U.S. Department of Transp
Federal Railroad

High Speed Rail Noise Standards ar

CONTRAST

- **Spreadsheet-Based Tool for Com**
- **Conversion Tool for Noise Regula**

Program Worksheet Index and High Leve

Worksheet Index

Worksheet Name
Program Overview
Train Set Data Requirements
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Passby Data Set 3 Output
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Passby Data Set 4 Output
Passby Data Set 5
Passby Data Set 5 Output
Common Reference Data Set
Common Reference Data Set Output

Program Flow Chart

Assemble **librar**
CONTRAST inclu
be added.

Data are to be c
instrumentatior

From the passl
US: $L_{max\ (fast)}$, L
EU: $L_{pAeq,Tp}$, L_{pA}
to 250 km/
China: L_d, L_n
Other: L_{pASmax}

Scale selected pa
$L_{pAeq,Tp}$ normalize

Use this scaled d
EU, China, Japan.

Using noise met
rail noise regula

ortation
Administration

nd Regulations

Comparison Of Noise for TRAin STandards

paring Noise Standards and Regulations

ations and Standards to Common Reference

l Flow Chart

Contents
Program Description, Program Capabilities, Legal Terms & Conditions
Descriptions of instrumentation and measurement procedures regulations and standards, note on measurement accuracy and uncertainty
Descriptions of Train Sets Contained in the Current Library
Summary of Current High Speed Train Noise Regulations and Metrics
Comparisons of US, EU, China, and Japan High Speed Noise Regulations to a Common Reference. The common reference train pass-by noise data set is based on a scaled sound pressure level graph that exactly meets the EU TSI Normalized Equivalent 80 km/hr and 250 km/hr normalized limits. The corresponding US, China, and Japan limits are then calculated using the same data set, thus allowing direct comparisons.
Comparisons of the data sets in the program library relative to the identified passby noise metrics associated with the regulations of each country
Train set information and pass-by sound pressure measurement data for the Korean HEMU-430X
Calculated noise metrics for the Korean HEMU-430X based on the passby data set
Train set information and passby sound pressure measurement data for the Thalys PBKA
Calculated noise metrics for the Thalys PBKA based on the passby data set
Train set information and passby sound pressure measurement data for the China CRH3 Series Trains, Microphone Position 2
Calculated noise metrics for the China CRH3 Series Trains, Microphone Position 2, based on the passby da
Train set information and pass-by sound pressure measurement data for the China CRH3 Series Trains, Mi
Calculated noise metrics for the China CRH3 Series Trains, Microphone Position 1, based on the passby da
Train set information and passby sound pressure measurement data for the China CRH3 Series Trains, Mic
Calculated noise metrics for the China CRH3 Series Trains, Microphone Position 3, based on the passby data set
The scaled passby data set that exactly meets the TSI NOI (2014) normalized limits
Analysis of the noise metrics for the common reference data set

ry of passby noise data for high speed train sets. The initial version of
udes five HS train data sets. The spreadsheet program allows other train sets

obtained according to **regulations and standards requirements** for
n and measurement procedures.

by noise data sets, calculate the **noise metrics** associated with each regulatio

L_{pAEmax}

$L_{pAeq,Tp}$ normalized to 80 km/hr, $L_{pAeq,Tp}$ normalized
/hr.

$$L_{pAeq,T_p} = 10 \lg \left(\frac{1}{T_2 -}\right.$$

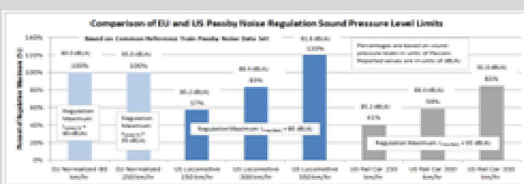
Japan: L_{eq}, L_{amax}

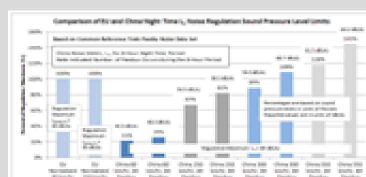
, L_{pAFmax}, $L_{pAeq\ (passby)}$, TEL, SEL, L_{10}, L_{50}, L_{90}, L_p (maximum)

assby data set to exactly meet EU TSI NOI (2014) normalized noise metrics:
d to 80 km/hr, $L_{pAeq,Tp}$ normalized to 250 km/hr.

ata set as the **Common Reference** to calculate noise metrics for each regulat
. Adjust metrics to account for **microphone position** and **train speed**.

trics for the Common Reference Data Set, generate **Comparison Charts** for th
ations.





Compar
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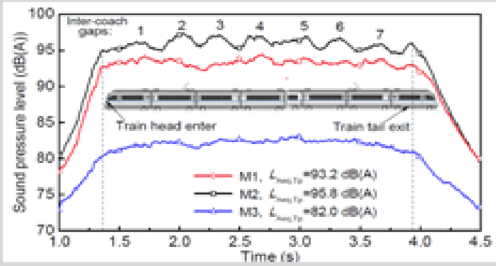
values f

Program Version:	7	14-Oct-19

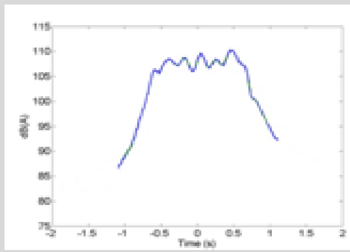
ta set
crophone Position 1
ta set
:rophone Position 3

; to

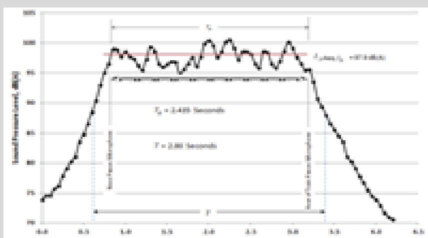


on:

$$\frac{\quad}{T_1}\int_{T_1}^{T_2}\frac{p_A^2(t)}{p_0^2}dt\Bigg) \quad \text{dB}$$



tion: US,



ne US, EU, China and Japan high speed

rison charts are shown as percentages
mum allowable sound pressure level
or each regulation.

Federal Railroad Administration
High Speed Rail Noise Standards and Regulations
CONTRAST **Comparison Of Noise for TRAin STandards**

Program Version:

- **Spreadsheet-Based Tool for Comparing Noise Standards and Regulations**
- **Conversion Tool for Noise Regulations and Standards to Common Reference**

Program Key Features:

1. The program employs passby sound pressure level (SPL) data to determine whether a train set n
The program is based on a library of pass-by SPL data obtained using test procedures prescribed
agencies having jurisdiction, such as European Railway Agency (EU), U.S. Environmental Protect
Japan Ministry of the Environment, and the China Ministry of Transport.
Using the basic
 A. Compare selected train sets to US Regulations
  i. Determine passby noise level at distance of 30 m (100 ft) from track cente
  (microphone elevation is 1.2 m (4 ft) above track elevation)
  ii. Determine $L_{max(fast)}$ for selected train set at 30 m from track centerline and
  iii. Compare results to US FRA Noise Regulations (locomotives and rail cars)
  at speeds greater than 45 mph (72.4 km/hr)
 B. Compare train set pass-by data to EU Regulations
  i. Determine passby noise level at distance of 7.5 m (25 ft) from track cente
  (microphone elevation is 1.2 m (4 ft) above track elevation)
  ii. Normalize $L_{pAeq,Tp}$ data to 80 km/hr (50 mph) and 250 km/hr (155 mph) pe
  iii. Compare results to TSI Noise Regulations (electric locomotives)
  at reference speeds of 80 km/hr (50 mph) and 250 km/hr (155 mph)
 C. Compare train set passby data to Japanese Regulations
  i. Determine pass-by noise level at boundary of railroad property,
  defined as 25 m (82 ft) from outer track centerline and 1.2 m (4 ft) above
  ii. Calculate the noise metrics L_{eq} and L_{Amax} using the energy mean of the pe
  ii. Provide indication whether noise barriers are required
 D. Compare train set pass-by data to Chinese Regulations
  i. Determine pass-by noise level at boundary of railroad property,
  defined as 30 m (100 ft) from outer track centerline and 1.2 m (4 ft) abov
  ii. Determine number of train set passbys allowed during daytime period
  iii. Determine number of train set passbys allowed during nightime period

2. Use of Common Reference high speed train passby sound pressure levels to compare regulation
A representative passby noise data set was scaled so the equivalent sound pressure level ($L_{pAeq,T}$
the normalized TSI Noise (2014) regulations: $L_{pAeq,Tp}$ for 80 km/hr, which is 80 dB(A) and $L_{pAeq,Tp}$ f
This "Common Reference" data set was then employed to determine the noise metrics correspo
and Japan to allow direct comparison of the noise regulations.

For countries that impose immission regulations, the program calculates the maximum number
that will not exceed regulation limits.

Legal Terms and Conditions:

The CONTRAST Spreadsheet-Based Analysis Tool was developed as an aid to evaluating train passby noise da
train noise regulations as part of FRA Program 693JJ618C000020, "High Speed Rail: Cost of Compliance for N
It is provided "as is" to US DOT Federal Railroad Administration for their internal use only. Ricardo offfers n
usage of this analysis tool.

References:

Acela Graphic Reference: National Railroad Passenger Corporation, *Amtrak Fiver Year Service Line Plans*, Base (FY 2018) -
Five Year Strategic Plan (FY 2019-2013), 2018.

Note: this spreadsheet-based program was developed by Ricardo Strategic Consulting for the Federal Railroad Administra
Contract Number 693JJ618C000020

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neets noise regulations:
by
ion Agency,

erline

1.2 m elevationii. Determine $L_{max(fast)}$ for selected train set at 30 m from track centerline and 1.2 m elevation

rline

r TSI 1304 (2014)ii. Normalize $L_{pAeq,Tp}$ data to 80 km/hr (50 mph) and 250 km/hr (155 mph) per TSI 1304 (2014)

top of rail
ak noise levels

ve top of rail

s from the US, EU, China, and Japan:
$_p$) for the passby period was equal to
for 250 km/hr, which is 95 dB(A)
onding to the other countries (US, China,

of train passby events

ata relative to identified high speed
Noise Mitigation Procedures."
o warranties or guarantees of any kind regarding

+

ation under

Federal Railroad Administration
High Speed Rail Noise Standards and Regulations
CONTRAST Comparison Of Noise for TRAin STandards

Train Passby Data Set Requirements

Train pass-by sound pressure data is to be obtained using measurement pro

1. United States

- Instrumentation

Per U.S. Interstate Rail Carriers Noise Regulations, 40 CFR Part 20
Measurements are to be made using a sound level meter or alter
as a minimum, all the requirements of American National Standa
used with the "fast" or "slow" meter response characteristic.
In the event that a Type 1 instrument is not available, the measu
measured sound pressure levels are to be adjusted to account fo
The A-weighted levels for the instrument "fast" or "slow" meter
American National Standard S1.419711.

- Measurement Procedures

Per U.S. Interstate Rail Carriers Noise Regulations, 40CFR Part 20
For rail car passby tests, the microphone is to be positioned on a
from the track centerline.
The microphone is to be located at an elevation of 1.2 m (4 ft) ab
Brake squeal should not be present and tracks are to be well mai
FRA references ISO Standard 3095: *Railway Applications - Acoust*

Per U.S. Interstate Rail Carriers Noise Regulations, 40CFR Part 20
Measurement locations must be selected such that no substanti
or commercial unit wall or facility boundary noise barrier, that ex
10 meters (33.3 feet) of the microphone and that no exterior wa
2.0 meters (6.6 feet) of the microphone.
Average wind velocity should be 12 mph (19.3 km/hr) or less and

2. European Union

- Instrumentation

Per EN ISO 3095: 2013, Acoustics - Railway Applications - Measur
The instrumentation system, including the microphones, cables a
a type 1 instrument specified in EN 61672-1.
The microphones shall have an essentially flat frequency respons
The 1/3 octave band filters shall meet the requirements of class

A suitable windscreen shall always be used.
Before and after each series of measurements a sound calibrator
shall be applied to the microphone(s) for verifying the calibration
over the frequency range of interest. If the difference between t
measurement results shall be rejected.
The compliance of the calibrator with the requirements of EN 60
the instrumentation system with the requirements of EN 61672-
The date of the last verification of the compliance with the relev

- Measurement Procedures

Per *EN ISO 3095: 2013, Acoustics - Railway Applications - Measu*
Test Environment: must meet acoustical environment (ground fl
conditions (no rain or falling snow), and background sound press
Microphone Positions: permitted positions are summarized belo

Perpendicular Position from Track Centerline (m)
7.5
7.5
25

Vehicle Conditions: Vehicle shall have run in normal c
is to be unloaded and unoccupied except for the train crew. Doc
operating auxiliary equipment shall be in action.
Track Conditions: the track is to meet guidelines specified in ISO
Test Procedure: Measurements to be made for pass-by events i
third octave bands according to EN ISO 266.

3. China

- Instrumentation

Chinese Standard *GB/T 3785.2-2010, Sound Level Meters* applies
level meters, testing and test methods for Chinese Standard *GB/*
level meters, testing and test methods for
Class l and 2 sound level meters. Its purpose is to ensure that all
Instruments must meet the following standards (compatible wit
GB 9254-2008 Radio disturbance limits and measurement meth
GB/T 17312 sound level meter random incidence and diffusion f
GB/T 17799.2-2003 Electromagnetic compatibility - General stan
(IEC 61000-6-2..1999,IDT)
GB/T 3785.1-2010 electroacoustics sound level meter - Part 1. S
GB/T 15173 (IEC 60942) electroacoustic sound calibrator
IEC 61000-4-2..2001 Electromagnetic compatibility (EMC) - Part
discharge immunity test 1)
IEC 61000-4-3..2002 Electromagnetic compatibility (EMC) - Part
electromagnetic radiation immunity Test 2)
IEC 61000-4-6..2001 Electromagnetic compatibility (EMC) - Part
of radio frequency field induction Immunity 3)
Measurement of microphones - Part 1. Specification for laborat
Guide, Guidance on Measurement Uncertainty

ISO /IEC , International Basic and General Metrology terminology
CISPR16-1..1999 Specification for radio frequency interference a
Part 1. Radio frequency interference and immunity test.

