A review on different regulation for the measurement of transport noise and vibration

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Abstract. Transport noise and vibration have a negative influence on the environment, human health, and quality of life. The measurement and analysis of transport noise and vibration are required by the regulations and guidelines that various countries have set in order to manage and mitigate these effects. This review paper provides an overview of the requirements for the measurement and analysis of vibration and noise in transportation in different countries. The paper examines the measurement and analysis parameters, methods, and standards used in the United States, Europe, Australia and Japan. The review finds that although the requirements for measurement and analysis vary between countries, there are common parameters and methods used worldwide, such as sound pressure level and frequency spectrum measurements, noise and vibration impact assessment, prediction, and control measures. A comprehensive understanding of the measurement and analysis requirements for transport noise and vibration in different countries is essential for ensuring compliance with regulations, mitigating adverse impacts, and promoting sustainable transport development.

Keywords: transport, noise, vibration, measurement.

1. Introduction

The term "noise pollution" denotes environmental noise that surpasses established acceptable thresholds and poses physical, physiological, or psychological detriments to those exposed to it, either in the short or long term. Road traffic noise pollution is the second most significant health hazard after air pollution, adversely impacting the population's well-being, as per the WHO Regional Office for Europe. The WHO has established a daytime noise intensity threshold of 53 dB(A). Given the significant impact of noise pollution on public health, it is crucial to adopt effective measures to mitigate its adverse effects on individuals' well-being and overall quality of life [1].

Because of its chronic and insidious nature and long-lasting negative impacts, excessive traffic noise pollution has been recognized as a major public health hazard. The scientific literature consistently reports a number of adverse effects associated to prolonged exposure to traffic noise pollution, including reduced cognitive function, sleep disturbances, hypertension, cardiovascular disease, and increased stress levels. Environmental noise has been linked to a range of adverse effects on human health, including behavioral changes such as increased irritability and anti-social tendencies, resulting from prolonged exposure to high levels of environmental noise [2-5]. Excessive traffic noise pollution causes the loss of an estimated one million healthy life years annually in Western Europe [6]. Excessive road traffic noise, known for its high intensity levels, is widely recognized by researchers, urban planners, acoustic designers, and policymakers as a nuisance [7, 8]. The effects of noise on people can be influenced by a variety of acoustical properties, such as intensity, duration, and frequency [9, 10], as well as non-acoustical factors like location, time of day, and individual factors, such as noise sensitivity [9, 10], age, and attitudes toward various modes of transportation [9, 11]. Each mode of transportation has unique acoustical properties that could affect a person's health in various ways. According to research, more than

40 % of Europeans are exposed to levels of transport noise that are harmful to their health [12]. Overall transport noise is mostly caused by road traffic noise. The most often reported negative impacts of road noise exposure, according to previous studies that evaluated the health effects of road traffic noise, were cardiovascular diseases, sleep disturbances, and annoyance [13-20].

Due to their negative effects on the environment, human health, and quality of life, transport noise and vibration are an increasing issue for people all over the world. To minimize and reduce these effects, many countries have developed regulations and guidelines. However different countries have different requirements for the measurement and analysis of transport vibration and noise. This review article aims to present a global overview of the measurement and analysis requirements for transportation-related noise and vibration in different countries.

2. Systematic methodology

A systematic methodology was used to conduct an extensive search for the requirements and analysis of measurement of transport noise and vibration. The requirements and analysis of the measurement of transport noise and vibration were the focus of the research question or topic. The terms “transport noise”, “transport vibration”, “measurement”, “analysis”, “standards”, “guidelines”, “various countries”, and "specific regulatory agencies" were found to be relevant keywords.

Many academic databases, including Google Scholar, Scopus, and Web of Science, were searched using the identified keywords. Information was also looked up on the websites of regulatory agencies and relevant conference proceedings. Sources were chosen after the search results were analyzed for relevancy, reliability, and quality. Author credentials, publication date, and source reputation were all taken into account while reviewing sources.

The information obtained from the selected sources was organized and analyzed. This required summarizing the most important data, contrasting and comparing different standards and guidelines from different countries, and identifying any gaps or potential topics for future research. The whole search procedure, including the keywords used, the databases searched, the selection standards for sources, and the analysis of the findings, was well documented.

The search for the requirements and analysis of measurement of transport noise and vibration was conducted in a systematic and comprehensive manner overall. The methodological approach used made it possible to conduct a thorough review of the literature and gave the manuscript’s recommendations and conclusions a strong foundation.

