problematic within the US. There are currently no tracks that allow train speeds in excess of 160 mph (257/km/h). Thus, the trainsets will likely be constructed prior to the track being ready. Sending the train sets to be tested at overseas facilities may not be a viable option, not only because of the costs involved, but also because the track conditions will likely be significantly different and will lead to non-transferable results (3).

7.2.3 Noise Measurement Procedures

Procedures and Regulation Requirements

Studies indicate noise emitted by high speed trains has annoyance levels (i.e., community tolerance levels) that are 5 dB(A) to 10 dB(A) higher than those for conventional passenger trains at the same sound pressure levels, due to the higher frequency levels (5).

For conventional (e.g., low to medium speed) trains, maximum regulated sound pressure levels are typically 5 dB(A) higher than those for road vehicles due to lower annoyance levels [66] (5).

Noise test accuracy and repeatability are very good if measurements are made with the same vehicle on the same track. But differences between measurements made on different tracks can be significant. Repeatability of track quality (roughness) measurements also suffers from repeatability issues. There are two measurements related to noise levels: 1) surface roughness and 2) track decay rates (i.e., vibration decay). Roughness of track and wheel generates vibration affected by stiffness of track to tie connection (stiffer = lower the vibration). Track quality can affect noise readings by 2–3 dB(A) at low speed, and 1–2 dB(A) for high speed (1, 7).

It is challenging to find sections of track acceptable to TSI requirements where noise measurements can be made (1, 7).

Any regulation changes being considered should be referenced to train speed, because noise source contributions are coupled to speed, with aerodynamic noise becoming predominant at speeds above 330 km/hr (205 mph) (3) [223].

A key challenge for defining effective sound measurement procedures is to standardize the track and environmental factors under which the tests are conducted. This would include track and wheel design and surface condition/maintenance as well as changes that occur over time (e.g., vibration damping characteristics). The goal will be to achieve repeatable and accurate noise pressure readings (3).

It is suggested that noise regulations acknowledge accuracy limits of measurement equipment and set maximum sound pressure levels based on this accuracy range (2).

No current plans are in place to unify the various sound pressure level measurement regulations. However, ANSI and ISO appear are in communication and there is coordination in their standards (2).

Standardizing noise tests for US high speed rail are key to ensuring new regulations can be adapted for future trains and operations. Frequent public reviews will ensure proposed regulations are acceptable to all stakeholders. High speed rail should be viewed as a system (train + infrastructure) and the regulations should reflect this. Early on, a determination must be made whether to develop the regulations from a train-set-only or as full system, with the goal of mitigating effects on receivers (3).

In Japan, measurement of noise is regularly carried out by local governments along the Shinkansen line. The measurement methods are issued by the Environmental Agency (presently the Ministry of the Environment) as follows. No issues have been reported with respect to the accuracy of measurements (4) [67].

A. Measurements shall be carried out by recording the peak noise level of each of the Shinkansen trains passing in both directions, in principle, for 20 successive trains.

B. Measurements shall be carried out outdoors and in principle at the height of 1.2 m (about 4 ft.) above the ground. Measurement points shall be selected to represent the Shinkansen railway noise levels in the area concerned, as well as points where the noise is posing a problem.

C. Any period when there are special weather conditions or when the speed of the trains is considered lower than normal shall be avoided when selecting the measurement time.

D. The Shinkansen railway noise shall be evaluated by the energy mean value of the higher half of the measured peak noise levels.

E. The measuring instrument used shall be a noise meter that meets the requirements of Article 88 of the Measuring Law (Law No. 207 of 1951), with A-weighted calibration and slow dynamic response (4).

Studies conducted by the International Institute of Noise Control Engineering (I-INCE) indicate that no uniform approach to assessing the effectiveness of noise regulations at the international level. Current methods for evaluating effectiveness include: 1) examining changes in noise-related complaints over time, 2) assessing the results of periodic inspections, 3) reducing the number of people exposed to community noise, and 4) examining the results of questionnaire surveys (1,7) [80].

Equipment and Regulation Requirements

Based on the Acoutrain project in the EU, it has become clear that the current ISO standards for sound power estimation were not developed for vehicle noise source modeling and do not provide sufficient detail for such purpose (7) [229].

Rolling noise is very dependent upon track condition (roughness factors). This makes it difficult to find locations having uniform and repeatable rolling noise levels (1).

Sound level measurement equipment can be expensive (up to $10,000 per system) and must be regularly certified to ISO and ANSI standards. However, use by certified acousticians is well understood and accuracy issues are not a concern (2, 5) [195].

Identification of Industry Standards

Local regulations and land use planning controls typically impose building standards that define acceptable internal noise levels for new dwellings. Thus, both emissions and immissions sound pressure levels must be measured. Standards for measuring internal noise levels have been defined by agencies such as OSHA (US) and the International Organization for Standardization (13.140 - Noise with respect to human beings) (2, 8) [226].

High speed rail rolling stock manufacturers would like to see greater standardization among countries, with the recommendation that ISO 3095: 2013, Acoustics, Measurement of Noise Emitted by Rail Bound Vehicles, be used as the basis for noise measurements (5, 7).

Industry standard procedures for noise measurements are well accepted, accurate, and repeatable (1, 2, 5, 8).

Sound level meters specified in ANSI S 1.4 (Type 1 or Type 2) have not changed in many years and are not significantly difference than those defined in EN 61672 (Parts 1 and 2) or China GB3/85 or IESC Publication 179. Regulations allow use of either Type 1 or 2, but tolerances are different (Type 1 has higher tolerances, but more expensive) (2, 5).

High speed rail noise mitigation has been effective in Japan using a combination of noise source reduction and noise pathway barriers in combination. Future noise measurement procedures should be developed to account for both approaches in measuring immission levels at designated receiver locations (3) [235].

The 2008 version of TSI included 1 dB(A) tolerance for noise measurements to allow for variation in environment and equipment. This was removed from subsequent versions of the TSI. An analysis should be performed to determine whether measurement tolerances are warranted for inclusion in high speed train noise regulations (3) [50].