- Measurement Procedures

Per Chinese Regulation GB 12525-90. The regulation requires fiv
property with the microphone located 1.2 m (3.94 ft) above the
Measurements are taken at a distance of 30 m (98.4 ft) from the
Measuring conditions should meet the GB 3222 standards (Meas
should be taken in the absence of rain or snow. Measurement ti
measurements and 8 hours is the duration for night measureme

4. Japan

- Instrumentation

Instrumentation must comply with JIS C1502 which requires the
Publication 179

Japanese Noise Instrument Standards and Corresponding ISO Sta

JIS Number	Measured Quantity	Measurement Environment	Accuracy Grade
Z 8731:1999	Sound Pressure	Free-Field & Hemi-Field	Engineering
Z 8732:xxxx	Sound Pressure	Free-Field & Hemi-Field	Precision
Z 8733:xxxx	Sound Pressure	Approximately Hemi Free-Field	Engineering
Z 8734:xxxx	Sound Pressure	Reverberant	Precision
Z 8736-1:99	Sound Intensity	Any	Precision, Engineering, Survey
Z 8735-2	Sound Intensity	Any	Engineering, Survey

Reference: Ministry of the Environment, Government of Japan, "Environme
Notification No. 91," Japan Ministry of the Environment, Tokyo, J

- Measurement Procedures

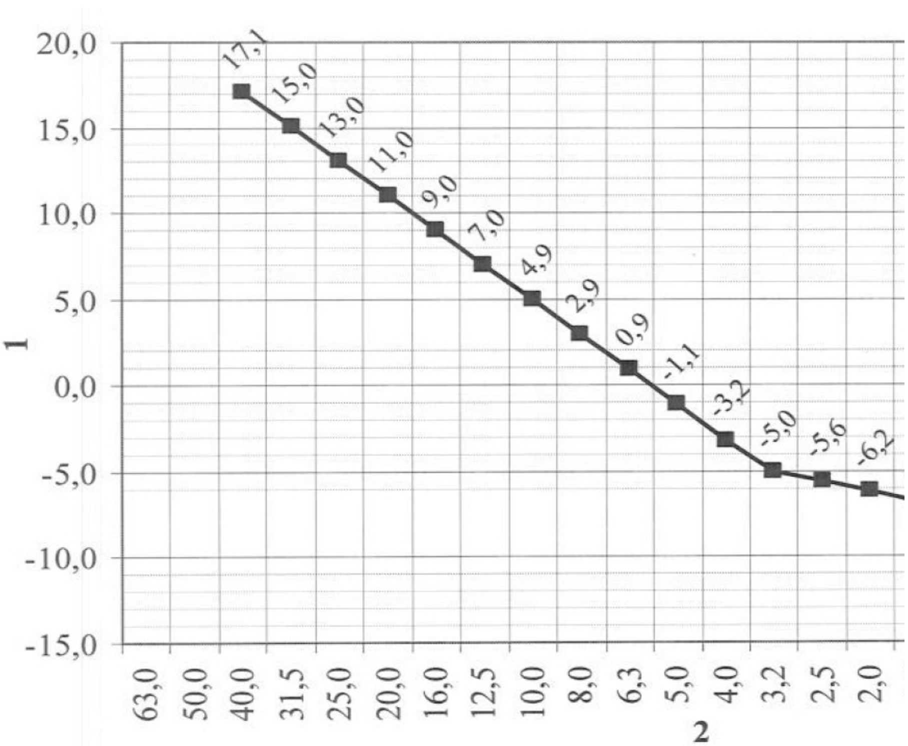
Compliance with ISO 11201:95 Acoustics - Noise Emitted by Mac
Compliance with ISO 112012:95 Acoustics - Noise Emitted by Ma
The Shinkansen Superexpress Railway Noise regulation requires a
the ground in the open air along the railway line with the measu
This is not applicable in sparsely inhabited forests, agricultural la
According to the environmental quality standards for the Shinka

- Measurement are to be carried out by recording the peak nois in principle for 20 successive trains
- Measurement shall be carried out outdoors and in principle at represent Shinkansen railway noise levels in the area concerne
- Any period when there are special weather conditions or when
- The Shinkansen railway noise shall be evaluated by the energy
- The measuring instrument used shall be a noise meter that me

with A weighted calibration & slow dynamic response
• The environmental quality standards shall apply between 6AM

Track Roughness
Track roughness can impact pass-by sound pressure levels (SPLs) by up to 9 dB(A), depe
pass-by noise measurements under acceptable roughness conditions. The CONTraST pr
levels. The EU TSI NOI provided guidelines for determining acceptable levels of track su

The EU Technical Specifications for Interoperability define track surface roughness and
track is considered suitable for comparable measurements if the one-third octave band
Measurement Related to Rolling Noise Generation)2 throughout the test, fulfill the follo
[0.010 ft to 0.328 ft (0.118 inches to 3.94 inches)] corresponding to the graph below.

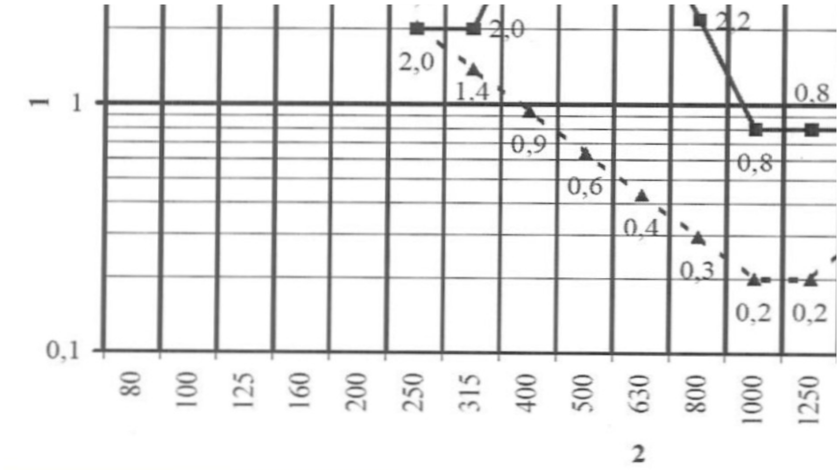


Upper Limit Curve for TSI-Compliant Acoustic R

where

1 is the 1/3 octave band roughness level, dB(A)
2 is the wavelength (cm)
3 is the 1/3 octave band roughness level, dB(A)

The dynamic properties of the test track are considered suitable for acceptable noise m
(European Standard for Characterization of the Dynamic Properties of Track Selections f
below.



Lower Limit Curves for TSI-Compliant Track Decay Rates

where **1** is the track decay rate, dB/m
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

References:

[1]D. Biasin and B. Leermakers, "Interoperability Unit, Trans-European Conven
Reference IU-NOI-11032010_TSI rev 3.0," The European Railway Agency, Eu
[2]European Committee for Standardization (CEN), "BS EN 15610, Railway App
British Standards Institution, London, England, 2009.
[3]E. C. f. Standardization, "BS EN 15461: 2008 + A1: 2010, Railway Application
Measurements," British Standards Institute, London, England, 2010.

A Note on Accuracy and Uncertainty:

The data sets contained in the library for the CONTRAST spreadsheet-based analysis too
and instruments described above. It is important to know that there are many factors t
Zoontjens[2] in Australia for both passenger and freight trains included extensive measure
obtain the standard deviation for each pass-by event and for multiple data sets collecte
measured noise levels was analyzed for single data sets as well as 5, 10, 15, 20, and 60 c
instruments and procedures, showed standard deviations in LAE of approximately 5 dB
calculated noise levels are within ±3 dB of the true $L_{Aeq(period)}$ noise levels when at least 2(
assessment parameter, the uncertainty increases to approximately ±5 dB for the same r
The 2008 version of the EU TSI Noise Regulation included an uncertainty level of ±1 dB(/
not included in the 2014 version of the the TSI Noise Regulation.

References:

[1]International Electrotechnical Commission, "IEC 60942:2003, Electroaccous
[2] C. Weber and L. Zoontjens, "The Uncertainty Associated with Short-Term N
IWRN 12 , Terrigal, NSW, Australia, 2016.
[3]International Organization for Standardization, "Draft International Standar
Part 1: Basic Quantities and Assessment Procedures, Reference Number ISO,
[4]K. Brinkmann, "Treatment of Measurement Uncertainties in International a
Le Mans, France, 2005, https://www.bruit.fr/revues/78_11096.PDF.

Spreadsheet-Based Tool for Comparing Noise Standards and Regulations
Conversion Tool for Noise Regulations and Standards to Common Reference

Program Version: 7 14-Oct-19

cedures as defined by the respective regulations.

)1.21 and Part 201.22, US EPA Measurement Criteria
rnate sound level measurement system that meets,
ırd S1.419711 for a Type 1 (or S1A) instrument, to be

rements may be made with a Type 2 instruement, but
ır possible instrument errors.
response characteristics are to be as defined in

1.24, US EPA Measurement Criteria
line perpendicular to the track 30 m (100 ft)

ove the track.
ntained (see TSI roughness requirements below).
:ics - Measurement of Noise Emitted by Railbound Vehicles

1.25, US EPA Measurement Criteria
ılly vertical plane surface, other than a residential
xceeds 1.2 meters (4 feet) in height is located within
ll of a residential or commercial structure is located within

l maximum wind gust must be 20 mph (32.2 km/hr) or less.

rement of Noise Emitted by Railbound Vehicles
ınd recording devices shall meet the requirements for

se in a free sound field.
1 according to EN 61260.

· meeting the requirements of class 1 according to EN 60942
ı of the entire measuring system at one or more frequencies
he two calibrations is more than 0.5 dB all the

942 shall be verified at least once a year. The compliance of
1 and EN 61672-2 shall be verified at least every 2 years.
ant European Standards shall be recorded.

·ement of Noise Emitted by Railbound Vehicles
ıtness, free of large reflecting objects), meteorological
ure levels (10 dB below value during pass-by event).
w:

Elevation above Top of Rail (m)
1.2
3.5
3.5

ɔnditions at least 3,000 km on track with normal traffic. The train
ɔrs and windows are to be kept closed and normally-

3095 including levelness, curvature, and roughness.
ıclude: $L_{pAeq,Tp}$ and, if frequency analysis is included, at lease in one

to multi-channel sound
T 3785.2-2010, Sound Level Meters applies to multi-channel sound

testing laboratories can perform a consistent evaluation tests.
ı global standards IEC 651 & ANSI S1.4):
ɔds for information technology equipment (CISPR22..1997, IDT)
eld calibration (GB/T 17312-1998, eqvIEC 61183..1994)
dards - Immunity test in industrial environments

ɔecifications (IEC 61672-1..2002, IDT): sound meter performance

ł-2. Test and measurement techniques Electrostatic

ł-3. Test and measurement techniques radio frequency

ł-6. Test and measurement techniques Conducted disturbance

ry standard microphones (IEC 61094-1..2000); ISO Presentation

,
nd immunity test instruments and methods:

e measurement points to be taken at the border of the railway
ground and not less than 1 m (3.28 ft) from a reflective surface.
centerline of the outer track.
urement Methods for Community Noise which states measurements
me to be day or night; 16 hours is the duration for day
nts.

precision noise meter prescribed by International Electric Standards Conference (IESC)

ndards JIS = Japanese Industrial Standard

Corresponding ISO Standard
ISO 1996-1:2016
ISO/DIS 3745
ISO 3744:94
ISO 3741:99
ISO 9614-1:93
ISO 9614-2:96

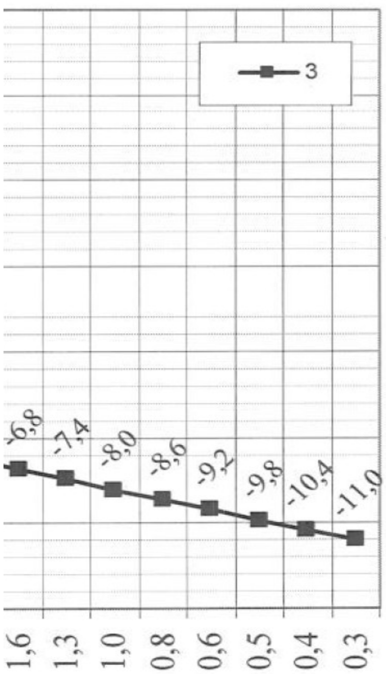
ntal Quality Standards for Shinkansen Superexpress Railway Noise,
apan, 1993.

hinery and Equipment (Free Field over a Reflecting Plane)
chinery and Equipment (Environmental Corrections)
a power mean of the peak noise level shall be measured at 1.2 m (3.94 ft) above
ring point located at 25 m (82 ft) from the centre line of the near side of the track.
nds etc.
nsen Superexpress, noise measurements are to be performed as described below:
e level of each of the Shinkansen trains passing in both the directions,

the height of 1.2m above the ground. Measurement points shall be selected to
d as well as the points where the noise is posing a problem
the speed of the trains is lower than normal shall not be considered
mean value of the higher half of the measured peak noise levels
ets the requirements of Article 88 of the measuring Law (Law no 207 of 1951),

nding upon train speed, microphone distance, and degree of roughness. It is thus important to conduct
ogram assumes the pass-by noise data sets were obtained at sites with acceptable track roughness
rface roughness.