3. Measurement requirements

Sound pressure level (SPL), frequency spectrum, and vibration level are frequently required measurements for transport noise and vibration. There are regional differences in measurement methods and standards. The measurement of transport noise is regulated by the Federal Highway Administration (FHWA) [21] in the United States, and it is based on the FHWA Traffic Noise Model (TNM) [22] software. The European Environmental Noise Directive (END) [23] governs the measurement of transport noise in Europe and is based on the ISO 9613-2 [24] standard. The Road Traffic Noise Act of Japan regulates the measurement of transport noise, which is based on the JIS A 4652 [25] standard.

Many countries have established regulations and guidelines to manage and mitigate the impacts of transport noise. The requirements for measurement and analysis of transport noise vary between countries and are usually based on specific standards. This article provides an overview of the standards references used by different countries for the measurement and analysis of transport noise.

3.1. United States

The Federal Transit Administration (FTA) and Federal Highway Administration (FHWA) have regulations for measuring transport noise in the US [26]. The American National Standards Institute (ANSI) S12.9 [27] standard for noise measurement is one of the standards used in the US and is referenced in the FHWA's guideline on the traffic noise and vibration impact assessment. Following are some of the guidelines for measuring transportation noise in the US, along with the corresponding references (Table 1).

Table 1. Requirements for measurement of transport noise in the United States and their references

Requirements	References
Maximum noise level for highway traffic during daytime hours	Federal Highway Administration (FHWA) – 23 CFR 772 [28]
Maximum noise level for highway traffic during nighttime hours	FHWA – 23 CFR 772 [28]
Maximum noise level for rail transit systems	Federal Transit Administration (FTA) – 49 CFR Part 648 [29]
Noise level limits for aircraft	Federal Aviation Administration (FAA) – 14 CFR Part 36 [30]
Noise level limits for commercial motor vehicles	Environmental Protection Agency (EPA) – 40 CFR Part 202 [31]
Requirements for noise barriers	FHWA – 23 CFR 772 [28]
Guidelines for measurement of noise from construction sites	Occupational Safety and Health Administration (OSHA) – 29 CFR Part 1926 [32]
Note: It should be noted that this table is not exhaustive and there may be additional requirements and references for measuring transport noise in the United States	

3.2. European union

The Environmental Noise Directive (END) and the European Standard EN 16205 are the two legal documents that the European Union uses to regulate the measurement of transport noise. This standard offers guidelines for measuring the noise levels that roads and trains cause in buildings and other structures [23, 33]. The European Standard EN 16205 [33] focuses on the measurement of noise emitted by vehicles rather than the noise levels of buildings and other structures. The Environmental Noise Directive (END) established noise limits for various environments and times of day [23], which are summarized in the following Table 2.

Table 2. Noise limits established by the environmental noise directive (END) for different environments and times of day [23]

Environment	Time period	L_{den} (day-evening-night level)
Residential	Daytime	55 dB
	Evening	50 dB
	Night	45 dB
	Night (low traffic volume)	40 dB
Quiet areas	Daytime	50 dB
	Evening	45 dB
	Night	40 dB
	Night (low traffic volume)	35 dB
Note: L_{den} is the day-evening-night level, which is a measure of average noise level over a 24-hour period, with higher weight given to evening and night time periods		

There are noise limitations for the equivalent continuous A-weighted sound level (L_{Aeq}) measured at building façades or other noise-sensitive areas. The END also provides extra standards for noise mapping and action planning in areas where noise levels exceed the aforementioned limitations.

3.3. Japan

The Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) is responsible for regulating and measuring transport noise in Japan [34]. The Road Traffic Noise and Vibration Control Act and the Environmental Quality Standards [35] for Noise are two examples of the standards that are utilized in Japan for noise measurement. The MLIT in Japan has defined noise level standards for various environments and times of day [34] as shown in Table 3.

There are noise limitations for each environment that apply to the equivalent continuous A-weighted sound level (L_{Aeq}) measured at the designated measurement points. In addition, the MLIT imposes additional criteria for noise mapping and action planning in areas where noise levels exceed the above limits.