7.2.4 Compliance, Enforcement, Penalties

How are Regulations Enforced and by What Organization?

Three approaches were identified for the legislative and administrative structures for the enactment and enforcement of noise policies and regulations (5) [80]:

- Centralized—Noise-control regulations were enacted and enforced by the national government. Norway and France had centralized approaches to control of community noise.
- Tiered—The national government enacts noise-control laws. Local governments enforce specific regulations, ordinances, building codes, etc. Countries with tiered approaches included Germany, Japan, Korea, Netherlands, Slovenia, Turkey, UK, and USA.
- Decentralized—In a decentralized system, noise-control regulations, especially immission-oriented requirements, were enacted and enforced by local governments. Australia used the decentralized approach. However, in many countries with a decentralized approach for noise immission there was also a centralized approach for noise-emission requirements, such as for control of noise emission from automobiles, trucks, and motorcycles.

Immissions (receiver) noise regulations have been implemented in most countries. Frequently, rail noise regulations are imposed by central governments to prevent local governments from interfering with national and international and interstate transportation systems.

European Member States are under a lot of public pressure to reduce train noise levels through a more-stringent TSI. ERA general consensus is that TSI limits cannot be lowered much from current levels. This is because there is too much uncertainty regarding noise sources, including: track conditions, reflections, decay rate of track, environment, etc. More research is needed to determine cost effective approaches to lowering noise source levels. Stricter regulations are expensive to implement and could adversely affect the rail industry. UIC does not feel that stronger regulations are appropriate (1) [86].

The current approach being taken by FRA to understand existing high-speed rail noise regulations in other countries, including definition of the range of noise reduction levels possible with current technology, is supported by manufacturers and operators as a good approach to support the establishment of effective and achievable US regulations (3).

In Japan, the Environmental Quality Standards for Shinkansen Superexpress Railway Noise, first issued by the Environmental Agency (presently the Ministry of the Environment) is based on the Basic Environment Act of 1993 and delineates the standard values for maintaining the quality of the environment and sets the period for achieving environmental goals. It did not set any penalties for non-compliance (4) [158].

Variations in Enforcement Procedures vs. Location

ERA is of consensus that TSI noise limits cannot be lowered due to uncertainties in track conditions and surrounding topology (1).

The maximum US sound level for the train horn is 110 dB(A) which is a new requirement as of 2012. The minimum sound level remains 96 dB(A). Under the 49 CFR Part 222–Use of Locomotive Horns at Public Highway-rail Grade Crossings, localities nationwide have the option to mitigate the effects of train horn noise by establishing "new quiet zones" where horns may be used only during emergency situations (8). These quite zones might impact high speed rail (6) [61].

Legislation is difficult to compare and the immission data simply cannot be compared in any meaningful way (1) [80].

Where there are no national noise control limits and noise control is left to the States or localities, there can be significant differences to approaches and enforcement: some States actively manage railway noise, while others have no restrictions (5) [226].

EU directives prevent member countries or local governments from imposing noise restrictions greater than those included in the TSI and European Environmental Noise Directive END) (i.e., to prevent disruption of inter-country transportation (1) [84].

To properly assess effectiveness of EU and Asian regulations regarding noise from high speed trains, comparisons should be made regarding current source and receiver noise levels near established routes. This should be done for a range of train sets to ensure that the regulations are realistic and are having the desired effect. The results can be compared to both the rolling stock emissions and receiver immissions levels relative to the regulation requirements (3).

To ensure no disruption in interstate rail traffic within the US, Federally-imposed noise regulations must remain independent of local and state noise regulations as is currently the case (2) [23].

What Penalties are Imposed for Noncompliance and What Incentives are Available for Reducing Noise?

The US is one of the few countries that list specific noise regulations fines in the CFR. However, discussions with FRA inspectors indicate these fines are rarely imposed (6).

The EU has defined Noise-Differentiated Track Access Charges (NDTACs) primarily to address freight wagons equipped with cast-iron brake blocks. Public funds are offered as incentives for reducing train noise levels in conjunction with lower track access charges. Consideration is being given to imposing surcharges for high noise level rolling stock (5) [226].

Within the EU, train sets that do not meet TSI requirements can operate within one country, but cannot move between countries without TSI certification. Penalties for doing so could be imposed on the operator that purchases train sets. The penalty may be shared with the rolling stock manufacturer, depending on the guarantees provided at the time the rolling stock was purchased. All trains operating between EU countries are currently compliant with the TSI (7).

Within the EU, infrastructure managers are responsible for immissions levels at rail property boundaries and are the responsible party that must respond to complaints. Typically, private operators work together to address noise issues on joint routes (1).

Enforcement of EU noise regulations is rare; all current high-speed train sets provided by the major manufacturers meet the TSI noise regulations (1).

Within the US, quiet zones can be established according to 49 CFR Part 222 [61]. Within the quiet zones, train horns can be used only during emergency situations. Crossing equipment is not maintained by the railroads; that responsibility resides with the local municipality or county. Fines resulting from quiet zone noise violations also reside with the local municipality or county. Railroad operators are not subject to noise violation fines. Currently, quiet zone noise requirements apply only to horns (6, 8).

Noise complaints rarely result in fines to the railroad operators within the US, even though the regulations and penalties are codified by EPA and enforceable by FRA. The regulations are difficult to enforce without corresponding test data performed by certified acousticians (6).

In general, noise immission limits are incorporated into non-mandatory guidelines, while noise emission limits exist as regulations where compliance is legally required (1, 5, 6) [80].

7.2.5 Public Concerns

Has there been Public Resistance to Existing Regulations?

Resistance has been offered to high speed rail projects at every location they have been installed or are currently proposed (5).

Noise due to rail freight traffic is a bigger issue than noise originating with high speed rail (1, 5).

In Japan, the noise of the Shinkansen high speed trains have been identified as being highly annoying relative to conventional train noise, likely due to the frequency spectrum (4) [225].