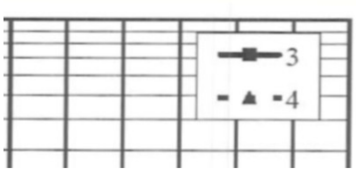
dynamics characteristics for pass-by noise measurements.[1] The “rail acoustic roughness” of the test
roughness spectra assessed according to EN15610 (European Standard for Rail Roughness
wing upper limit: the wavelength bandwidth is to be at least 0.003 m to 0.10 m (0.3 cm to 10.0 cm)

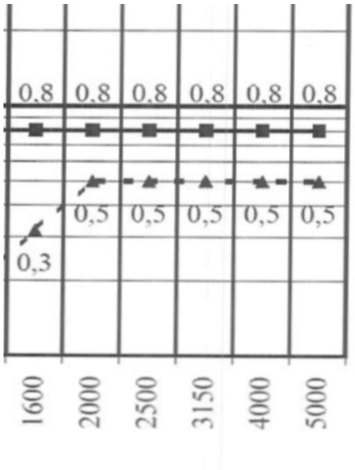


ail Roughness

Reference, TSI Noise Regulations (2014)

easurements if the one-third octave band track decay rates spectra measured according to EN15461
or Pass By Noise Measurements)[3] throughout the test section fulfill the limits shown in the graph





Reference, TSI Noise Regulations (2014)

tional Rail System, Subsystem Rolling Stock, TSI Rolling Stock - Noise,
ropean Commission, Valenciennes, France, 2010.
lications; Noise Emission; Rail Roughness Measurement Related to Rolling Noise Generation,"

ıs, Noise Emission, Characterization of the Dynamic Properties of Track Selections for Pass By Noise

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ɔl were obtained by a number of researchers using standardized the standardized test procedures
hat affect the accuracy and uncertainty of these data sets.[1,2,3,4] Tests performed by Weber and and instrun
ements of pass-by noise levels (L_{AE}). Statistical analyses were performed for each set of data to Zoontjens[2]
d over periods ranging from one week to over six months. The maximum range in log-averaged
data sets for each site. Tests conducted on passenger trains using ISO standard-compliant
which led to the statement: "For the measurements in this study, there is a 95% confidence that the
0 train pass-bys of each type under the same operating conditions are measured. For the $L_{Amax\ calculated\ noise\ level}$
number of train pass-bys".
A) relative to maximum pass-by sound pressure measurement limits. This allowance factor wasThe 2008 version of the

tics - Sound Calibrators," 2003, https://webstore.iec.ch/publication/3954. [1]International Electrotechnical C
loise Measurements of Passenger and Freight Trains," in International Workshop on Railway Noise, [2] C. Wel

d ISO/DIS 1996-1, Acoustics - Description, Measurement and Assessment of Environmental Noise, [3]Interna
/DIS 1996:2014(E)," International Organization for Standardization, Geneva, Switzerland, 2014.
nd European Standards on Acoustics," *Acoustique & Techniques* No. 40, in Uncertainty - Noise,

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ıents described above. It is important to know that there are many factors that affect the accuracy anc
in Australia for both passenger and freight trains included extensive measurements of pass-by noise le\

s are within ±3 dB of the true LAeq(period) noise levels when at least 20 train pass-bys of each type under the same oper

EU TSI Noise Regulation included an uncertainty level of ±1 dB(A) relative to maximum pass-by sound pressure me

ommission, "IEC 60942:2003, Electroaccoustics - Sound Calibrators," 2003, https://webstore.iec.ch/puk
ɔer and L. Zoontjens, "The Uncertainty Associated with Short-Term Noise Measurements of Passenger a

tional Organization for Standardization, "Draft International Standard ISO/DIS 1996-1, Acoustics - Descr

ɹ uncertainty of these data sets.[1,2,3,4] Tests performed by Weber and
ɹvels (L_{AE}). Statistical analyses were performed for each set of data to

ating conditions are measured. For the L_{Amax}

ɹasurement limits. This allowance factor was

ɹlication/3954.
ɹnd Freight Trains," in International Workshop on Railway Noise,

ɹiption, Measurement and Assessment of Environmental Noise,

U.S. Department of Transportation
Federal Railroad Administration

Federal Railroad Administration
High Speed Rail Noise Standards and Regulations

Train Set Pass-By Noise Library

Input: Selection of Train Sets See individual worksheets for details of each t

Current Library:

Data Set Number	Data Set Name	Train Set
		Manufacturer
1	Korean HEMU-430X	Hyundai Rotem
2	Thalys PBKA	GEC-Alsthom
3	CRH3 Series (based on Siemens)	Changchun Railway Vehicles, Siemens
4	CRH3 Series (based on Siemens)	Changchun Railway Vehicles, Siemens
5	CRH3 Series (based on Siemens)	Changchun Railway Vehicles, Siemens

Spreadsheet-Based Tool for Comparing Noise Standards and Regu
Conversion Tool for Noise Regulations and Standards to Common

CONTRAST **Comparison Of Noise for TRAin STandards**

rain set.

Operator	Train Length (m)	Test Train Speed (km/hr)	Pass-By Time, T_p (sec)	Position Designation
Korail	147.40	400	1.33	2
Thalys	200.19	296	2.43	1
China Railway Corporation	200.00	271	2.66	2
China Railway Corporation	200.00	271	2.66	1
China Railway Corporation	200.00	271	2.66	3


KA[2]


China CRH3 Series Train[2]

lations
Reference

Program Version: 7 14-Oct-19

Microphone Position	
Distance from Track Centerline (m)	**Elevation above Top of Rail (m)**
7.5	3.5
7.5	1.2
7.5	3.5
7.5	1.5
25	3.5

U.S. Department of Transportation
Federal Railroad Administration

Federal Railroad Administration
High Speed Rail Noise Standards and Regulations

Regulations (US, EU, China, Japan)

Regulations Summary

For Moving Trains		Applicable Rolling Stock	Sound Pressure Measurement Method	Train Speed (km/h)
Location	**Reference**			
US	40 CFR Part 201.12	Locomotives	L_{max}(fast)	all
	40 CFR Part 201.13	Rail Cars	L_{max}(fast)	>45
EU	TSI Noise 2014	Locomotives	$L_{pAeq,Tp}$	80
				250
		EMUs		80
				250
		DMUs		80
				250
China	GB 12525-90	All Rolling Stock	L_d	all
			L_n	all
Japan	Environmental Law 91 of 1993	High Speed Rail: Shinkansen	L_{eq}, Zone I	all
			L_{eq}, Zone II	all

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

Metrics

US

L_{pASmax} is the maximum sound pressure level, slow and A-weighted and L_{pAFmax} = maximum sound pr

L_{pAFmax} is equal to L_{max}(fast)

L_{max} (fast) can be calculated as the logarithmic average of the recorded Sound Pressure Levels (SPLs

EU

$L_{pAeq,Tp}$ is the A-weighted equivalent continuous sound pressure level produced by the train as meas

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

where

T_p	is the pass-
T_1	is the time
T_2	is the time
$P_A(t)$	is the A-we
p_0	is the refer
Δt_i	is the time
$P_A(i)$	is the A-we

China

L_d The A-weighted equivalent sound level measured during the day time, dB(A). The sounc 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 fractio during time peri

Measuring conditions should meet the GB 3222 standards (Measurement Methods for Community
Measurement time to be day or night; 16 hours is the duration for day measurements and 8 hours

Japan

L_{eq} (hour) = $10 \log_{10} \left[\sum_{j=1}^{N} t(j) 10^{\frac{L(j)}{10}} \right]$ The time increment for calculating t(j) is 1 hour (3

For areas adjacent to Japan's high speed train lines, the Shinkansen Superexpress Railwa
Shinkansen noise limits vary by adjacent land use categories. Zone I is designated as res

Another noise metric employed in Japan is L_{amax} and is defined as the power- or energy-a

$$L_{Amax} = 10 \log_{10} \left[\frac{1}{20} \sum_{i=1}^{20} 10^{(L_{max,s})_i / 10} \right]$$

Spreadsheet-Based Tool for Comparing Noise Standards and Regulations
Conversion Tool for Noise Regulations and Standards to Common Reference

CONTRAST Comparison Of Noise for TRAin STandards Program Version:

Maximum Allowable Sound Pressure, dB(A)	Measurement Location	
	Elevation (m)	Distance from Track Centerline (m)
90	1.2 (above top of rail)	30
93		
84	1.2 (above top or rail)	7.5
99		
80		
95		
81		
96		
70	1.2 (above top of rail)	30
60		
70*	1.2 above ground	25
75*		
ods.		

For the measurements in this study, there is a
within ±3 dB of the true values.

Tests conducted on passenger trains using ISO
standard deviations in LAE of approximately 5
this study, there is a 95% confidence that the
LAeq(period) noise levels when at least 20 tra
conditions are measured. For the LAmax asse
approximately ±5 dB for the same number of

Calculation procedures for Ld and Ln can be f
Ross, J.C., and Towers, D.A., High-Speed Grou
U.S. Department of Transportation, Federal R
September 2012.

ressure level, fast and A-weighted. The time period for the "slow" reading is 1 second. The time period for th

) for the 0.125 second time interval containing the highest values ured during the pass-by event

-by time interval = time when trail tail passes microphone minus time when train nose passes microphone = T

when the train nose passes the microphone

when the train tail passes the microphone

eighted instantaneous sound pressure in Pa at time t

ence sound pressure: p_0 = 20μPa = 0.00002 Pa

increment between measured data points (0.05 seconds for the data sets included in this program).

eighted instantaneous sound pressure in Pa at pass-by time increment i

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

on of time during which sound pressure level, $L(j)$, occurs

iod over which L_d applies

Noise [139] which states measurements should be taken in the absence of rain or snow.

is the duration for night measurements.

	L_{eq} =	Receiver's cumulative noise exposure from all events over a
3,600 seconds)	$L_A(t)$ =	A-weighted equivalent continuous sound pressure level proc where the 1-hour time interval extends from t_1 to t_2 and T = the time increment for calculating t(j) is 1 hour (3,600 second

ay Noise regulations apply and supersede the stricter Environmental Quality standards.

sidential areas and has an L_{eq} (hour) limit of 70 dB(A); Zone 2 is designaed as commercial and industrial and ha

average of the "slow" maximum sound pressure level ($L_{max, s}$) of 20 consecutive train passbys:

7 | 14-Oct-19

ı 95% confidence that the calculated passby noise levels are

ↄ standard-compliant instruments and procedures, showed
5 dB which led to the statement: "For the measurements in
calculated noise levels are within ±3 dB of the true
ain pass-bys of each type under the same operating
essment parameter, the uncertainty increases to
f train pass-bys."

found in Appendix A of the following reference: Hanson, C. E.,
ınd Transportation Noise and Vibration Impact Assessment
ailroad Administration, Final Report DOT/FRA/ORD-12/15,

ıe "fast" reading is 0.125 seconds.

T_2 - T_1

The
ıding to

specified time period (1 hour)
luced by the train as measured during the passby event
$t_2 - t_1$ = 1 hour
ds) and $L_{A(j)}$ = *L(j)*

as an L_{eq} (hour) limit of 75 dB(A

U.S. Department of Transportation
Federal Railroad Administration

Federal Railroad Administration
High Speed Rail Noise Standards and Regulations

The Common Reference is based on scaled pass-by data for the Thalys PBKA train set
The Common Reference data set was scaled so that the TSI NOI (2014) maximum nor

The corresponding pass-by metrics for the other regulations (US, China, Japan) are th
maximum allowable pass-by values for each noise regulation (EU, US, China, Japan).

Comparison of EU and US Regulations

Regulation	Maximum Value, dB(A)	Common Reference Value, dB(A)	Maximum Value, Pa
EU Normalized 80 km/hr	80	80	0.2000000
EU Normalized 250 km/hr	95	95	1.1246827
US Locomotive 250 km/hr	90	84.2	0.6324555
US Locomotive 300 km/hr	90	87.4	0.6324555
US Locomotive 350 km/hr	90	90.6	0.6324555
US Rail Car 250 km/hr	93	84.2	0.8933672
US Rail Car 300 km/hr	93	87.4	0.8933672
US Rail Car 350 km/hr	93	90.6	0.8933672

How to Interpret this Graph: The Common Reference Train Set exhibits pass-by noise sound pressure levels that correspond to the maximum allowable values in the TSI regulation. The same train set is predicted to emit sound pressure levels that range range from 41% to 120% of the maximum levels allowed by US railroad noise regulations.

Comparison of EU and China Regulations

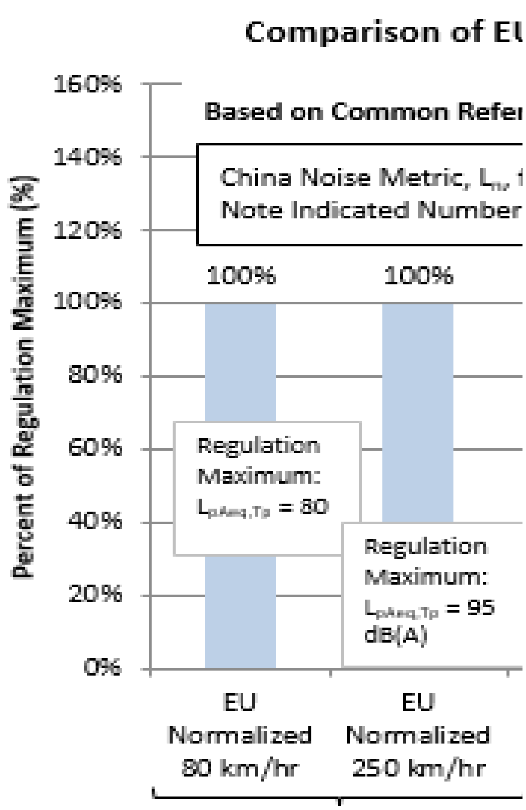
To complete comparisons for China regulations, need to calculate L_n and L_d for Common Refe

L_n Calculations

Common Parameters	Value	Units
Duration of Night Time Period	8	hours
	28,800	sec
Reference Train Length	200.19	m

$L_d =$

Calculation of Chinese L_n based on Common Reference Train Data Set			
Time of Pass-By Event	sec	9.01	2.88
t(j): Ratio of Pass-By Time to 8-Hour Night Period		0.0003128	0.0001001
Train Speed	km/hr	80.00	250.00
	m/sec	22.22	69.44
$L_{pAEQ,pass-by}$ (microphone position 4)	dB(A)	65.55	80.50
Number of Trains during 8-Hour Night Period		L_n (the A-weighted equivalent sound level me	
8		39.53	49.54
16		42.55	52.55
24		44.31	54.31
32		45.56	55.56
40		46.52	56.53
48		47.32	57.32
56		47.99	57.99
60		48.29	58.29

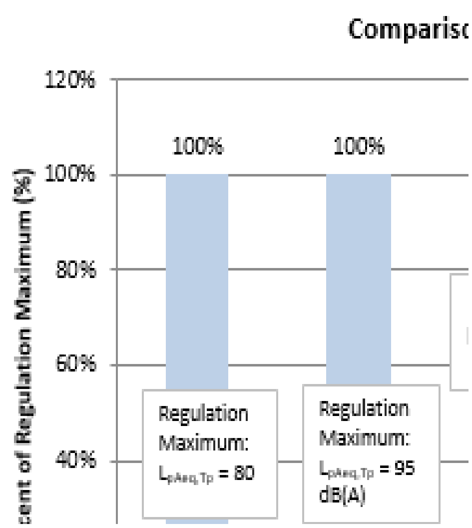


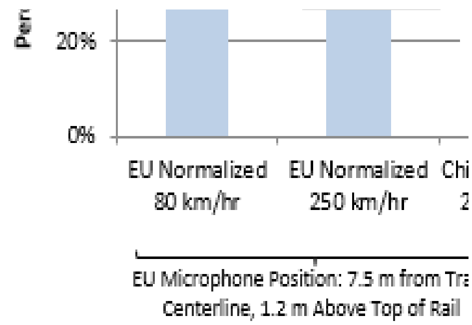
EU Microphone Position: 7.5 m fron
Centerline, 1.2 m Above Top of