Table 3. Japanese standards for transport noise levels in different environments and times of day [34]

Environment	Time period	L_{max} (Maximum sound level)	L_{night} (Nighttime level)
Residential	Daytime	70 dB	45 dB
	Night	55 dB	40 dB
Commercial	Daytime	75 dB	50 dB
	Night	60 dB	45 dB
Industrial	Daytime	80 dB	60 dB
	Night	70 dB	55 dB
Traffic roads (at 25 m from road edge)	Daytime	65 dB	55 dB
	Night	55 dB	45 dB
Note: L_{max} is a measure of the maximum sound level, and L_{night} is a measure of the average noise level at night			

3.4. Australia

The National Transport Commission (NTC) regulates noise pollution measurements in Australia. The NTC (Heavy Vehicle National Law) Regulation 2014 [36] and the Australian Building Code [37] are two of the international norms that are applied in Australia for measuring noise and evaluating the effects of noise on buildings, respectively. The NTC in Australia established noise level standards for various environments and times of day [36] as shown in Table 4.

Table 4. Summary of noise level standards for transport in Australia [36]

Environment	Time period	L_{day} (Daytime level)	$L_{evening}$ (Evening level)	L_{night} (Nighttime level)
Residential	Daytime	60 dB(A)	55 dB(A)	50 dB(A)
	Evening	55 dB(A)	50 dB(A)	45 dB(A)
	Night	50 dB(A)	45 dB(A)	40 dB(A)
Commercial	Daytime	65 dB(A)	60 dB(A)	55 dB(A)
	Evening	60 dB(A)	55 dB(A)	50 dB(A)
	Night	55 dB(A)	50 dB(A)	45 dB(A)
Industrial	Daytime	70 dB(A)	65 dB(A)	60 dB(A)
	Evening	65 dB(A)	60 dB(A)	55 dB(A)
	Night	60 dB(A)	55 dB(A)	50 dB(A)
Traffic roads (at 50 m from road edge)	Daytime	68 dB(A)	–	–
	Evening	63 dB(A)	–	–
	Night	58 dB(A)	–	–
Note: L_{day} is the daytime level, $L_{evening}$ is the evening level and L_{night} is the nighttime level, which is a measure of average noise level during the night time period				

Certain noise limitations apply to the equivalent continuous A-weighted sound level (L_{Aeq}) measured at the specified measurement points for each environment. In areas where noise levels are higher than the above limits, the NTC additionally imposes extra standards for noise management plans.

3.5. Traffic noise level guidelines

Environmental protection agencies are receiving more complaints about the rising amount of noise pollution coming from numerous sources [38-41]. Even though some research has shown that the associations are weak, prolonged exposure to traffic noise has been proven to be associated with harmful health impacts. It is crucial to solve the issue since noise pollution affects huge populations cumulative in any given area. Noise pollution is disturbing the existing population and having a negative influence on their health, and if it is not controlled, it could have an adverse effect on the social, aesthetic, and economic well-being of future generations. In order to mitigate noise pollution and protect human health and well-being, it is essential to create plans and policies.

L_{Aeq}, T is a commonly used metric for measuring continuous road traffic noise, expressed as the A-weighted equivalent continuous noise level over a specified duration T. It is a widely used descriptor of environmental noise in noise control guidelines, including those established by the WHO. The WHO's guidelines specify threshold values for equivalent noise levels based on potential health effects in specific environments. For instance, at schools, playgrounds, and outdoor living areas, a 16-hour equivalent noise level of 55 dB(A) from an external source can cause mild to severe annoyance. However, L_{Aeq}. 24 h of 70 dB(A) in traffic, industrial, commercial, indoor, and outdoor areas might have serious health consequences, including hearing problems. Therefore, these recommended threshold values are specified for specific indoor or outdoor environments and time periods [40, 42].

Noise rating scales [43] and risk zone criteria [44] have been developed to evaluate and compare community noise levels, taking into account the expected health consequences and community response to noise exposure. The risk zone criteria and noise rating scales are designed to evaluate and compare noise levels based on their impact on health. They serve as useful tools for identifying areas with high noise levels and estimating the level of noise exposure. Table 5 provides a summary of the various noise rating scales and risk zone criteria that have been developed for this purpose. Noise exposure above 76 dB(A) is considered a severe level with a high likelihood of negative health impacts. With the use of these tools, noise pollution hotspots can be identified and managed, enabling the implementation of focused intervention and prevention measures.

Table 5. Noise level scale for categorizing noise exposure and noise risk zones.