Concern regarding equivalent or averaged noise levels has been expressed by residents living near rail lines. They point out that the noise associated with individual events is a better indicator of annoyance, especially during night time periods (7; discussion with Ricardo Rail Netherlands).

Although noise complaints arise with the public, there is little public awareness of current high speed rail noise regulations. Urban acceptance of train noise is better than rural acceptance, primarily due to effects on wildlife and farm animals (2).

Which Organizations are Supporting/Organizing this Resistance?

Several organizations within the UK and Europe have developed to offer resistance to high speed trains, including Stop HS2 and Stopherrie HSL in the Netherlands. Key issues promoted by these organizations is increased noise emissions, impact on nature reserves and wildlife, damage or demolition of historic buildings, transfer of jobs, and negative impact on view sheds (1) [1] [112].

In Germany, several non-government organizations have conducted train noise measurements, including Bundesvereinigung gegen Schienenlärm (Organization Against Perceived Noise) and Bund für Umwelt und Naturschutz Deutschland (Friends of the Earth, Germany) (Ricardo research, discussion with Ricardo Rail, Netherlands) [129] [134].

Additional railroad noise resulting from increases in high speed rail traffic, and current threats of additional Member States leaving the EU could lead to separate and uncoordinated approaches to reducing noise that would be incompatible with interoperability (1, 3).

Has Public Resistance Resulted in Changes to the Regulations?

The World Health Organization published population-based noise targets, including Guidelines for Community Noise (1999) and Night Noise Guidelines for Europe (2009) (1, 5) [222][234].

EU action groups have been successful in influencing noise policies (1, 5). Complaints about railway noise are a political issue; it is important that communities that are exposed to high noise levels are treated fairly and the policies applied are perceived to be reasonable and appropriate (5) [226].

In the Netherlands, following the opening of the HSL during 2009, public protests regarding noise levels, particularly startle (onset) noise led to pressure on the national government by local politicians to mitigate noise. These concerns were partly justified, which led to control measures being developed (Ricardo Rail discussion).

After the Tokaido Shinkansen line opened in 1964 as the first high speed train in Japan, many people living along the line started to complain of the noise and vibration from the Shinkansen trains and it became a social issue. Therefore, the Environmental Agency (presently the Ministry of the Environment) issued the Environmental Quality Standards for Shinkansen Superexpress Railway Noise in 1975, and its standards have continued unchanged since that time (4) [164] [225].

7.3 Stakeholder Interviews: Compare and Contrast Responses

Table 84 through Table 98 summarized the interview responses contained in Section 7.2, which are divided into the following categories:

1. Rolling Stock
2. Noise Attenuation
3. Noise Measurement
4. Compliance Enforcement
5. Public Concerns

Table 84: Rolling Stock, Impact of Noise Regulations on Vehicle Design

Rolling Stock: Impact of Noise Regulations on Vehicle Design		
Topic	**Similarities**	**Differences**
Design Improvements	Regulations set minimum emissions standards	Varying levels of support for exceeding regulatory requirements ranging from reduced rail access charges to monetary incentives.
Track Quality	Track and wheel quality (roughness) varies widely and causes issues with meeting noise target through design improvements	Regulations do not employ uniform approaches to accounting for track roughness. Some define minimum track conditions for testing.
Future Regulations	Manufacturers and operators must anticipate noise regulation changes over the life of the vehicle.	Regulatory agencies have not provided road maps regarding anticipated future noise standards. Some agencies have included stakeholders in design discussions, such as the EU.
Emissions and Immission Noise Reduction Integration	Some regulations, for example Japan, allows both vehicle and wayside modifications to meet noise targets.	Most train noise regulations are overseen by separate agencies for emissions (rolling stock) and immissions (sound pathway attenuation methods).
Key Design Drivers	Train manufacturers and operators are driven by regulations, cost, and consumer requirements.	Manufacturers have found that specifications and contract terms are key drivers for vehicle design and often exceed regulatory requirements. These contract terms vary widely among operators.
High Speed Issues	Key aerodynamic noise sources are 1) pantograph, 2) inter-car gaps, and 3) wheels.	Countries vary in their approaches to reducing aerodynamic noise, including dedicated use of track for high speed operation vs. sharing lines with freight, integration of wayside and on-vehicle design solutions, and quality of track, ballast v slab, and maintenance requirements.
Train Speed	High speed rail noise increase with train speed.	Some countries set a single noise limit for trains, or set limits based on land use (residential or commercial/industrial); others allow variations in source noise as a function of speed.

Table 85: Rolling Stock, Impact of Noise Regulations on Vehicle Cost

Rolling Stock: Impact of Noise Regulations on Vehicle Cost		
Topic	**Similarities**	**Differences**
Regulation Changes	Regulatory agencies regularly evaluate noise limits to determine if changes are required.	Some regulations are rarely changed (e.g. Japan Shinkansen regulation has remained unchanged for decades), and others undergo frequent review (e.g. EU TSI and Noise Directive). Frequent changes impose new design requirements and possible retrofits.
Manufacturing Costs	Regulations are one of the drivers for vehicles designs. All noise reduction modifications result in capital cost increases.	Vehicle noise design requirements vary by operators and countries and depend upon regulatory targets, track conditions, track access (HS only or sharing with freight), and track access fees (lower noise levels result in lower access fees, that must be evaluated in terms of increased capital costs).
Vehicle Noise Targets	Trains must meet noise regulations	Various approaches to meeting regulatory requirements are taken depending upon the condition of the track (roughness), height of the catenary (pantograph design), and maintenance requirements (e.g. wheel access behind skirts).
Regulation Driven Design	Trains must meet noise regulations	Many manufacturers and operators are of the opinion that stricter regulations may not have the desired noise reduction impacts because the added costs may drive transportation to other modes such as trucks or buses.