L_d Calculations

Common Parameters	Value	Units
Duration of Day Time Period	16	hours
	57,600	sec
Reference Train Length	200.19	m

Calculation of Chinese L_d based on Common Reference Train Data Set			
Time of Pass-by Event	sec	9.01	2.88
t(j): Ratio of Pass-by Time to 16-Hour Day Period		0.0001564	0.0000500
Train Speed	km/hr	80.00	250.00
	m/sec	22.22	69.44
$L_{pAEQ,pass\text{-}by}$ (microphone position 4)	dB(A)	65.55	80.50
Number of Trains during 16-Day Time Period		L_d (the A-weighted equivalent sound leve	
50		44.48	54.49
100		47.49	57.50
150		49.25	59.26
200		50.50	60.51
250		51.47	61.48
300		52.26	62.27
350		52.93	62.94
400		53.51	63.52



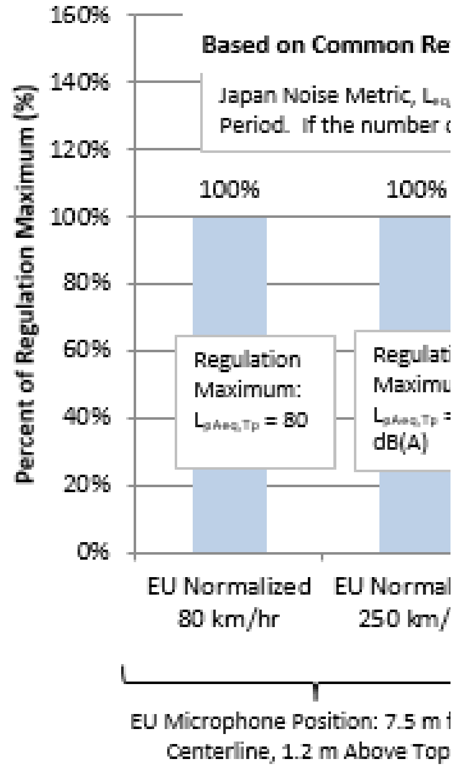


Comparison of EU and Japan Regulations for Japan Shinkansen High Speed Rail: Zone I, Residen

L_{eq} (hour) = $$10\log_{10}\left[\sum_{j=1}^{N} t(j)10^{\frac{L(j)}{10}}\right]$$ the time increment for calculating t(j) is 1 hour (3,600 secor

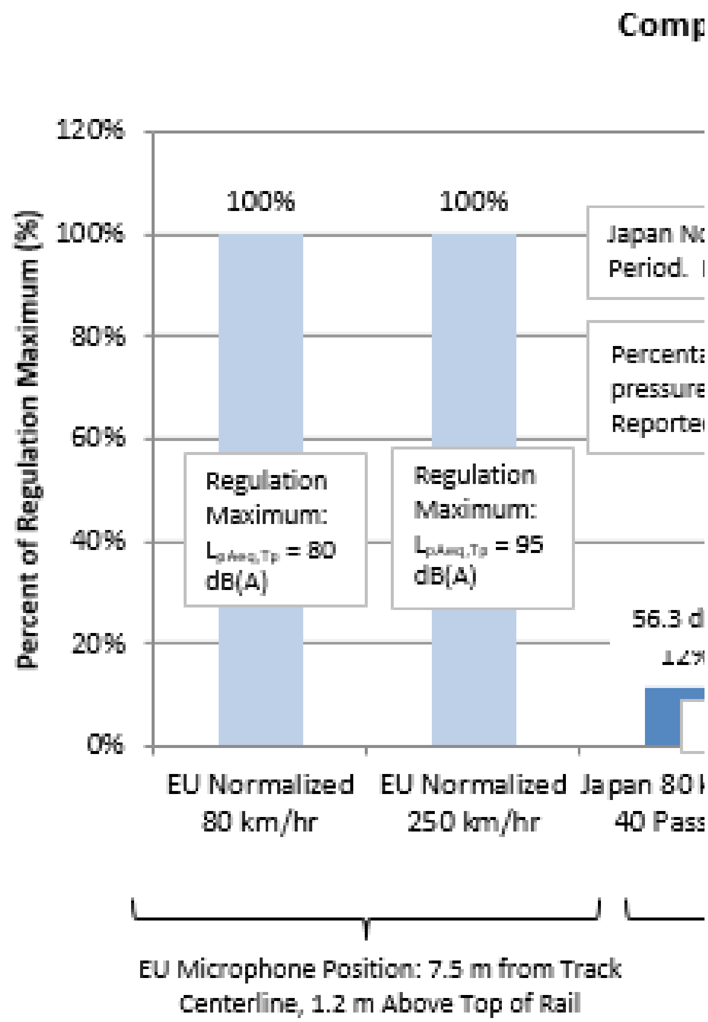
Common Parameters	Value	Units
Duration of Day Time Period	1	hour
	3,600	sec
Reference Train Length	200.19	m

Calculation of Japanese L_{eq} based on Common Reference Train Data Set			
Time of Passby Event	sec	9.01	2.88
t(j): Ratio of Passby Time to 16-Hour Day Period		0.0025024	0.0008008
Train Speed	km/hr	80.00	250.00
	m/sec	22.22	69.44
$L_{pAEQ,pass\text{-}by}$ (microphone position 3)	dB(A)	66.34	81.30
Number of Trains during 1-Hour Time Period		L_d (the A-weighted equivalent sound level me	
8		49.36	59.36
16		52.37	62.37
24		54.13	64.13
32		55.38	65.38
40		56.35	66.35
48		57.14	67.14
56		57.81	67.81
60		58.11	68.11



Comparison of EU and Japan Regulations for Japan Shinkansen High Speed Rail: Zone II, Comme

Reference: Ministry of the Environment, Government of Japan, Environmental Quality Standa
Supeexpress Railway Noise, Notification No. 91 of 1993, Article 16 of the Basic Enviornmental
Quality Standards, https://www.env.go.jp/en/air/noise/railway.html



Comp
120%
100%
80%
60%
40%
20%
0%
Percent of Regulation Maximum (%)
100%
100%
Regulation Maximum: L_pAeq,Tp = 80 dB(A)
Regulation Maximum: L_pAeq,Tp = 95 dB(A)
Japan No
Period.
Percenta
pressure
Reporte
56.3 d
EU Normalized 80 km/hr
EU Normalized 250 km/hr
Japan 80 k
40 Pass
EU Microphone Position: 7.5 m from Track Centerline, 1.2 m Above Top of Rail

Spreadsheet-Based Tool for Comparing Noise Standa
Conversion Tool for Noise Regulations and Standards

CONTRAST Comparison Of Noise for TRAin STandards

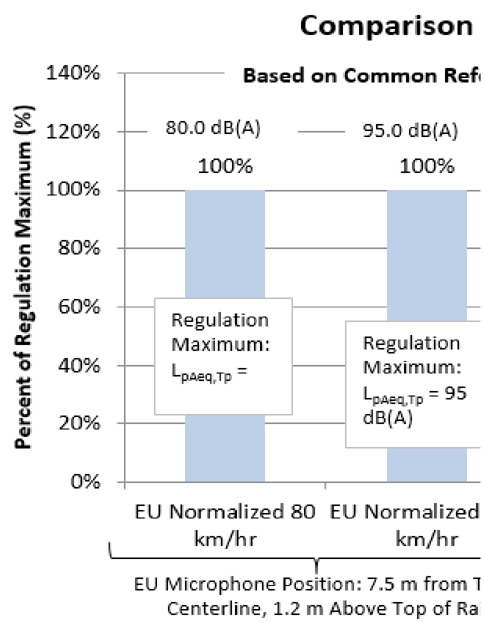
Comparisons of Noise Regulations for US, EU, China, and Japan, based on Com

: (see Common Reference Data Set worksheets).
malized values, $L_{pAeq,Tp\ (80\ km/hour)}$ and $L_{pAeq,Tp\ (250\ km/hr)}$ are exactly achieved (values are 100% of maximum allowab
en calculated using this Common Reference dat set. Comparions are made based on percentages of

For the measurements in this study, there is a 95% co

Common Reference Value, Pa	Percent of Maximum Allowed Value %
0.200000	100%
1.124683	100%
0.324777	51%
0.471339	75%
0.677876	107%
0.324777	36%
0.471339	53%
0.677876	76%

→



rence Data Set.

Pa = 0.00002*(10$^{(dB/20)}$)

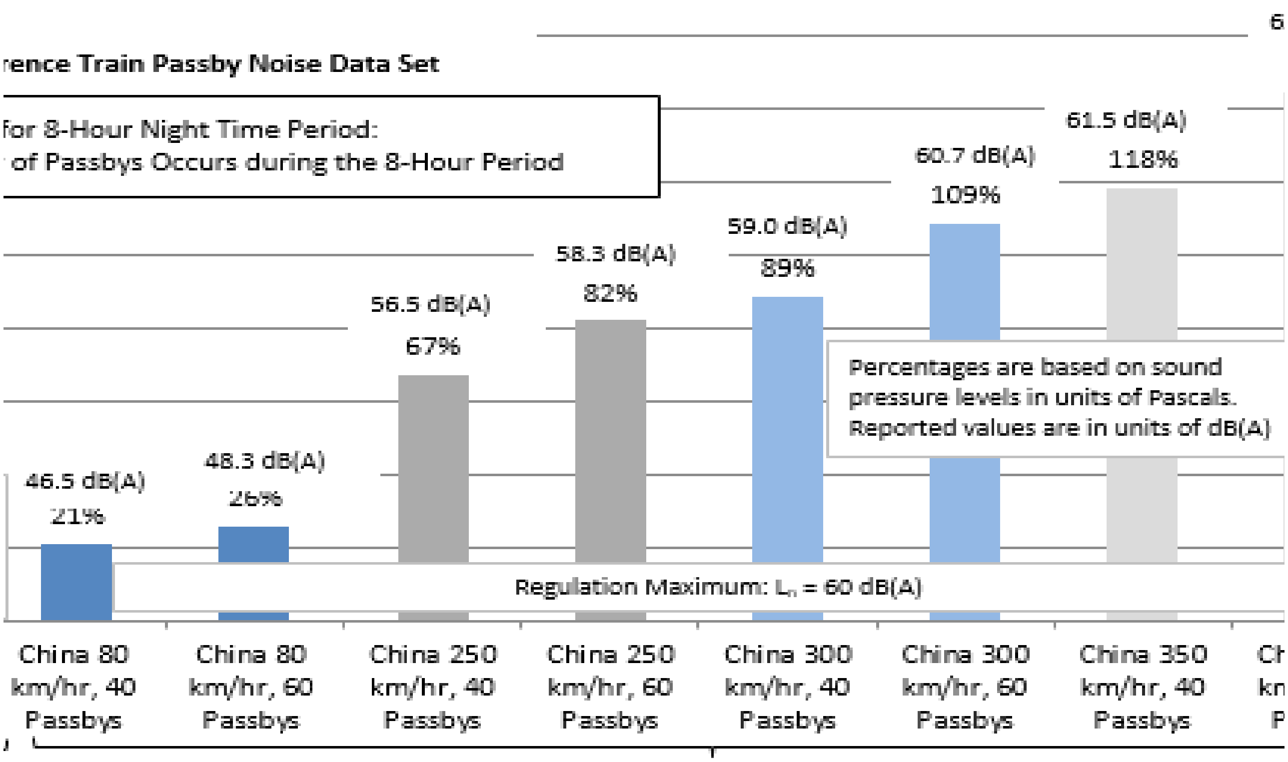
The calculation includes all of the pass-by data points from the time recording of the microphone SPL signals starts until the time recording of microphone SPL signals ends.

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

2.40	2.06
0.0000834	0.0000715
300.00	350.00
83.33	97.22
83.74	86.89
easured during the night time), dB(A)	
51.98	54.47
54.99	57.48
56.75	59.24
58.00	60.49
58.97	61.46
59.76	62.25
60.43	62.92
60.73	63.22

Regulation	Maximum Value, dB(A)
EU Normalized 80 km/hr	80
EU Normalized 250 km/hr	95
China 80 km/hr, 40 Pass-bys	60
China 80 km/hr, 60 Pass-bys	60
China 250 km/hr, 40 Pass-bys	60
China 250 km/hr, 60 Pass-bys	60
China 300 km/hr, 40 Pass-bys	60
China 300 km/hr, 60 Pass-bys	60
China 350 km/hr, 40 Pass-bys	60
China 350 km/hr, 60 Pass-bys	60

J and China Night Time L_n Noise Regulation Sound Pressure Level Limits



n Track
Rail

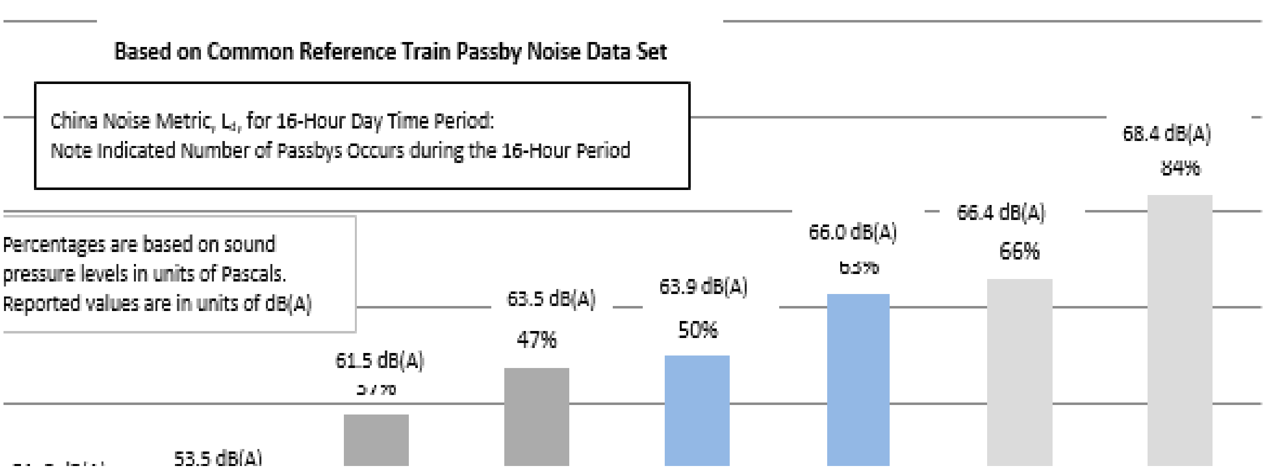
China Microphone Position: 30 m from Track
Centerline, 1.2 m Above Top of Rail

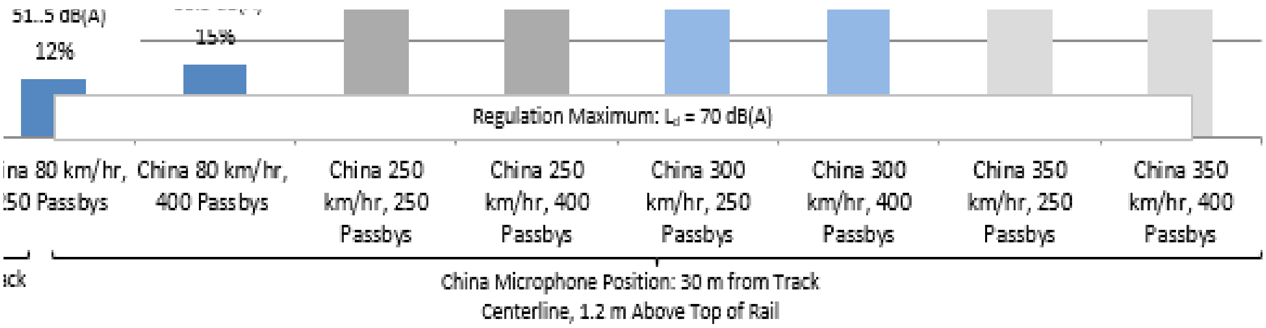
The calculation includes all of the pass-by data points from the time recording of the microphone SPL signals starts until the time recording of microphone SPL signals ends.