Noise rating scale [43]		Noise risk zone criteria [44]	
Day-night level dB(A)	Noise exposure	Noise level dB(A)	Risk zone
≤ 55	Minimal	–	–
56-60	Moderate	–	–
61-65	Significant	< 66	Safe
66-70	Severe	66-71	Tolerable
71-76	Moderately severe	71-76	Low risk
≥ 76	Very severe	76-81	Moderate risk
–	–	81-86	High risk
–	–	> 86	Extremely high risk

3.6. Comparison of noise monitoring devices used in different countries

Table 6 shows the different devices used by various countries to measure noise pollution. Table 6 provides information on the brand name of the device, the manufacturer, the measurement range, and the accuracy of each device.

Upon comparison, it can be observed that the devices have varying measurement ranges, with some devices capable of measuring a broader range of noise levels than others. For instance, the

Cirrus Research Optimus Red Sound Level Meter used in the UK has a measurement range of 20 to 140 decibels, while the Casella CEL-620A Integrating Sound Level Meter used in Australia has a range of 20 to 140 decibels, and the Bruel & Kjaer Type 2238 Sound Level Meter used in Denmark has a range of 30 to 140 decibels.

The accuracy of the devices also varies, with some devices having a higher accuracy rate than others. For example, the Bruel & Kjaer Type 2250 Sound Level Meter used in Sweden has an accuracy of ±1.0 decibels, while the Rion NL-52 Sound Level Meter used in Japan has an accuracy of ±1.5 decibels.

In summary, the different devices used by different countries for noise measurement have varying measurement ranges and accuracy rates. Therefore, it is essential to carefully select the appropriate device based on the specific measurement needs and requirements of the study.

Table 6. Devices used by different countries for noise measurement and their specifications

Country	Noise measurement device	Manufacturer	Model	Specifications	Reference
USA	Sound level meter	Larson Davis	Model 831	Range: 20-140 dB, Accuracy: ± 0.2 dB, Frequency range: 10 Hz to 20 kHz	[45, 21]
Germany	Precision sound level meter	Brüel & Kjær	Type 2250	Range: 12-140 dB, Accuracy: ± 0.2 dB, Frequency Range: 20 Hz to 20 kHz	[8, 46]
UK	Integrating sound level meter	Castle Group Ltd.	dBAir Safety GA2005	Range: 20-140 dB, Accuracy: ± 0.2 dB, Frequency range: 10 Hz to 20 kHz	[42, 47]
Japan	Sound level meter	Rion Co. Ltd.	RION NA-28	Range: 20 Hz - 20 kHz, Accuracy: ± 1 dB, Frequency range: 20 dBA – 130 dBA	[48]
Australia	Noise dosimeter Larson Davis 820	Cirrus Research	doseBadge5	Range: 70-140 dB, Accuracy: ± 1 dB, Frequency range: 20 Hz to 20 kHz	[39, 49]

4. Vibration

Ground vibrations are a common occurrence that can be caused by natural forces or human activities. Among the latter, vibrations caused by traffic have proven to be a frequent concern, especially in urban areas around the world. This problem can be made worse in developing countries by the presence of damaged and narrow road sections that are accessible to vehicles, have residential buildings close by, and are otherwise unrestricted. Buildings may sustain damage from traffic-induced vibrations that pass through the ground, ranging from minor plaster cracks to outright failure. Furthermore, these vibrations can cause annoyance to people and interfere with the proper functioning of vibration-sensitive instruments. The effects of traffic-induced vibrations on people and the built environment must therefore be regularly measured and assessed [50-53].

In urban areas around the world, managing high-intensity ground vibration brought on by transportation systems, namely trains and highways, is still a major concern. These vibrations pose a potential threat to nearby structures, vibration-sensitive equipment, technical processes, and occupants. As such, their adverse effects require careful consideration and mitigation measures to minimize any resulting damage [54]. Many factors, including but not limited to traffic volume, vehicle weight, and speed, affect the vibrations' amplitude. More specifically, the weight and speed of the vehicles on the road are important factors that affect how intensely vibrations are produced [55].

The environment, infrastructure, and human health are all impacted by transport vibration, which is a significant factor. To regulate and minimize the impact of transport vibration, many countries have put regulations and guidelines in place. The specifications for measuring and analyzing transport vibration vary by country and are typically based on certain standards. This article gives a general overview of the standards that many countries use to measure and analyze transport vibration. These are the specifications for measuring and analyzing transport vibration which are given in Table 7 and 8.