Table 86: Rolling Stock, Identification of Cost Effective Approaches

Rolling Stock: Identification of Cost Effective Approaches		
Topic	**Similarities**	**Differences**
Mechanical: Wheels	Wheel/rail noise is a key component of noise emissions from high speed trains.	A variety of approaches have been taken to reduce rolling noise, including moving from tread brakes to disc brakes, grinding to maintain the rail surface, design of the wheel flange and tread, wheel dampers, and maintaining the wheel surface.
Mechanical: Weight	Higher vehicle weight increases bearing wear as well as wheel/rail noise.	Various methods have been employed to reduce train weight, including the use of composite materials, lightweight structures, and improved wheel designs.
Aerodynamics	Aerodynamic noise is the predominant component of train noise at speed above 330 km/hr. To meet regulations, all HS rolling stock manufacturers are seeking reductions in aerodynamic noise. Key modifications include nose design, wheel skirts, inter-car gap seals, and pantograph covers/barriers.	Aerodynamic modifications are dependent upon regulatory limits, tradeoffs between emission and immission solutions, sharing of the HS track with freight operations (affects height of pantograph), maintenance requirements (access to vehicle interior), costs, and track conditions (ballast type, adjacent reflective surfaces, etc.).

Table 87: Noise Attenuation, Source vs. Wayside & Receiver Approaches

Noise Attenuation: Source (Rolling Stock) vs. Wayside & Receiver Approaches		
Topic	**Similarities**	**Differences**
Noise Source: Noise Modeling	Manufacturers and operators require accurate definition of noise sources for specific train applications in order to assess cost effectiveness of tentative solutions.	Current noise models vary in accuracy and effectiveness. Geography, land use, track conditions, and regulatory targets vary for each route and location. Solutions that are appropriate for one rail operator may not be effective for another.
Regulations and Contract Specifications	Regulations and contract terms must be addressed by manufacturers and operators.	Approaches to regulatory compliance vary based on both emission and immission requirements and coordination between the overseeing agencies. Japan's approach is to integrate both vehicle and wayside noise attenuation systems. Most other countries separate the regulatory requirements.
Source Noise Reductions	All manufactures and operators must deal with rolling, mechanical, and aerodynamic noise sources.	Approaches to reducing rolling noise sources varies depending upon the roughness of the track upon which the train will be operated. Mechanical noise sources such as motors, engine, or HVAC systems can be addressed using noise insulation systems. Aerodynamic modifications typically include pantograph covers and barriers, followed by intercar gap seals, and side skirts,
Integrated Approaches	Most countries are evaluating integrated approaches. Others, like Japan, have included integrated source and wayside designs from the onset.	Approaches vary depending upon track and vehicle type. Skirts on the vehicle and low-level barriers are effective at dealing with wheel related noise, including aerodynamic noise originating at this area. Pantograph noise is addressed in a number of ways depending upon the height of the pantograph and the speed of the train and includes on-train shields and barriers as well as trackside barriers.

Table 88: Noise Attenuation, Ranking of Approaches by Effectiveness

Noise Attenuation: Ranking of Approaches by Noise Attenuation Effectiveness		
Topic	**Similarities**	**Differences**
Acoustic Simulation	Acoustic simulation is a cost effective way of assessing the impact of candidate design modifications.	Simulation methods vary in accuracy and cost. The best simulations are now accurate to within ±1 dB(A) and are effective at evaluating the noise reduction associated with proposed design concepts, including a full frequency analysis.
Ranking of Noise Reduction Approaches	Source, wayside, and receiver approaches all fall into key categories, but vary in effectiveness: vehicle body, rail & wheel, sound barriers, reflective surfaces, and building modifications.	Effectiveness at reducing sound pressure at the receiver varies depending upon track conditions, surrounding structures, train design, ambient conditions, and topology. Those approaches found to be the most effective at reducing noise from high speed trains include: speed restriction, wheel/rail design, underbody and wheels (including damping), rail damping, sound insulation of mechanical equipment, reducing number of pantographs, reducing vehicle weight, increased curve radii, pantograph shields and barriers, sound absorbing barriers, resilient slab padding, low acoustical transmission walls and doors, improved track and building foundation designs.

Table 89: Noise Attenuation, Identification of Cost Effective Approaches

Noise Attenuation: Identification of Cost Effective Approaches		
Topic	**Similarities**	**Differences**
Government Incentives	Many agencies having jurisdiction offer financial support to operators and residents for installation of noise reduction systems.	The type of incentives offered vary from reduced track access charges for rolling stock that has noise level less than regulatory requirements to support of sound barrier construction and addition of sound insulation to buildings.
Track Modifications	Operators have the choice of employing noise reduction technologies to tracks, rolling stock and wayside structures.	The cost effectiveness of track modifications varies by track and ballast type (open ballast, slab track, track roughness). Those that have proven to be cost effective include resilient fasteners, increased radii, rail grinding, rail lubrication, rail gap reducers, tuned rail dampers.
Vehicle Modifications	Vehicle modifications involve addressing noise originating at the wheels, mechanical equipment and aerodynamics	Cost effective vehicle modifications vary by train maximum speed, track conditions, and topology adjacent to the track. Some that have proven effective include use of insulation to shield noise from mechanical equipment, use of low friction bearings, damped wheels, wheel profile/surface systems, disc brakes, vehicle body design, gap seals, pantograph covers and barriers, skirts, and undercarriage noise absorption.
Wayside Modifications	Wayside modifications include barriers and sound absorbing systems.	Choices for cost effective solutions varies based on track location (urban, rural), regulatory requirements, land use, and train noise emissions levels. Some cost effective approaches include: barriers (reflective and absorbing), trenches, and berms.
Receiver Modifications	Receiver modifications include barriers, sound absorbing systems, and sound insulation.	There are more similarities than differences related to receiver modifications. Cost effective approaches include low acoustic transmission windows and walls, vibration barriers at foundations, noise barriers and sound absorption barriers.