2.40	2.06
0.0000417	0.0000357
300.00	350.00
83.33	97.22
83.74	86.89
l measured during the day time), dB(A)	
56.93	59.42
59.94	62.43
61.70	64.19
62.95	65.44
63.92	66.41
64.71	67.20
65.38	67.87
65.96	68.45

Regulation	Maximum Value, dB(A)
EU Normalized 80 km/hr	80
EU Normalized 250 km/hr	95
China 80 km/hr, 250 Passbys	70
China 80 km/hr, 400 Passbys	70
China 250 km/hr, 250 Passbys	70
China 250 km/hr, 400 Passbys	70
China 300 km/hr, 250 Passbys	70
China 300 km/hr, 400 Passbys	70
China 350 km/hr, 250 Passbys	70
China 350 km/hr, 400 Passbys	70

on of EU and China Day Time L_d Noise Regulation Sound Pressure Level Limits





ıtial Areas

ıds)

L_{eq} = Receiver's cumulative noise exposure from all

$L_A(t)$ = A-weighted equivalent continuous sound pres
where the 1-hour time interval extends from

the time increment for calculating t(j) is 1 hou

The calculation includes all of the pass-by data points from the time recording of the microphone SPL signals starts until the time recording of microphone SPL signals ends.

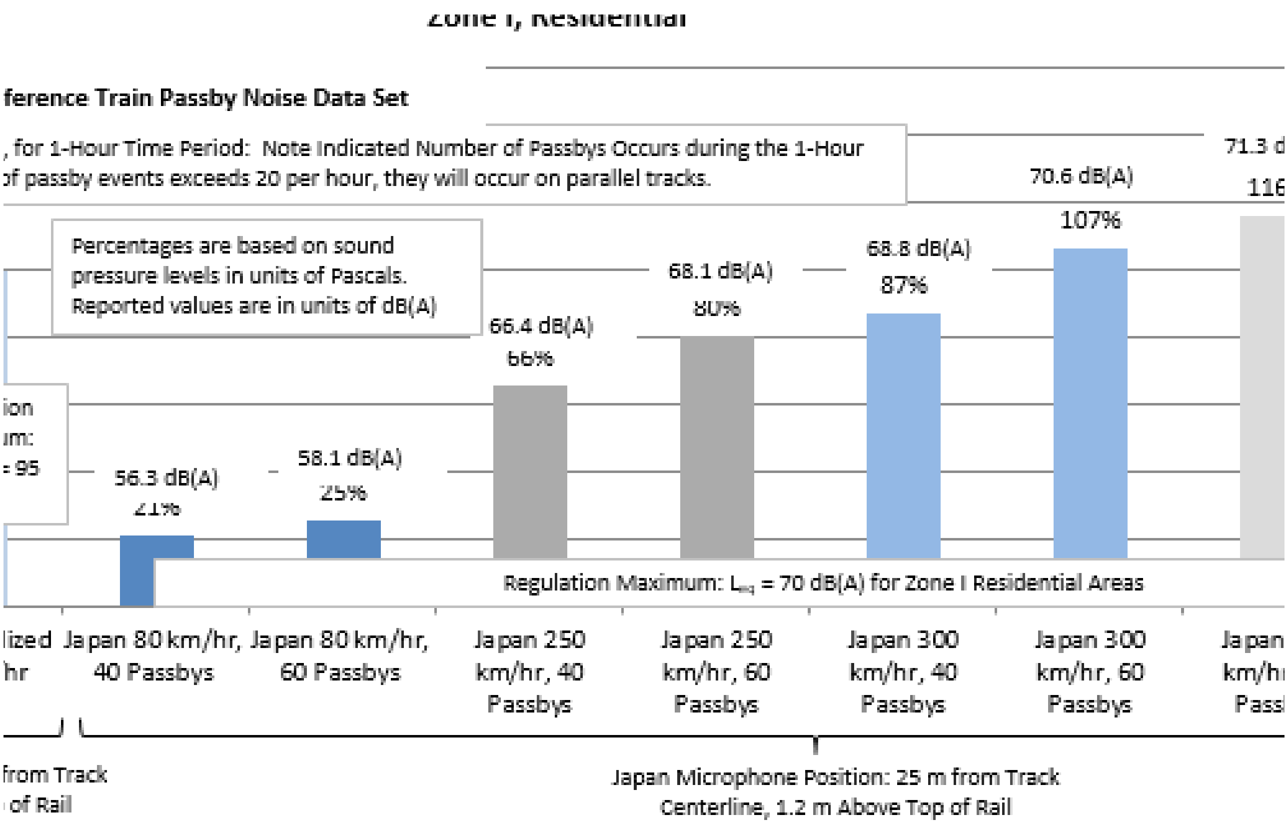
The Japan Shinkansen Train noise regulations are related to Microphone Position 3 (25 m from track centerline and 1.

2.40	2.06
0.0006673	0.0005720
300.00	350.00
83.33	97.22
84.53	87.69
ıeasured during the 1-hour time period), dB(A)	
61.80	64.29
64.81	67.30
66.58	69.06
67.83	70.31
68.79	71.28
69.59	72.07
70.26	72.74
70.56	73.04

Regulation	Maximum Value, dB(A)
EU Normalized 80 km/hr	80
EU Normalized 250 km/hr	95
Japan 80 km/hr, 40 Passbys	70
Japan 80 km/hr, 60 Passbys	70
Japan 250 km/hr, 40 Passbys	70
Japan 250 km/hr, 60 Passbys	70
Japan 300 km/hr, 40 Passbys	70
Japan 300 km/hr, 60 Passbys	70
Japan 350 km/hr, 40 Passbys	70
Japan 350 km/hr, 60 Passbys	70

Table Above is for L_{eq} relative to Zo

Comparison of EU and Japan L_{eq} (1-hour) Noise Regulation Limits:

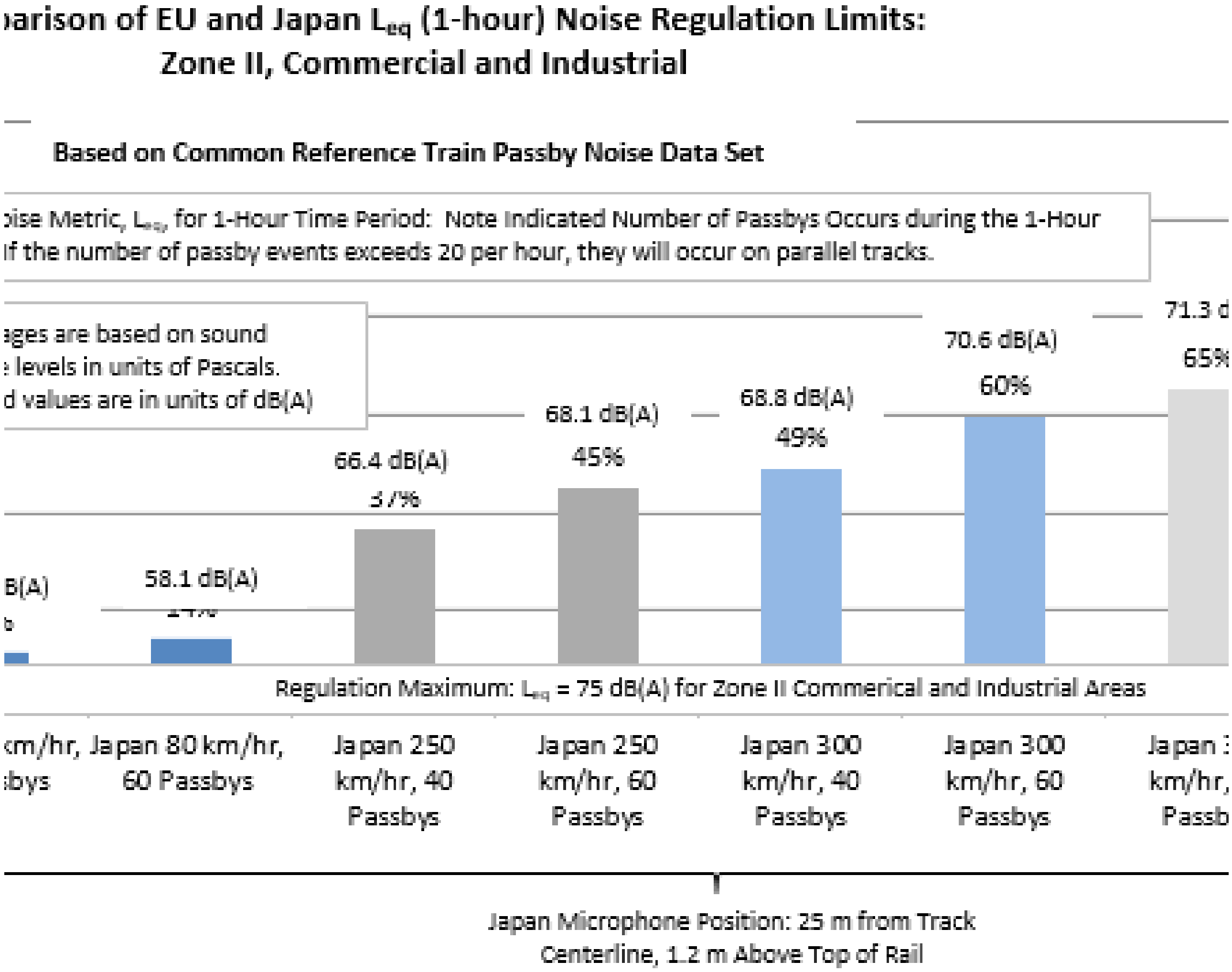


ercial and Industrial Areas

rds for Shinkansen
Law, Environmental

Regulation	Maximum Value, dB(A)
EU Normalized 80 km/hr	80
EU Normalized 250 km/hr	95
Japan 80 km/hr, 40 Pass-bys	75
Japan 80 km/hr, 60 Pass-bys	75
Japan 250 km/hr, 40 Pass-bys	75
Japan 250 km/hr, 60 Pass-bys	75
Japan 300 km/hr, 40 Pass-bys	75
Japan 300 km/hr, 60 Pass-bys	75
Japan 350 km/hr, 40 Pass-bys	75
Japan 350 km/hr, 60 Pass-bys	75

Table Above is for L_{eq} relative to Zone II, Co



arison of EU and Japan L_{eq} (1-hour) Noise Regulation Limits:
Zone II, Commercial and Industrial
Based on Common Reference Train Passby Noise Data Set
ise Metric, L_{eq}, for 1-Hour Time Period: Note Indicated Number of Passbys Occurs during the 1-Hour
If the number of passby events exceeds 20 per hour, they will occur on parallel tracks.
ages are based on sound
levels in units of Pascals.
d values are in units of dB(A)
B(A)
58.1 dB(A)
66.4 dB(A)
68.1 dB(A)
45%
68.8 dB(A)
49%
70.6 dB(A)
60%
71.3 d
65%
Regulation Maximum: L_{eq} = 75 dB(A) for Zone II Commerical and Industrial Areas
km/hr, bys
Japan 80 km/hr, 60 Passbys
Japan 250 km/hr, 40 Passbys
Japan 250 km/hr, 60 Passbys
Japan 300 km/hr, 40 Passbys
Japan 300 km/hr, 60 Passbys
Japan km/hr, Passb
Japan Microphone Position: 25 m from Track Centerline, 1.2 m Above Top of Rail

rds and Regulations
. to Common Reference

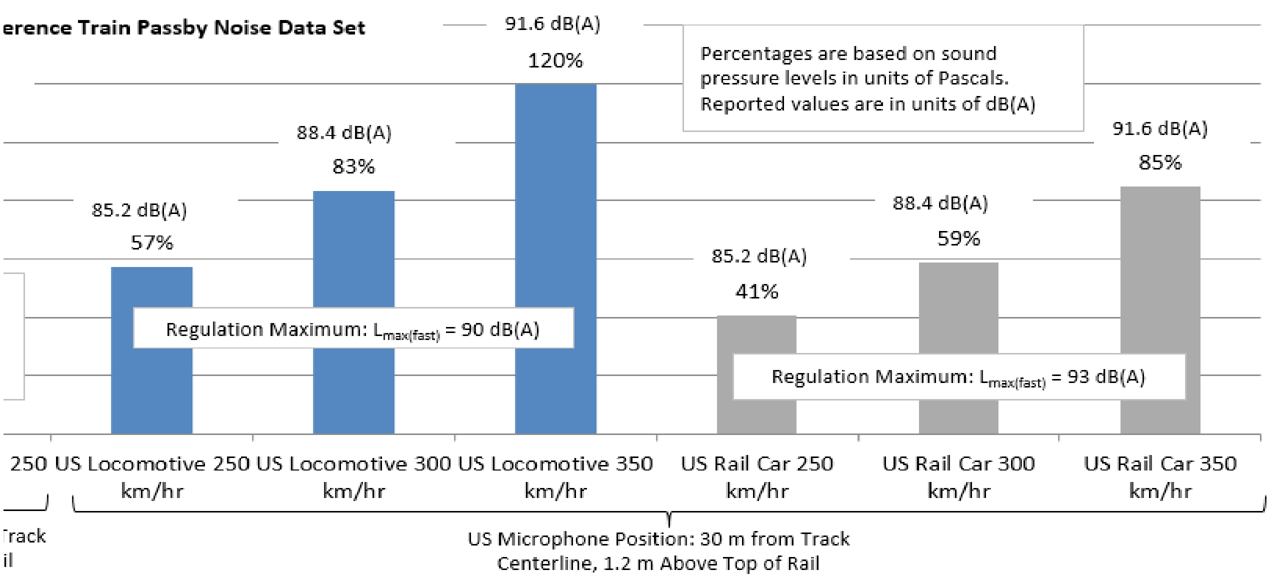
Program Version: 7 14-Oct-19

mon Reference

ɔle)