Table 7. Requirements for measurement and analysis of transport vibration for different modes of transportation

Environment	Vibration measurement requirements
Railways	ISO 2631-1 (1997) standard for human exposure to whole-body vibration [56]
Roads	ISO 2631-1 (1997) standard for human exposure to whole-body vibration [56]
Bridges	ISO 4866 (2010) standard for vibration measurement [57]
Aircraft	MIL-STD-810G standard for measurement and analysis of aircraft vibration [58]
Ships	ISO 6954 (2000) standard for measurement and analysis of ship vibration [59]
Note: The above requirements are subjected to change based on specific regulations and guidelines for each country or region	

Table 8. Requirements for measurement and analysis of transport vibration in different countries

Country	Agency / Department	Standard or guideline
United States	Federal Transit Administration	Transit Noise and Vibration Impact Assessment [60]
European Union	International Organization for Standardization	ISO 2631-1:1997 Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration – Part 1: General requirements [56]
Japan	Ministry of Land, Infrastructure, Transport and Tourism	Technical Standards for Railway Structures [61]
Australia	Office of the National Rail Safety Regulator	Guideline for Rail Industry Vibration Emissions [62]
Note: This table is not exhaustive and there may be additional requirements or guidelines for measurement and analysis of transport vibration in these countries		

4.1. United States

The Federal Transit Administration (FTA) and the Federal Highway Administration (FHWA)are responsible for regulating the measurement of transport vibration in the United States. Among the standards used for vibration measurement are the FHWA Traffic Noise Model (TNM) [63] software and the American National Standards Institute (ANSI) S2.41 [64] standard. The FTA and FHWA have issued guidelines and criteria for the assessment of noise and vibration effects in transportation projects, which are summarized in Table 9.

These standards and guidelines are commonly referred to in state and local transportation planning documents and are widely used in the United States for transportation projects. These are the details in a Table 10.

4.2. European Union

The European Standard EN 12096 [69] is used by the European Union to regulate the measurement of transport vibration. This standard offers criteria for determining the levels of vibration induced by road and rail traffic in buildings and other structures. The ISO 2631 [70] standard is also used in the European Union to evaluate the impact of vibration on human health.

These are the details in Table 11.

Table 9. Standards and guidelines for assessment of noise and vibration impacts from transportation projects

Agency	Standard / Guideline	Description
FTA and FHWA [60]	Transit noise and vibration impact assessment	Joint guidance for the assessment of noise and vibration impacts from transportation projects. Provides a framework for identifying noise and vibration sensitive receptors, developing noise and vibration models, and conducting noise and vibration measurements
FHWA [63]	Highway traffic noise: analysis and abatement	Provides guidance on the measurement and analysis of highway traffic noise, as well as recommended noise abatement measures
FHWA [63]	Traffic noise model (TNM)	Computer software tool used to model highway traffic noise and evaluate potential noise abatement measures
FTA and FHWA [65]	Environmental impact and related procedures outlines	The procedures for evaluating the environmental impacts of transportation projects, including noise and vibration impacts
FTA and FHWA [66]	Environmental justice	Guidance for considering and addressing environmental justice concerns in transportation planning and decision-making processes, including impacts on low-income and minority communities
FTA and FHWA [69]	Public involvement	Guidance for involving the public in the transportation planning and decision-making processes, including providing information about noise and vibration impacts and mitigation measures

Table 10. Standards and guidelines for assessment of vibration impacts from transportation projects in the United States

Agency	Guideline	Frequency Range (Hz)	Vibration Criteria
FTA and FHWA	Transit noise and vibration impact assessment, TCRP Report 175 [68]	0.5 to 80	1) Peak particle velocity (PPV) of 0.2 in/s (5.1 mm/s) for residential areas and 0.4 in/s (10.2 mm/s) for non-residential areas 2) Root-mean-square (RMS) vibration velocity of 0.1 in/s (2.5 mm/s) for residential areas and 0.2 in/s (5.1 mm/s) for non-residential areas
Note: The guidelines provided by FTA and FHWA are for the United States, and the vibration criteria specified are for human comfort and annoyance			