Table 90: Noise Measurement, Equipment and Regulations

Noise Measurement: Equipment and Regulation Requirements		
Topic	**Similarities**	**Differences**
Annoyance Levels	Sound from trains causes annoyance based on pressure level and frequency.	Train annoyance factors are less than those for road vehicles at the same sound pressure levels. The difference is on the order of 5 dB(A). However, high speed trains have a higher annoyance factor than conventional trains due to the higher frequencies.
Noise Test Accuracy and Repeatability	Test results are highly dependent upon track condition.	Differences in measured sound pressures varies based on track and wheel roughness. Track quality can affect noise readings by 2-3 dB(A) at low speed, and 1-2 dB(A) for high speed
Test Locations	Noise tests are required for all railroad vehicles.	It is challenging to find track sections that provide acceptable surface roughness, track decay rates, and open areas required by the regulations. This makes it difficult to show compliance with the regulations. Regulations vary in their definitions of acceptable track conditions required for noise tests.
Unified Regulations	Possible international coordination of sound test procedures.	No current plans are in place to unify the various sound pressure level measurement regulations. However, ANSI and ISO appear are in communication and there is coordination in their standards.
Measurement Accuracy	It is generally acknowledged that current test instrumentation is adequate for currently required measurements.	It is suggested that noise regulations acknowledge accuracy limits of measurement equipment and set maximum sound pressure levels based on this accuracy range.
Impact of Regulations	Operators and manufacturers suggest studies be performed to determine the effectiveness of regulations on achieving target noise levels.	No uniform approach to assessing the effectiveness of noise regulations exists at the international level. Current methods for evaluating effectiveness include: 1) examining changes in noise-related complaints over time, (2) assessing the results of periodic inspections, (3) reducing the number of people exposed to community noise, and (4) examining the results of questionnaire surveys.

Table 91: Noise Measurement Procedures, Procedures and Requirements

Noise Measurement Procedures: Procedures and Regulatory Requirements		
Topic	**Similarities**	**Differences**
Acoustic Modeling	Acoustic models are cost effective tools for assessing candidate noise reduction modifications.	Based on the Acoutrain project (EU), it has become clear that the current ISO standards for sound power estimation were not developed for vehicles source modeling and do not provide sufficient detail for such purpose.
Acoustic Test Cost	Regulations specify test equipment and procedures.	Sound level measurement equipment can be expensive (up to $10K per system) and must be regularly certified to ISO and ANSI standards. Accuracy varies by instrument type and cost. However, use by certified acousticians is well understood and accuracy issues are not a concern.

Table 92: Noise Measurement Procedures, Identification of Industry Standards

Noise Measurement Procedures: Identification of Industry Standards		
Topic	**Similarities**	**Differences**
Immission Measurements	Regulations require measurements of both emissions and immissions.	Differences exist between the immission measurement procedures defied by the various agencies, such as OSHA and ISO. This can make it difficult to compare measurements using the different procedures.
Standardization	Rolling stock manufacturers and operators would like to see standardization of the various measurement procedures.	It has been recommended that ISO 3095: 2013, Acoustics, Measurement of Noise Emitted by Rail Bound Vehicles, be used as the basis for noise measurements.
Equipment	Each noise regulation specifies measurement equipment requirements.	Sound level meters specified in ANSI S 1.4 (Type 1 or Type 2) have not changed in many years and are not significantly difference than those defined in EN 61672 (Parts 1 and 2) or China GB3/85 or IESC (International Electric Standards Conference) Publication 179. Regulations allow use of either Type 1 or 2, but tolerances are different (Type 1 has higher tolerances, but more expensive).
Tolerance	The accuracy of the test equipment must be included in the regulations.	The 2008 version of TSI included 1 dB(A) tolerance for noise measurements to allow for variation in environment and equipment. This was removed from subsequent versions of the TSI. An analysis should be performed to determine whether measurement tolerances are warranted for inclusion in high speed train noise regulations

Table 93: Enforcement Procedures and Organizations

Compliance, Enforcement, Penalties: How are Regulations Enforced and by What Organization?		
Topic	**Similarities**	**Differences**
Legislative and Administrative Structures for Enactment and Enforcement	All railroad noise regulations include target noise levels typically delineated by train type and application.	Three types of enactment and enforcement structures have been identified: 1) Centralized—Noise-control regulations were enacted and enforced by the national government. 2) Tiered—The national government enacts noise-control laws. Local governments enforce specific regulations, ordinances, building codes, etc., and 3) Decentralized—In a decentralized system, noise-control regulations, especially immission-oriented requirements, were enacted and enforced by local governments.
Immissions vs. Rail Noise	Receiver noise regulations have been implemented in most countries.	Frequently, rail noise regulations are imposed by central governments to prevent local governments from interfering with national and international and interstate transportation systems.
Government Initiatives	Noise legislation is under constant review by most countries and country unions	US: The United States is conducting research on all aspects of high speed rail noise legislation including the range of noise reduction levels possible with current technology prior to beginning rule making. Japan: Quality Standards for Shinkansen Superexpress Railway Noise, first issued by the Environmental Agency (presently the Ministry of the Environment) is based on the Basic Environment Act of 1993 and delineates the standard values for maintaining the quality of the environment and sets the period for achieving environmental goals.

Table 94: Variations in Enforcement Procedures vs. Jurisdiction

Compliance, Enforcement, Penalties: Variations in Enforcement Procedures vs. Location		
Topic	**Similarities**	**Differences**
EU TSI Status	The TSI sets uniform standards across all EU Member States.	Pressure to impose stricter TSI noise levels have been resisted by the European Union Agency for Railroads (ERA), because of too much uncertainty regarding noise sources, including track conditions, reflections, decay rate of the track and environmental factors.
Quiet Zones	Most noise regulations include limits on use and loudness of train horns.	Maximum train horn noise levels range from 101 dB(A) in the UK to 96 dB(A) in the US. Restrictions on night time use and within quiet zones (imposed by local governments) are also imposed, except in the case of emergencies.
Enforcement	Most railroad noise regulations are not aggressively enforced.	Where there is no national noise control limits and noise control is left to the states or localities, there can be significant differences to approaches and enforcement: some states actively manage railway noise, while others have no restrictions. Noise complaints rarely result in fines to the railroad operators within the US, even though the regulations and penalties are codified by EPA and enforceable by FRA. The regulations are difficult to enforce without corresponding test data performed by certified acousticians.
Local Jurisdiction	Interstate and Intercountry train operations are generally subject to national noise regulations and exempt from local regulations.	In the US, EU, Japan, and China, train noise regulations are imposed and enforced by the EU or Federal government. EU directives prevent member countries or local governments from imposing noise restrictions greater than those included in the TSI and EDN (in order to prevent disruption of inter-country transportation