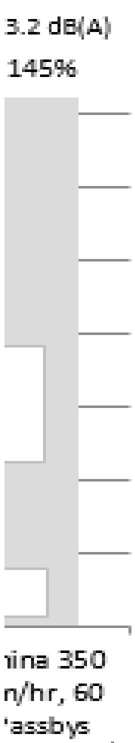
ɔnfidence that the calculated pass-by noise levels are within ±3 dB of the true values.

of EU and US Passby Noise Regulation Sound Pressure Level Limits



US Pass-by Noise Metric = L_{pAFmax} = $L_{max(fast)}$

Common Reference Value, dB(A)	Maximum Value, Pa	Common Reference Value, Pa	Percent of Maximum Allowed Value %
80.0	0.2000000	0.2000000	100%
95.0	1.1246827	1.1246827	100%
46.5	0.0200000	0.0042389	21%
48.3	0.0200000	0.0051916	26%
56.5	0.0200000	0.0134105	67%
58.3	0.0200000	0.0164245	82%
59.0	0.0200000	0.0177665	89%
60.7	0.0200000	0.0217595	109%
61.5	0.0200000	0.0236563	118%
63.2	0.0200000	0.0289729	145%



Common Reference Value, dB(A)	Maximum Value, Pa	Common Reference Value, Pa	Percent of Maximum Allowed Value %
80.0	0.2000000	0.2000000	100%
95.0	1.1246827	1.1246827	100%
51.5	0.0632456	0.0074935	12%
53.5	0.0632456	0.0094786	15%
61.5	0.0632456	0.0237067	37%
63.5	0.0632456	0.0299868	47%
63.9	0.0632456	0.0314071	50%
66.0	0.0632456	0.0397272	63%
66.4	0.0632456	0.0418188	66%
68.4	0.0632456	0.0528971	84%

l events over a specified time period (1 hour)

ssure level produced by the train as measured during the pass-by event

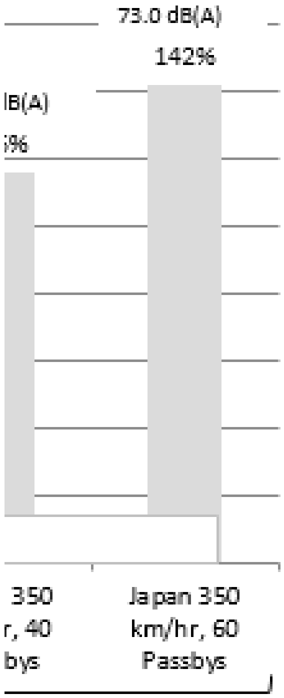
t_1 to t_2 and T = $t_2 - t_1$ = 1 hour

ır (3,600 seconds) and $L_{A(j)}$ = *L(j)*

2 m above top of rail)

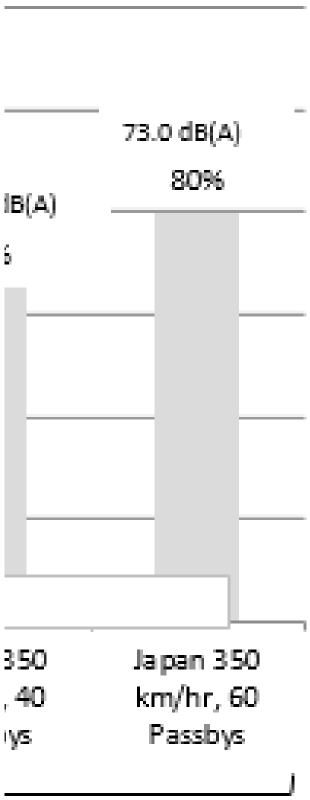
Common Reference Value, dB(A)	Maximum Value, Pa	Common Reference Value, Pa	Percent of Maximum Allowed Value %
80.0	0.2000000	0.2000000	100%
95.0	1.1246827	1.1246827	100%
56.3	0.0632456	0.0131339	21%
58.1	0.0632456	0.0160856	25%
66.4	0.0632456	0.0415510	66%
68.1	0.0632456	0.0508893	80%
68.8	0.0632456	0.0550476	87%
70.6	0.0632456	0.0674193	107%
71.3	0.0632456	0.0732964	116%
73.0	0.0632456	0.0897693	142%

ıne I, Residential Areas



Common Reference Value, dB(A)	Maximum Value, Pa	Common Reference Value, Pa	Percent of Maximum Allowed Value %
80.0	0.2000000	0.2000000	100%
95.0	1.1246827	1.1246827	100%
56.3	0.1124683	0.0131339	12%
58.1	0.1124683	0.0160856	14%
66.4	0.1124683	0.0415510	37%
68.1	0.1124683	0.0508893	45%
68.8	0.1124683	0.0550476	49%
70.6	0.1124683	0.0674193	60%
71.3	0.1124683	0.0732964	65%
73.0	0.1124683	0.0897693	80%

ommercial and Industrial Areas



73.0 dB(A)
80%
Japan 350 km/hr, 60 Passbys

Federal Railroad Administration
High Speed Rail Noise Standards and Regulations

Pass-By Noise Comparisons

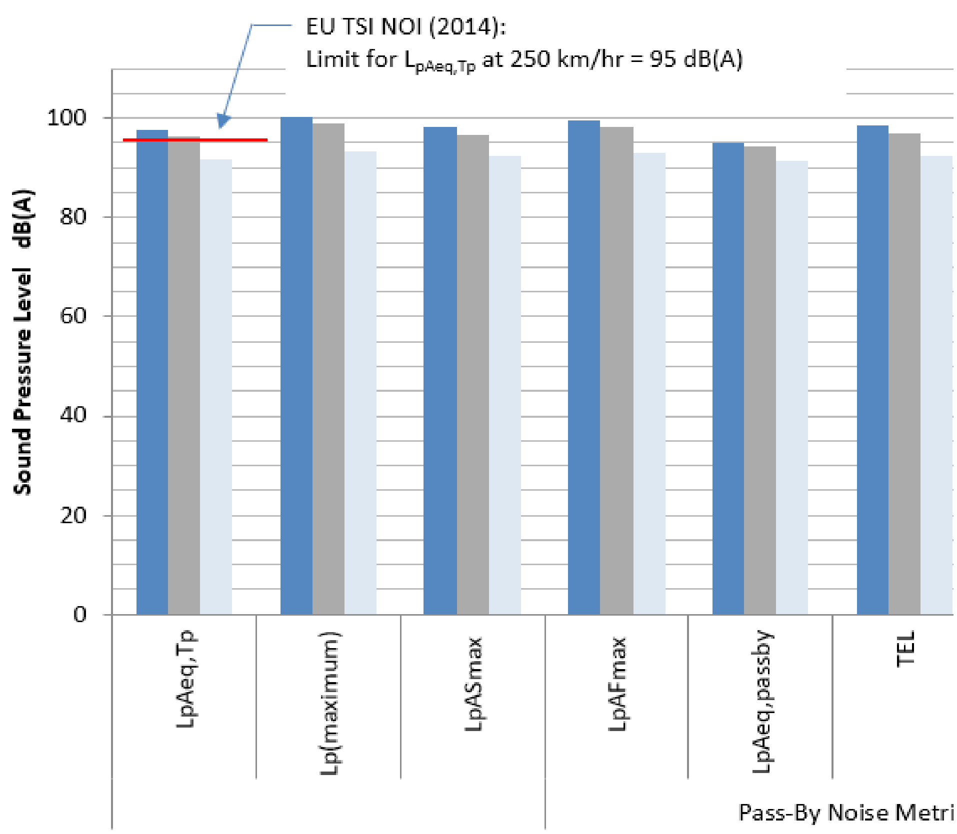
Summary of Pass-by Data Sets Currently in Library

Microphone Position 1:

Speed = 250 km/hr

Pass-By Noise Metrics

Train Set	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}
Korean HEMU-430X	97.61	100.34	98.18
Thalys PBKA	96.35	99.02	94.92
CRH3 Series (based on Siemens)	91.71	93.28	92.23

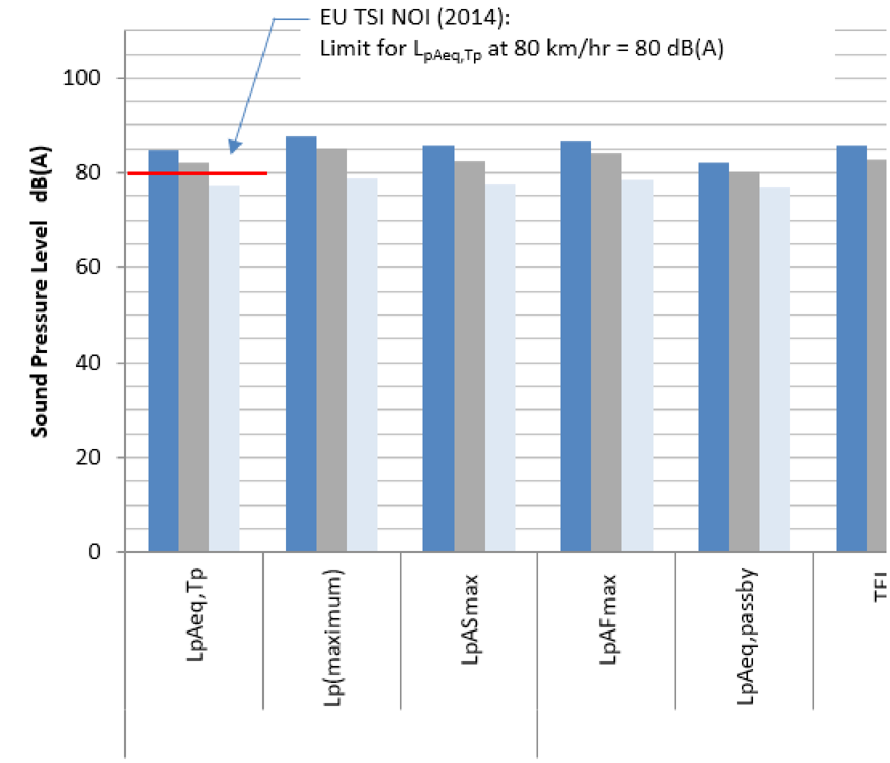


Microphone Position 1:

Speed = 80 km/hr

Pass-By Noise Metrics

Train Set			
	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}
Korean HEMU-430X	84.93	87.67	85.50
Thalys PBKA	82.29	84.95	80.85
CRH3 Series (based on Siemens)	77.23	78.80	77.76

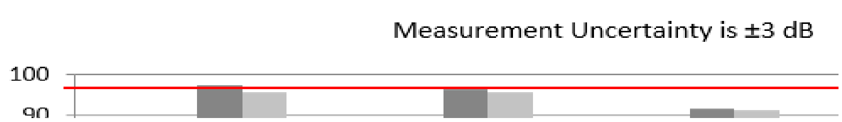


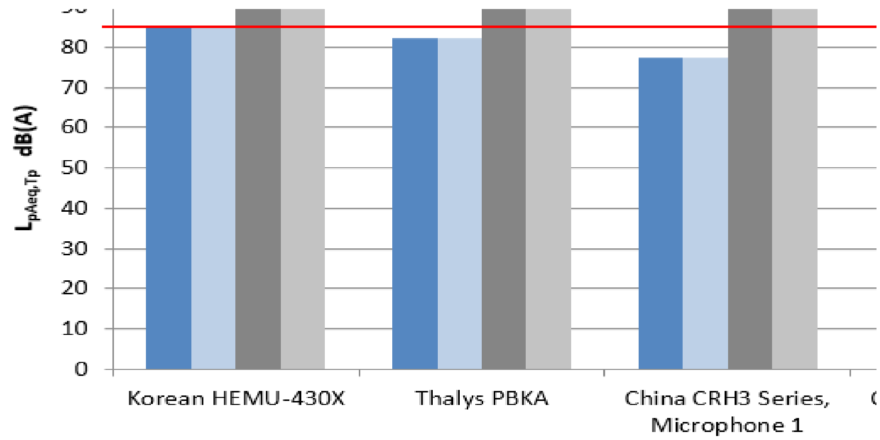
EU Regulations

Comparison of $L_{pAeq,Tp}$ values: Data Reduction vs. TSI NOI 2014 Methods

Train Set	$L_{pAeq,Tp\ (80\ kph)}$ dB(A)		
	Calculated	TSI NOI (2014)	Calculated
Korean HEMU-430X	84.9	84.9	97.6
Thalys PBKA	82.3	82.3	96.4
China CRH3 Series, Microphone 1	77.2	77.2	91.7
China CRH3 Series, Microphone 2	77.0	77.0	91.5
China CRH3 Series, Microphone 3	77.4	77.4	91.9