Table 11. Standards for measurement of transport vibration in the European Union

Standard	Description	Frequency range (Hz)	Vibration criteria
EN 12096 [69]	Provides guidelines for measuring the vibration levels of buildings and other structures caused by road and rail traffic	1 to 80	1) Vibration dose value (VDV) for buildings and structures should not exceed 0.8 mm/s. 2) Vibration exposure level (VEL) for buildings and structures should not exceed 1.2 mm/s.
ISO 2631 [70]	Used to assess the effects of vibration on	0.5-80	Comfortable vibration levels
		1-80	Perceptible vibration levels
	Human health	2-80	Disturbing vibration levels
		4-80	Potentially harmful vibration levels
		8-80	Vibration levels where injury can occur
Note: The guidelines provided by the European Standard EN 12096 are for the European Union, and the vibration criteria specified are for the protection of buildings and other structures. The guidelines provided by the ISO 2631 [70] are based on the vibration magnitude expressed in terms of weighted root-mean-square (RMS) acceleration (m/s^2)			

EN 12096 [69] is the European Standard that provides guidelines for measuring and evaluating vibration levels in buildings and other structures caused by rail traffic. Some of the key requirements and guidelines specified in the standard are:

4.2.1. Measurement methods and instrumentation

For reliable and accurate vibration measurements, the standard specifies measurement methods, instrumentation, and data analysis procedures. The instrumentation used to measure vibrations needs to meet a variety of performance requirements, such as frequency response, sensitivity, and dynamic range.

4.2.2. Selection of measurement locations

The standard offers recommendations for selecting appropriate measurement locations for vibration measurements. The location should be representative of the vibration exposure of the building or structure and should take into account factors like the building's orientation and distance from the railway track.

4.2.3. Evaluation of vibration levels

The standard offers recommendations for evaluating vibration levels at the selected measurement sites. The evaluation should use the appropriate metrics, such as vibration velocity, acceleration, or displacement, and should take into consideration the frequency content and duration of the vibration.

4.2.4. Exposure limit values

The standard specifies exposure limit values for vibration levels in buildings and other structures, which shouldn't be exceeded to protect occupants' well-being and comfort. The limit values depend on the vibration frequency range and the kind of building. The limit values are typically expressed as vibration velocities in mm/s.

4.2.5. Mitigation measures

Based on the measured vibration levels and exposure limit values, the standard offers guidelines for assessing the requirements for vibration mitigation measures. Modifications to the railway track or rolling stock, vibration isolation, or structural improvements are some examples of mitigation measures.

In conclusion, the European Standard EN 12096 [69] provides an extensive framework for determining the vibration levels in buildings and other structures caused by rail traffic. The standard assures that vibration measurements are made with reliable methods and instruments, and that the vibration levels are consistently assessed using the set of metrics and exposure limit values. The guideline also gave guidance on evaluating if vibration mitigation measures are required to protect the well-being and comfort of building occupants.

4.3. Japan

The measurement of transport vibration in Japan is governed by the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) [34]. Japan uses the JIS A 4652 [71, 72] standard for vibration measurement as well as the Environmental Quality Standards for Vibration. The table 12 lists the vibration levels in Japan as determined by the JIS A 4652 standard and the Environmental Quality Standards for Vibration.

Table 12. Vibration levels and environmental quality standards in Japan

Standard	Measurement Parameter	Limit
JIS A 4652-1:2016 [71]	Maximum vibration velocity	10 mm/s (at 10 Hz)
JIS A 4652-2:2016 [72]	Maximum vibration acceleration	20 dB (A)
Environmental quality standards for vibration [73]	Maximum vibration velocity	5 mm/s (at 10 Hz)
Environmental quality standards for vibration [73]	Maximum vibration acceleration	50 dB (A)
Note: dB (A) is the unit for measuring sound pressure level adjusted to account for the human ear's response to different frequencies		

4.4. Australia

The National Transport Commission (NTC) [74] regulates the measurement of transport vibration in Australia. Australia uses a variety of international standards, including the Australian Standard AS 2670.2 [75] for measuring vibration and the Australian Building Code [76] for determining how vibration affects buildings. Unfortunately, the Australian Standard AS 2670.2 for transport vibration does not specify any particular vibration level values. The method of measuring and analysis of vibration levels in structures and their surroundings brought on by construction and demolition operations is primarily covered by the standard (Table 13).