Table 95: Penalties Imposed for Noncompliance

Compliance, Enforcement, Penalties: What Penalties are Imposed for Non-Compliance?		
Topic	**Similarities**	**Differences**
Definition of Penalties Asia	The identified train noise regulations in China and Japan do not specifically specify penalties for non-compliance.	China: Penalties are not defined, but are determined on a case-by-case basis. Japan: Regulations for the Shinkansen Superexpress Railway noise levels do not set any penalties for non-compliance.
Definition of Penalties US	Most countries do not list specific monetary fines for non-compliance with railroad noise regulations.	The US is one of the few countries that list specific noise regulations fines in the CFR. However, discussions with FRA inspectors indicates these fines are rarely imposed
Definition of Penalties EU	Several countries, including Japan and EU Member States prevent non-compliant rolling stock from operating on specified sections of track.	Within the EU, train sets that don't meet TSI requirements can operate within one country, but cannot move between countries without TSI certification. Penalties for doing so could be imposed on the operator that purchases train sets. The penalty may be shared with the rolling stock manufacturer, depending on the guarantees provided at the time the rolling stock was purchased. All trains operating between EU countries are currently compliant with the TSI.
Incentives	There are few similarities between noise reduction incentive programs which range from lower track access charges to government grants.	The EU has defined Noise-Differentiated Track Access Charges (NDTACs) primarily to address freight wagons equipped with cast-iron brake blocks. Public funds are offered as incentives for reducing train noise levels in conjunction with lower track access charges. Consideration is being given to imposing surcharges for high noise level rolling stock.
Immissions	Noise levels at railroad property boundaries is typically the responsibility of the railroad operator or infrastructure manager.	Within the EU, infrastructure managers are responsible for immissions levels at rail property boundaries and is the responsible party that must respond to complaints. Typically, private operators work together to address noise issues on joint routes. Enforcement of EU noise regulations is rare; all current high speed train sets provided by the major manufacturers meet the TSI noise regulations. Within the US, quiet zones, which are administered by local governments, noise requirements apply only to horns.
Guidelines	In general, noise immissions limits are incorporated into non-mandatory guidelines.	Noise emission limits exist as regulations where compliance is legally required.

Table 96: Public Resistance to Existing Regulations

Public Concerns: Has there been Public Resistance to Existing Regulations?		
Topic	**Similarities**	**Differences**
Public Resistance	Resistance has been offered to high speed rail projects at every location they have been installed or are currently proposed.	Noise due to rail freight traffic is a bigger issue than high speed rail
Annoyance Levels	High speed rail has higher levels of noise annoyance than conventional passenger trains.	In Japan, the noise of the Shinkansen High Speed trains has been identified as being highly annoying relative to conventional train noise, likely due to the frequency spectrum
Reporting Methods	Most measurements of high speed rail noise is based on average or equivalent noise levels.	Concern regarding equivalent or averaged noise levels has been expressed by residents living near rail lines. They point out that the noise associated with individual events is a better indicator of annoyance, especially during night time periods, and therefore, peak noise values should be reported.
Public Knowledge	Public resistance to high speed rail projects is generally subjective and rarely supported by scientific measurements.	Although noise complaints arise with the public, there is little public awareness of current HS rail noise regulations. Urban acceptance of train noise is better than rural acceptance, primarily due to effects on wildlife and farm animals

Table 97: Organizations Supporting and Organizing Resistance

Public Concerns: Which Organizations are Supporting/Organizing this Resistance?		
Topic	**Similarities**	**Differences**
Resistance Organizations: Europe	Resistance to high speed train noise ranges from loosely organized protests to established non-government organizations.	Several organizations within the UK and Europe have developed to offer resistance to high speed trains, including Stop HS2 and Stopherrie HSL in the Netherlands. Key issues promoted by these organizations is increased noise emissions, impact on nature reserves and wildlife, damage or demolition of historic buildings, transfer of jobs, and negative impact on view sheds. In Germany, several non-government organizations have conducted train noise measurements, including Bundesvereinigung gegen Schienenlärm (Organization Against Perceived Noise) and Bund für Umwelt und Naturschutz Deutschland (Friends of the Earth, Germany).
Industry Concerns	Complaints and protests raise concerns among railroad operators.	Additional railroad noise resulting from increases in high speed rail traffic, and current threats of additional member states leaving the EU could lead to separate and uncoordinated approaches to reducing noise that would be incompatible with interoperability.

Table 98: Regulation Changes Resulting from Public Resistance

Public Concerns: Has Public Resistance Resulted in Changes to the Regulations?		
Topic	**Similarities**	**Differences**
EU	Organized protests have occurred relative to all EU high speed rail lines.	EU action groups have been successful in influencing noise policies
Resistance Support	Several organizations have published documents on the health impacts of high noise levels.	The World Health Organization has published population-based noise targets, including Guidelines for Community Noise (1999) and Night Noise Guidelines for Europe (2009)
Politics	Locations of high speed rail lines raise a number of political concerns related to impacts on infrastructure, property, and neighborhoods.	Complaints about railway noise are a political issue; it is important that communities that are exposed to high noise levels are treated fairly and the policies applied are perceived to be reasonable and appropriate
Startle Noise	High speed train onset noise is a concern and has been a focus of protest groups.	In the Netherlands, following opening of the high speed line (HSL) during 2009, public protests regarding noise levels, particularly startle (onset) noise led to pressure on the national government by local politicians to mitigate noise. These concerns were partly justified, which led to control measures being developed.
Japan	Protests regarding noise from the Tokaido Shinkansen line began immediately after the line was opened in 1964.	Many people living along the line started to complain of the noise and vibration from the Shinkansen trains and it became a social issue. Therefore the Environmental Agency (presently the Ministry of the Environment) issued the Environmental Quality Standards for Shinkansen Superexpress Railway Noise in 1975, and its standards have continued unchanged since that time.