Comparison of $L_{pAeq,Tp}$ Calculations



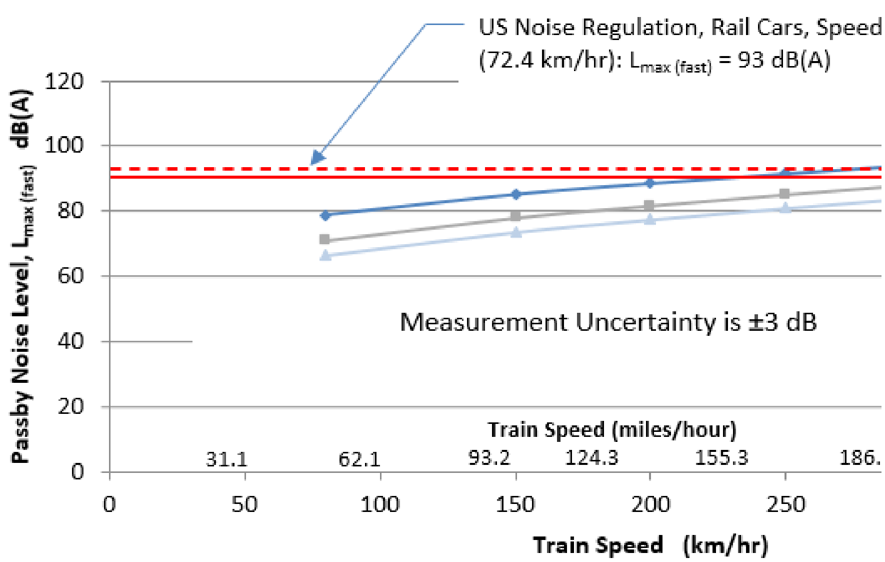


US Noise Regulations

Comparisons of $L_{max\ (fast)}$ (which is equal to L_{pAFmax}) for trainsets relative to US

Microphone Position 4 (30 m from track centerline and 1.2 meters above top

Train Set	$L_{max\ (fast)}$ dB(A		
	Train Speed		
	80	150	200
Korean HEMU-430X	79.8	86.2	89.5
Thalys PBKA	70.1	77.0	80.8
China CRH3 Series, Microphone 4	66.6	73.6	77.5



Compliance with China Noise Regulations Microphone

L_d = The A-weighted equivalent sound leve

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

where $t(j)$ du

$$\left\lfloor_{j=1} \right\rfloor$$

Similarly, L_n = The A-weighted equivalent sound leve
levels corresponding to the time perio

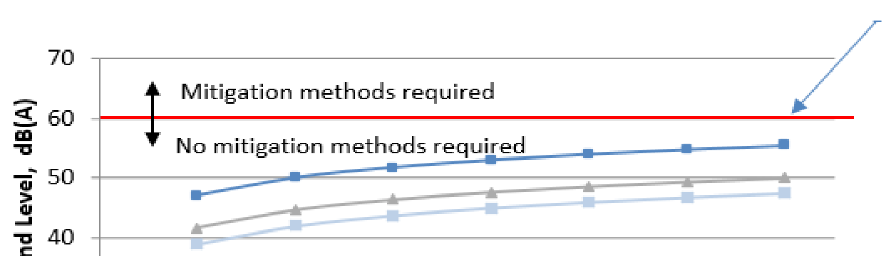
Example, the Thalys PBKA traveling at a speed of 296 km/hr, has a sound pressure le
The pass-by time is 4.2 seconds. If the pass-by event occurs during the 8 hour night
For this case, *t(j)* = 0.0001458 and L_n for two pass-by event:

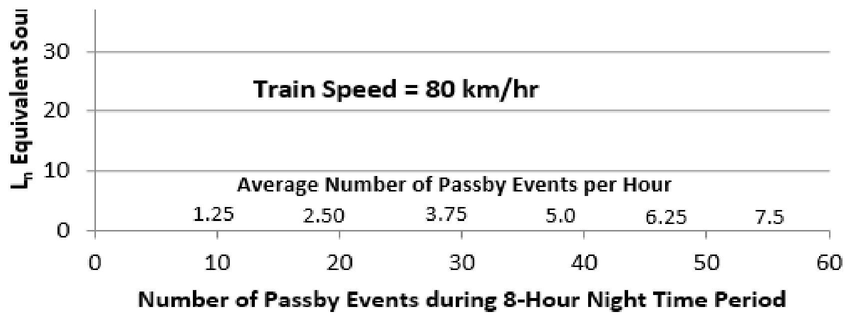
L_n Calculations

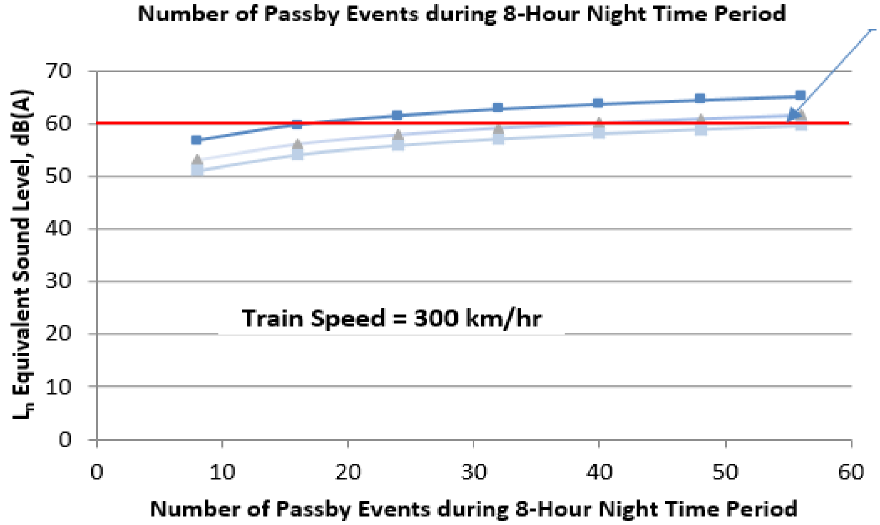
Common Parameters	Value	Units
Duration of Night Time Period	8	hours
	28,800	sec
Korean HEMU-430X Train Length	147.4	m
Thalys PBKA Train Length	200.19	m
China CRH3 Series Train Length	200	m

Specific Parameters	Units	Train Speed:	80
			22.22
		Korean HEMU-430X	Thalys PBKA
Time of Passby Event	sec	6.63	9.01
t(j): Ratio of Passby Time to 8-Hour Night Period		0.0002303	0.0003128
$L_{pAEQ,pass-by}$ (microphone position 4)	dB(A)	74.38	67.67
Number of Trains during 8-Hour Night Period			
8		47.04	41.65
16		50.05	44.66
24		51.81	46.42
32		53.06	47.67
40		54.03	48.64
48		54.82	49.43
56		55.49	50.10

Mitigation methods required if L_n exceeds 60 dB(A), for examples, barriers







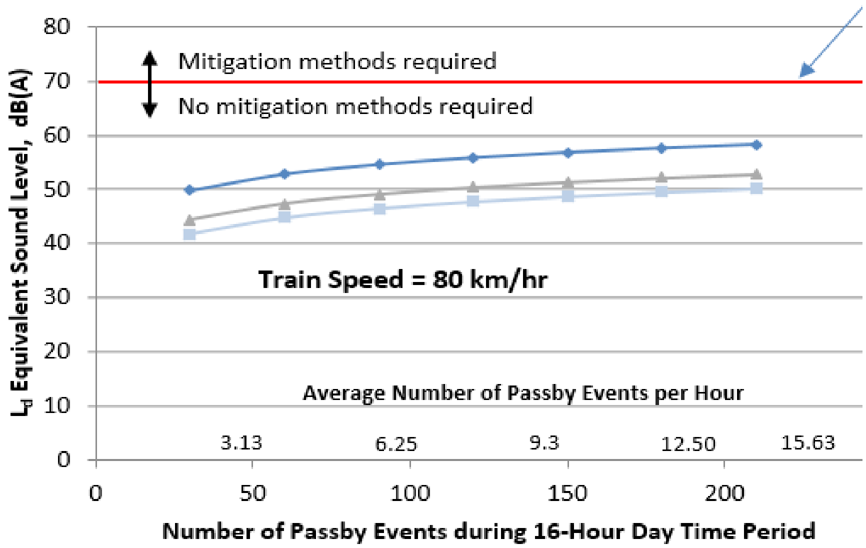
L_d *Calculations*

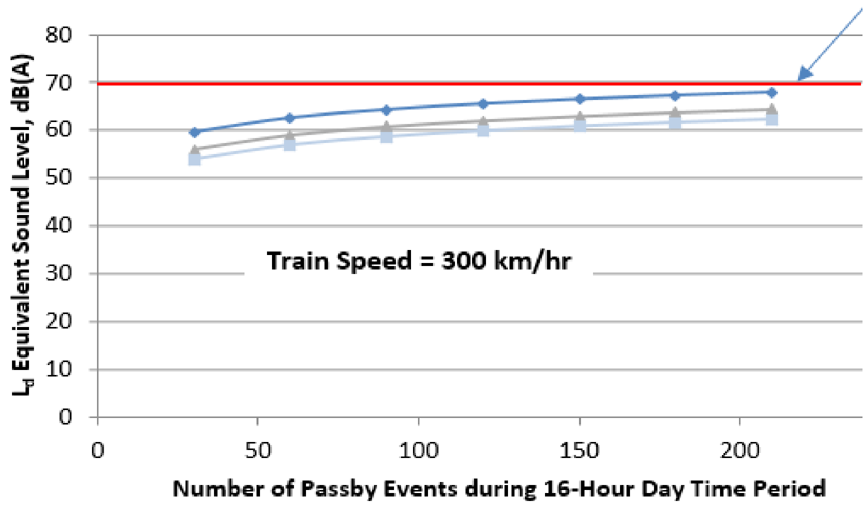
Common Parameters	Value	Units
Duration of Night Time Period	16	hours
	57,600	sec
Korean HEMU-430X Train Length	147.4	m
Thalys PBKA Train Length	200.19	m
China CRH3 Series Train Length	200	m

Specific Parameters	Units	Train Speed:	80
			22.22
		Korean HEMU-430X	Thalys PBKA
Time of Pass-by Event	sec	6.63	9.01
t(j): Ratio of Pass-by Time to 16-Hour Night Period		0.0001152	0.0001564
$L_{pAEQ,pass\text{-}by}$ (microphone position 4)	dB(A)	74.38	67.67
Number of Trains during 16-Hour Day Period			
30		49.77	44.38
60		52.78	47.39
90		54.54	49.15
120		55.79	50.40
150		56.76	51.37
180		57.55	52.16

210	58.22	52.83

Mitigation methods required if L_d exceeds 70 dB(A), for examples, barriers





Compliance with Japanese Regulations

In Japan, noise measurements are made at the railroad property line (microphone p

	Noise Limits for Japan Shinka		
Code	**Applies to:**	**Area Category**	**Maximum Sound Pressure Level dB(A)**
In accordance with Basic Environmental Law (Law 91 of 1993)	Shinkansen (HS Rail)	I	70 or less
		II	75 or less

Notes:

1. Area Categories: I Residential Zones
II Commercial and Industrial Zor

2. The noise metric L_{eq} is calculated using the energy mean of the peak noise levels
3. Sound pressure limits are not indexed by train speed
4. Measurements are to be carried out by recording the peak noise level of each of t
   directions, in principle for 20 successive trains
5. Wayside noise mitigation methods, such as barriers, can be implemented to meet

The L_{eq} noise metric is defined by the following equation:

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

The maximum speed for Shinkansen trains is 320 km/hr. Train speeds of 300

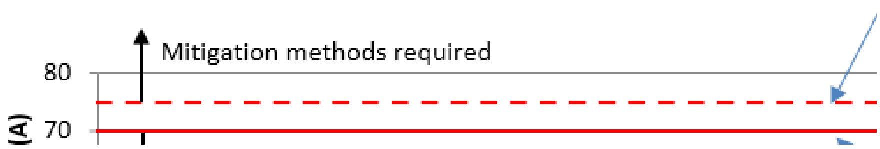
this is discretized as L_{eq}(hour) = $10\log_{10}[(1/T)\Sigma 10^{LA(j)(t)/10}\Delta t]$ j=1

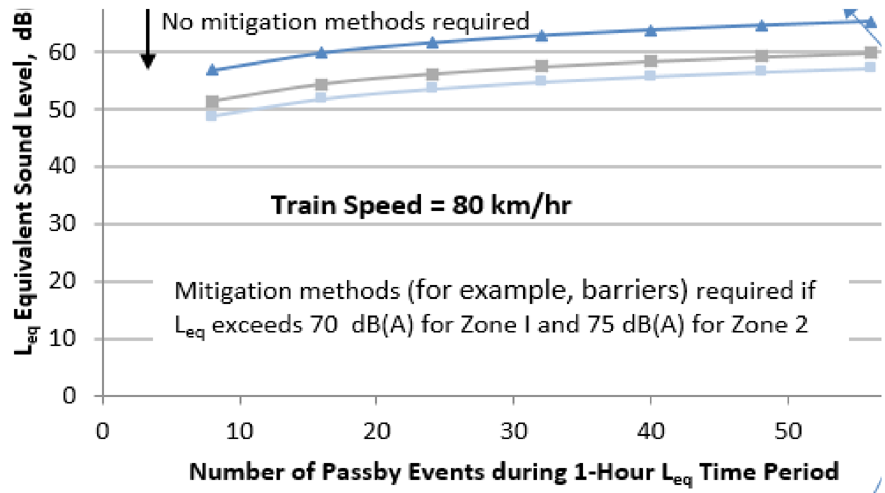
Thus, L_{eq} (hour) = $10\log_{10}\left[\sum_{j=1}^{N} t(j)10^{\frac{L(j)}{10}}\right]$ the time increment for calcula

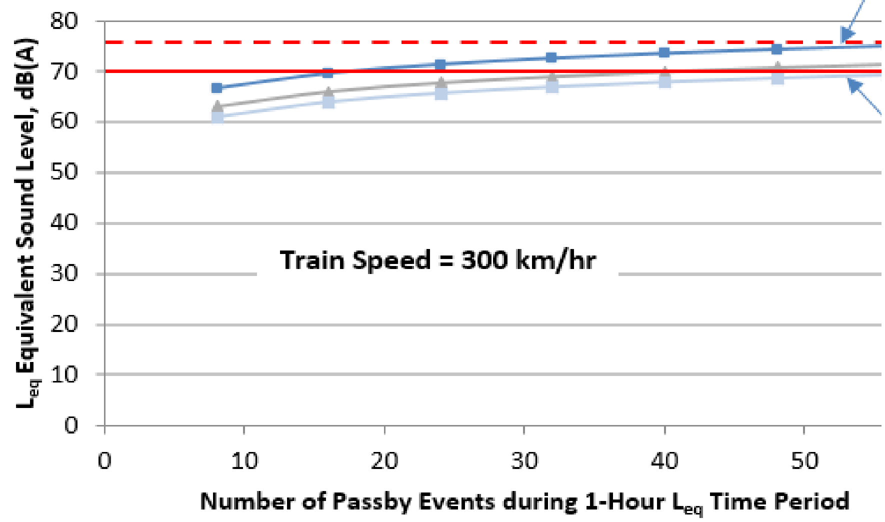
L_{eq} Calculations

Common Parameters	Value	Units
Duration of Night Time Period	1	hour
	3,600	sec
Korean HEMU-430X Train Length	147.4	m
Thalys PBKA Train Length	200.19	m
China CRH3 Series Train Length	200	m