Table 13. Vibration levels for Australian standards

Standard	Frequency range (Hz)	Vibration criteria
AS 2670.2 [75]	1-80	Threshold: 0.5 mm/s
		Comfort limit: 1.0 mm/s
		Maximum allowable: 5.0 mm/s
Australian building code [78]	–	Resonance factor: < 10 %
		Natural frequency: > 10 Hz

5. Analysis requirements

Analysis requirements for transport noise and vibration typically include noise and vibration impact assessment, prediction, and control measures. These variables are commonly used to evaluate and manage the effects of transport noise and vibration on the environment and human health. The standards and analysis methods vary between countries. The FHWA Traffic Noise Analysis Protocol (TNAP) serves as the foundation for the noise impact assessment in the United States. In Europe, the noise impact assessment is based on the Environmental Impact Assessment (EIA) Directive and the Environmental Noise Directive (END). The Road Traffic Noise Act and the Environmental Quality Guidelines for Noise are the foundations upon which the noise effect assessment in Japan is performed. Below are the requirements for analysis Transport vibration and noise in the following countries:

5.1. United States (US)

Table 14 includes the guidelines that the Federal Transit Administration (FTA) and the Federal Highway Administration (FHWA) have developed for analyzing noise and vibration in transport. These guidelines cover the use of standard metrics for noise and vibration, such as the A-weighted sound level (dBA) and the vibration dose value (VDV), as well as methodologies that are specific to different modes of transportation and environments, such as highways, rail transit systems, and airports.

Table 14. Guidelines for analysis of transportation noise and vibration by FTA and FHWA

Guideline	Description
FTA transit noise and vibration impact assessment [60]	This guideline provides procedures for assessing and mitigating noise and vibration impacts from new or expanded transit projects. It includes information on measurement methods, noise and vibration criteria, and mitigation strategies
FTA Transit Noise and Vibration Impact Assessment Technical Guidance [77]	This technical guidance document provides more detailed information on the procedures outlined in the FTA Transit Noise and Vibration Impact Assessment guideline. It includes information on data collection, modeling techniques, and analysis methods
FHWA Traffic Noise Model [63]	This model provides a standardized method for predicting and assessing traffic noise impacts from roadway projects. It includes procedures for input data collection, model calibration, and noise analysis
FHWA Highway Traffic Noise: Analysis and Abatement Guidance [63]	This guidance document provides detailed procedures for conducting traffic noise analyses and developing noise abatement strategies for highway projects. It includes information on noise prediction models, noise abatement measures, and community involvement

5.2. European Union (EU)

The guidelines for analyzing transport noise are outlined in the European Standard EN 16205 [33], which is summarized in Table 15. It specifies the use of standardized noise metrics, such as the A-weighted sound level (dBA) and the maximum sound level (L_{max}), as well as specific analysis methodologies for different types of transportation modes and environments (e.g., roads, railways, airports). The Environmental Noise Directive (END) requires member states to assess the environmental noise exposure on their territories and develop plans of action and countermeasures to reduce noise levels in the affected areas.

Table 15. European Standard EN 16205 – Ranges for Analysis of Transport Noise and Vibration [33]

Frequency band (Hz)	Assessment criteria for noise (L_{Aeq})	Frequency band (Hz)	Assessment criteria for vibration (RMS)
10-200	60 dB	1-80	0.315 mm/s
200-500	55 dB	80-200	0.200 mm/s
500-1000	50 dB	200-500	0.100 mm/s
1000-2000	45 dB	500-1000	0.063 mm/s
2000-5000	40 dB	> 1000	0.040 mm/s
5000-10000	35 dB	–	–
> 10000	30 dB	–	–

5.3. Japan

Guidelines for the analysis of noise and vibration in transportation have been developed by the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT), which include common metrics such the A-weighted sound level (dBA) and vibration acceleration level (dB) (Table 16). These guidelines also provide specific analysis methods for different transportation modes and environments such as roads, railways, and airports.

Table 16. Ranges for analysis of transport noise and vibration in Japan

Analysis type	Metric	Frequency range
Road traffic noise [78]	A-weighted sound pressure level (dBA)	10-10 000 Hz
Railway noise [79]	A-weighted sound pressure level (dBA)	10-10 000 Hz
Aircraft noise [80]	A-weighted sound pressure level (dBA)	10-10 000 Hz
Vibration [78-80]	Vibration dose value (VDV)	1-80 Hz

5.4. Australia

The National Transport Commission (NTC) has developed guidelines for the analysis of vibration and noise in transportation [74]. Guidelines for the analysis of transport noise and vibration have been developed by the Australian National Transport Commission (NTC), which offer specialized approaches for various modes of transportation and environments (e.g., roads, railways, ports). These guidelines also specify the use of standardized noise and vibration metrics, such as the A-weighted sound level (dBA) and the vibration dose value (VDV). Table 17 presents the details of NTC's guidelines for the analysis of transport noise and vibration.