8. Conclusion

Noise emissions (source) and immissions (receiver) are typically regulated by different branches of government, with emissions relegated to national transportation agencies and immissions to national environmental agencies as well as State and local governments. Rolling stock noise emissions limits are specified in EU and US regulations while China and Japan specify immissions limits only.

The US does not currently have specific noise regulation relating to high speed rail operations. At the present time, high speed trains, by default, are classified as locomotives in the US and the maximum noise limit is 90 dB(A), based on $L_{max\ (fast)}$ metric. The limit for US rail car noise is 93 db(A), based on $L_{max\ (fast)}$ metric, with measurements conducted at a distance of 30 meters (98.4 feet) from the track centerline. The noise limit for electric high speed trains in the EU at a reference speed of 250 km/h (155 mph) is 95 dB(A), based on $L_{pAeq,Tp}$ metric, measured at a distance of 7.5 meters (24.6 feet) from the track centerline. Currently, EU countries do not have the option to adopt regulations that are stricter than those contained in the TSI, thus facilitating inter-country operations. In China, the maximum allowable immissions limit for all rolling stock, including high speed rail, is 70 dB(A) during the day and 60 dB(A) during the night, based on the L_d and L_n metrics, measured at a distance of 30 meters (98.4 feet) from the track centerline. In Japan, high speed trains must have noise levels of 75 dB(A) or less, based on the L_{pASmax} metric, measured at a distance of 25 m (82 ft.) from the track centerline.

It is noted that direct comparisons of regulated noise limits are difficult due to the variations in metrics, measurement locations, and measurement procedures. It is recommended that a standardized method be developed to allow direct comparison of limits and test data. An evaluation of noise measurement methods and calculation procedures indicates a global-scale normalization process could be developed as a spread-sheet based program. The program would allow selection of train type and speed range. A library of available test data would serve as the basis for calculating the various sound measurement parameters, such as $L_{max(fast)}$, $L_{max(slow)}$, $L_{pAeq,Tp}$, L_d, L_n, L_{den} (CNEL), and L_{pASmax} as a function of background noise levels and number of train passing events. From these results, statistical calculations could be completed, including L_{90} (sound level exceeded 90 percent of the time), and L_{10} (sound level exceeded 10% of the time). Other parameters would include absorption and reflective characteristics of the slab or ballast. During the industry stakeholder interviews, it was discovered that at least three organizations performed research on this topic and have been successful in making quantifiable comparisons of some test procedures and metrics. The proposed spreadsheet program would extend these results to a wider range of reporting metrics.

Source noise emissions recorded for presently-available high speed trainsets from key manufacturers indicate current US railroad noise regulation limits may be exceeded for speeds above 200 mph (322 km/h). Calculations indicate the current US limit of 90 dB(A) will be exceeded by 0.4 dB(A) to 5.4 dB(A) based on measurement data for available high speed trainsets.

The information gathered in this report will inform FRA and the EPA in considering noise regulation that address high speed rail operations.

Railroad noise reduction approaches, ranked in order of cost effectiveness are:

1) ***Reducing source noise at the vehicle*:** noise emission sources in order of relative contribution total train noise levels is: a. pantograph; b. power car wheels; c. forebody, front window/roof interface; d. cooling fans; e. coach wheels; f. intercar gap; and g. wheel truck (bogie) aerodynamic noise. Noise reduction research for rolling stock is ongoing and many effective design modifications have already been implemented. It is projected that additional reductions of between 5 dB(A) and 10 dB(A) are still possible.

2) ***Interrupting the sound path using barriers and increasing distance to receivers*:** sound immission levels adjacent to roadways and railroad tracks can be reduced between 5 dB(A) and 12 dB(A) using a variety of materials, with concrete being the most cost effective. Barriers are most cost effective in densely-populated areas. Although not always feasible or practical, increasing the distance from tracks to receiver is also effective at reducing noise levels. When the distance to the train is doubled, the maximum sound level is reduced by 3–6 dB(A).

3) ***Applying sound insulation at the receiver*:** construction techniques and materials selection can reduce receiver immissions (interior) noise levels between 1 dB(A) and 25 dB(A).

Rail noise regulations should account for accuracy of measurement procedures. Sound meter accuracy is typically ±0.5 dB(A). Measurement repeatability: there is a 95 percent confidence that the calculated noise levels are within ±3 dB(A) of the true $L_{Aeq(period)}$ noise levels when at least 20 train passbys of each type under the same operating conditions are measured. For the L_{Amax} assessment parameter, the uncertainty increases to approximately ±5 dB for the same number of train passbys." Sources of the uncertainty include: speed variations, differences in rolling stock (e.g., due to manufacturing tolerances, age of vehicle and associated changes to suspensions, wheel surface roughness, bearings, etc.), track surface roughness, track alignment/curvature, track structure decay rates, and intermittent effects such as level of wheel hunting and flanging.

Rail noise regulations should also take train speed into account; the increase in passby noise levels measured for a train traveling at 250 km/h (155 mph) and the same train traveling at 350 km/h (217 mph) is 8 dB(A). Variations in passby noise levels up to 2 dB(A) have been measured for the same high-speed train operating on two different sections of track. Other research indicates variations in rolling noise (wheel/rail surface roughness effects), that can range to 9 dB(A). The standard deviation of these measurements was 7 dB(A). Thus, legislation regarding rolling stock emissions levels must include specifications for track roughness in order to provide valid measurements for compliance assessment.