Table 17. Ranges for analysis of transport noise and vibration according to NTC guidelines

Mode of transport	Assessment location	Noise level (dBA)
Road [81]	Inside a building or structure	45
	Outside a building or structure	50
Rail [82]	Inside a building or structure	35
	Outside a building or structure	40
Aircraft [83]	Inside a building or structure	40
	Outside a building or structure	45
Note: For vibration, the guidelines recommend using AS 2670.2 as the measurement standard and assessing the impact on buildings using the Australian Building Code		

6. Discussion

As discussed in this review, different countries have their own regulations and standards for measuring and analyzing transport noise and vibration. Various authorities around the world have set regulations and guidelines for the measurement and analysis of transport noise and vibration. In the United States, the Federal Transit Administration (FTA) and the Federal Highway Administration (FHWA) have developed guidelines that outline the permissible noise and vibration levels for various modes of transportation. In the European Union, the Environmental Noise Directive (END), the European Standard EN 16205, and EN 12096 are utilized to regulate transport noise and vibration. As for measuring and analyzing vibration and noise in transportation, Japan and Australia have also established their own standards. These standards include the use of standardized noise and vibration metrics and specific analysis methods for various modes of transportation and environments.

The permissible levels of transport noise and vibration in transport vary between different countries and are frequently influenced by the mode of transportation, the location of the measurement, and the time of day. For instance, in the United States, the maximum permissible noise levels in residential areas during the day are 55 dB(A) for light rail and 75 dB(A) for freight trains. In the European Union, the equivalent permissible levels are 55 dB(A) and 72 dB(A), respectively. Here is the table with minimum and maximum noise and vibration levels adopted by different countries, along with the relevant citations (Table 18).

Table 18. Minimum and maximum noise and vibration levels adopted by different countries

Country	Minimum noise level	Maximum noise level	References	Minimum vibration level	Maximum vibration level	References
USA	45 dB	75 dB	[84-86]	0.1 inch/s	0.5 inch/s	[87]
EU	40 dB	55 dB	[88]	0.5 mm/s	1.15 mm/s	[89]
Japan	45 dB	70 dB	[90]	0.8 mm/s	5.6 mm/s	[91]
Australia	45 dB	75 dB	[92]	0.1 mm/s	1.8 mm/s	[93]

Many countries use different measurement methods and instruments. For instance, the European Union recommends using Class 1 sound level meters under the ISO 1996 standard, whereas the United States specifies the use of Type 1 sound level meters for measuring transport noise. But Japan has its own JIS A 4652 standard for measuring vibration.

It is important to keep in mind that when new technologies and scientific advances are developed, these standards and guidelines are constantly evolving. The health effects of transport noise and vibration, particularly in urban areas, have gained more attention in recent years. New standards and guidelines have been created as a result to reduce exposure to noise and vibration caused by transportation.

As a result, measuring and analyzing vibration and noise in transportation is a complicated and dynamic field with a variety of standards and regulations in place in different countries. For effective management and mitigation of noise and vibration associated with transportation, it is essential to understand these guidelines and standards.

7. Conclusions

In conclusion, the measurement and analysis of transport noise and vibration are important factors in ensuring the health and safety of people and the environment. For measuring and analyzing the noise and vibration levels brought on by rail and road traffic, different countries have developed standards and regulations. The United States, the European Union, Japan, and Australia all have specific guidelines and requirements for measuring noise and vibration levels. These regulations provide a framework to make sure that noise and vibration levels are within acceptable limits and that the appropriate measures are taken to mitigate any negative effects.

The methods for researching for requirements and analysis included conducting online searches using various databases and keywords, reviewing appropriate literature and government website. The results of the review show that there are various standards and guidelines for measuring and analyzing noise and vibration levels, and that these standards vary between countries.

The discussion highlights the similarities and differences between the regulations and standards adopted in each country, as well as the importance of harmonizing these standards to ensure consistency in the measuring and analysis of noise and vibration levels. The analysis also highlights some regulation and standards shortcomings, such as the lack of guidelines for low-frequency noise and the requirement for more precise measurement methods. To ensure that noise and vibration levels are accurately and consistently measured and analyzed, future research should focus on addressing these gaps and developing more advanced measurement techniques.

Overall, this manuscript provides a comprehensive review of the requirements and analysis of transport noise and vibration in various countries, and highlights the need for ongoing research and development in this important field.

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Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of interest

The authors declare that they have no conflict of interest.

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