Although penalties are included in most noise regulations, ranging from reduced track access to monetary fines, enforcement is infrequent and not uniformly applied.

Other conclusions and recommendations expressed during the study are stated below.

Rolling Stock:

- Integrating source and noise path solutions as a system provides opportunities for cost-effective noise reduction.

- Current rolling stock noise reductions are generally driven by contractual terms rather than regulations because rail operators are anticipating stricter future noise limits.

Current high speed rail vehicles offered by the major manufacturers meet noise regulations now in effect, but do not meet many of the recently submitted and proposed contractual requirements. For example, HS2 (UK) has very complicated and strict noise requirements that will require new vehicle designs. (Stakeholder Interviews 1 and 7, see Section 7) and [1]. In Australia, Switzerland, and Sweden, operators set targets that are more stringent that the EU TSI (interviews 1 and 7) and [2] [3].

- Noise due to aerodynamic sources becomes greater than rolling noise at higher speeds. The speed at which aerodynamic noise becomes predominant varies with the train design and wheel/track conditions, but is generally in the range of 320 km/h (199 mph) to 340 km/h (211 mph), with the pantograph being the key noise source at speeds above these values.
- Testing of candidate trainsets within the US will present challenges because no tracks are rated for speeds above 160 mph (257 km/h).

Noise Measurement Procedures:

- Standardizing noise tests for high speed trains in the US is recommended.
- Regulations should define whether they apply to the vehicle only or the entire system.

Compliance, Enforcement, Penalties:

- More research is needed to determine cost effective approaches to lowering noise source levels. Stricter regulations are expensive to implement and could adversely affect the rail industry.
- Regulations of high speed rail noise at the highest level of government (Federal/EU/National) should take precedence over local and State levels due to the long-distance nature of rail transportation systems [5].
- Legislation should include well-defined penalties for non-compliance as well as time periods for attaining compliance should noise limits be exceeded.

Public Concerns:

- Public concerns in countries that have implemented high speed rail provide direction for implementing new high-speed projects, including approaches that have met public demands.
- Noise reduction systems accepted by the public in the EU and Asia provide guidance for new high-speed projects.

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Abbreviations and Acronyms

ACRONYMS	EXPLANATION
ASJ	Acoustical Society of Japan
ANC	Active Noise Control
AIST	Agency of Industrial Science and Technology
ANSI	American National Standards Institute
APTA	American Public Transportation Association
AHJ	Authority Having Jurisdiction
APL	Axles per Length (number of rail car axles divided by car length)
BSI	British Standards Institute
BImSchG	Bundes-Immissionsschutzgesetz
CaHSRA	California High Speed Rail Authority
CHSTS	California High-Speed Train System
CTRL	Channel Tunnel Rail Link
CREATE	Chicago Rail Efficiency and Transportation Efficiency
EPB	China: Local Environmental Protection Bureaus
MEP	China Ministry of Environmental Protection
CARS	Chinese Academy of Railway Sciences
CFR	Code of Federal Regulations
CNEL	Community Noise Equivalent Level
CER	Community of European Railway and Infrastructure Companies
CTL	Community Tolerance Levels
CR	Conventional Rail
CEQ	Council on Environmental Quality
DOL	Department of Labor
DB	Deutsche Bundebahn
DMU	Diesel Multiple Units
RMV	Dutch Noise Calculation and Measurement Instructions
RMR	Dutch Noise Level Calculation Procedure
EBA	Eisenbahn Bundesamt (German Federal Rail Agency)
EMU	Electric Multiple Units
EIA	Environmental Impact Assessment

ACRONYMS	EXPLANATION
EIS	Environmental Impact Statement
EPB	Environmental Protection Bureau
AEIF	European Association for Railway Interoperability
END	European Environmental Noise Directive
ERTMS	European Rail Transport Management System
EN	European Standards - Engineering
ETCS	European Train Control Systems
ERA	European Union Agency for Railways
END	European Union Environmental Noise Directive
EU	European Union
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
GPP	Geluidsproductieplafonds (Netherlands) or Noise Production Ceilings
DE	Germany
BImschG	German Federal Immissions Protection Act
HVAC	Heating, Ventilation, and Air Conditioning
HSL	High Speed Line
HS2	High Speed Two
IEEE	Institute of Electrical and Electronics Engineering
ICE3	InterCity Express 3
ICE	Intercity Express Trains (Europe)
ICNG	Intercity Next Generation Trains (Europe)
ICA	International Congress on Acoustics
IEC	International Electrotechnical Commission
IESC	International Electric Standards Conference
I-INCE	International Institute of Noise Control Engineering
ISO	International Organization for Standardization
UIC	International Union of Railways
UIP	International Union of Wagons Keepers
ISO DIS	ISO Draft International Standard

ACRONYMS	EXPLANATION
MITTI	Japanese Agency of Industrial Science and Technology
JIS	Japanese Industrial Standard
LCC	Life Cycle Cost
MEP	Ministry of Environmental Protection
NS	Nederlandse Spoorwegen: Netherlands passenger railway operator
NL	Netherlands
NDTAC	Noise-Differentiated Track Access Charges
NOEMIE	NOise Emission Measurement Campaign for High-Speed Interoperability in Europe
NEC	Northeast Corridor
OSHA	Occupational Safety and Health Administration
OTM	On Track Machine
PRIIA	Passenger Rail Investment and Improvement Act
PPP	Public Private Partnership
RGS	Railway Group Standards (European Union)
RSSB	Rail Safety Standards Board
RMV	Reken en Meet voorschrift
SEPA	State Environmental Protection Administration Bureau
SEL	Sound Exposure Level
TSI	Technical Specifications for Interoperability
CEN	The European Committee for Standardization
TGV	Train à Grande Vitesse (French High Speed Train)
TEL	Transient Exposure Level
TSI NOI	TSI Noise Regulation Number 1304/2014
DOT	US Department of Transportation
EPA	U.S. Environmental Protection Agency
NEPA	US National Environmental Policy Act
VT	Virtual Testing
WTO	World Trade Organization