Specific Parameters	Units	Train Speed:	80
			22.22
		Korean HEMU-430X	Thalys PBKA
Time of Pass-by Event	sec	6.63	9.01
t(j): Ratio of Passby Time to 1-Hour L_{eq} Time Period		0.0018425	0.0025024
$L_{eq,pass\text{-}by}$ (microphone position 3)	dB(A)	75.18	68.46
Number of Trains during 1-Hour L_{eq} Time Period			
	8	56.86	51.48
	16	59.87	54.49
	24	61.63	56.25
	32	62.88	57.50
	40	63.85	58.47
	48	64.64	59.26
	56	65.31	59.93







L_{Amax} Calculations

Another metric employed in Japan to describe the noise from train passages

L_{Amax} is defined as the power- or energy-average of the "slow" maximum leve

$$L_{Amax} = 10 \log_{10}\left[\frac{1}{20}\sum_{j=1}^{20} 10^{(L_{pASmax})_j/10}\right]$$

If we assume all 20 consecutive pass-by measurements are identical, for purp

$$L_{Amax} = 10 \log_{10}\left[\frac{20}{20}\ 10^{(L_{pASmax})/10}\right] = 10 \log_{10}\left[1\right.$$

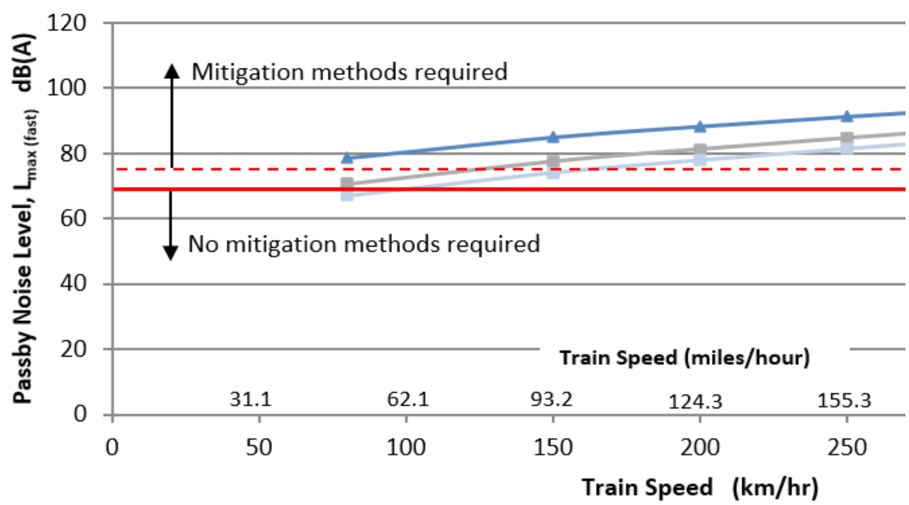
Since: $\log_{10}(x^y) = y \log_{10}(x)$ and $\log_{10}(10) =$

Comparisons of $L_{Amax\,(slow)}$ (which is equal to L_{pASmax}) for trainsets relative to J

Microphone Position 3 (25 m from track centerline and 1.2 meters above top

$L_{Amax\,(slow)}$ dB(A), Micropho			
Train Set	**Train Speed**		
	80	**150**	**200**
Korean HEMU-430X	78.4	84.8	88.1
Thalys PBKA	69.1	76.0	79.8
China CRH3 Series	67.1	74.1	78.0

Measurement Uncertainty is ±3

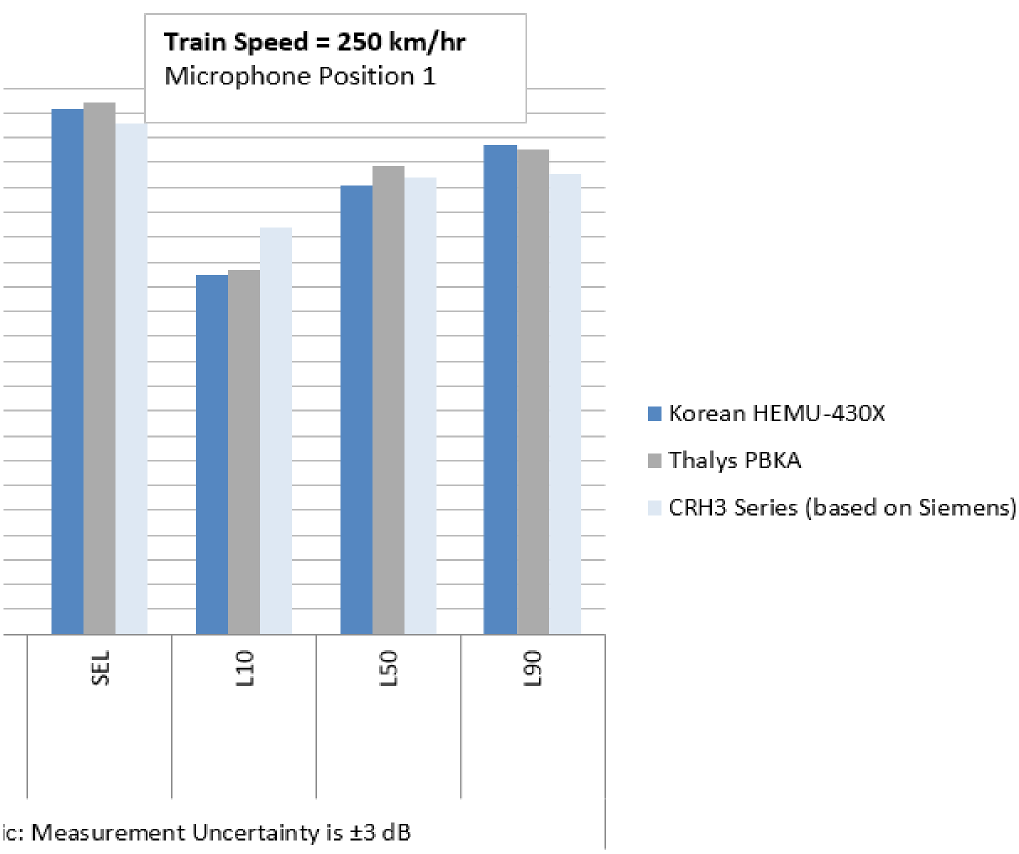


Spreadsheet-Based Tool for Comparing Noise Standards and Regulations
Conversion Tool for Noise Regulations and Standards to Common Reference

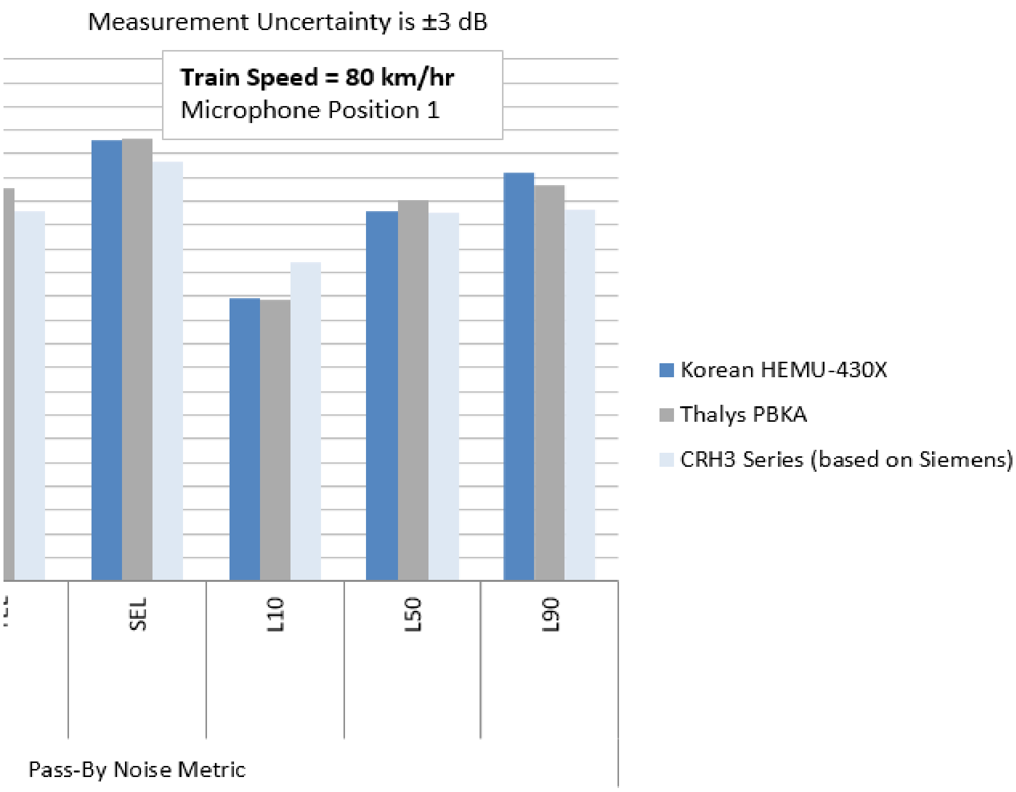
CONTRAST Comparison **O**f **N**oise for **TRA**i

Pass-By Noise Metric: Measurement Uncertainty is ±3 dB

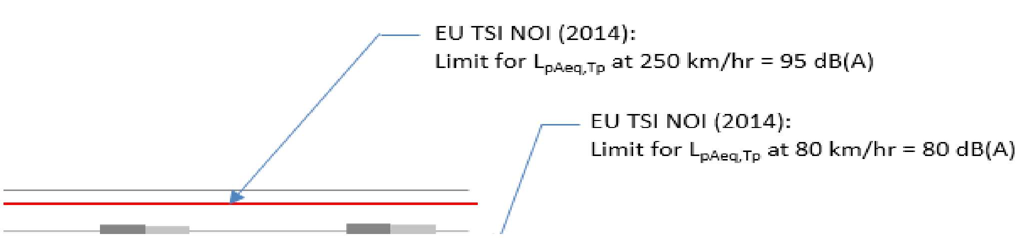
L_{pAFmax}	$L_{pAeq,pass-by}$	TEL	SEL	L_{10}	L_{50}
100.34	94.98	98.54	105.73	72.40	90.50
97.02	94.21	96.96	107.24	73.38	94.32
92.96	91.32	92.51	102.97	81.78	91.98

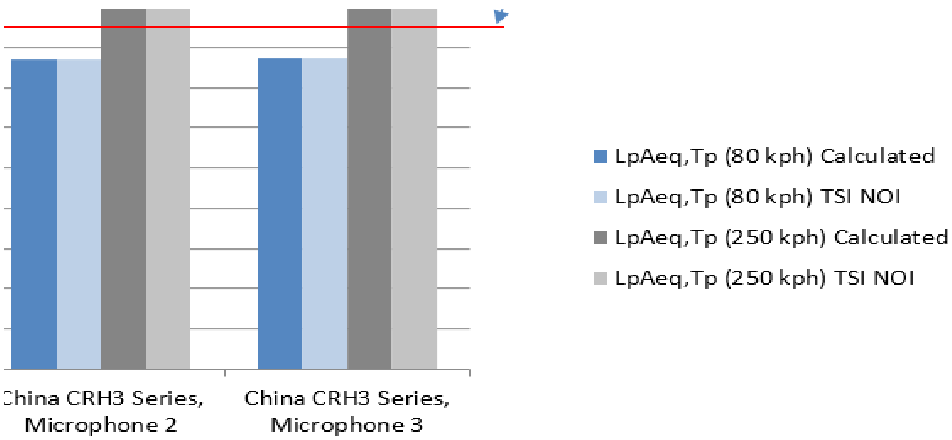


Pass-By Noise Metric					
L_{pAFmax}	$L_{pAeq,pass-by}$	TEL	SEL	L_{10}	L_{50}
87.67	82.30	85.86	93.05	59.72	77.83
82.95	80.14	82.89	93.17	59.31	80.25
78.49	76.85	78.04	88.50	67.30	77.50



$L_{pAeq,Tp\ (250\ kph)}$ dB(A)
TSI NOI (2014)
95.7
95.7
91.4
91.1
91.5

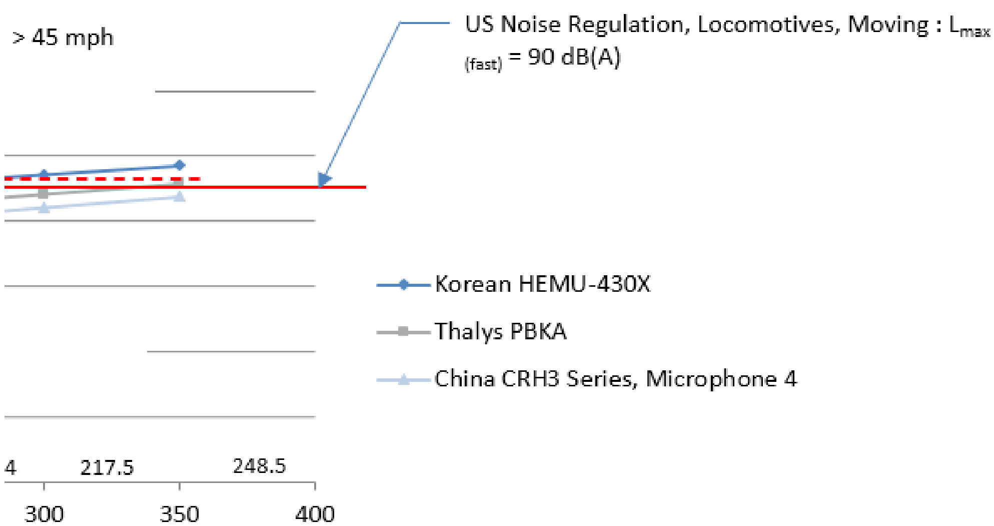




; regulations.

) of rail)

)		
(km/hr)		
250	**300**	**350**
92.5	95.3	98.1
84.2	87.4	90.6
81.0	84.4	87.7



Position 4 (30 m from track centerline, 1.2 m above top of rail)

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

) is the fraction of time during which sound pressure level, $L(j)$, occurs

ıring time period over which L_d applies l measured during the night time, dB(A). The equation for L_n would be the same as that for L_d with the sour

d defined as night .

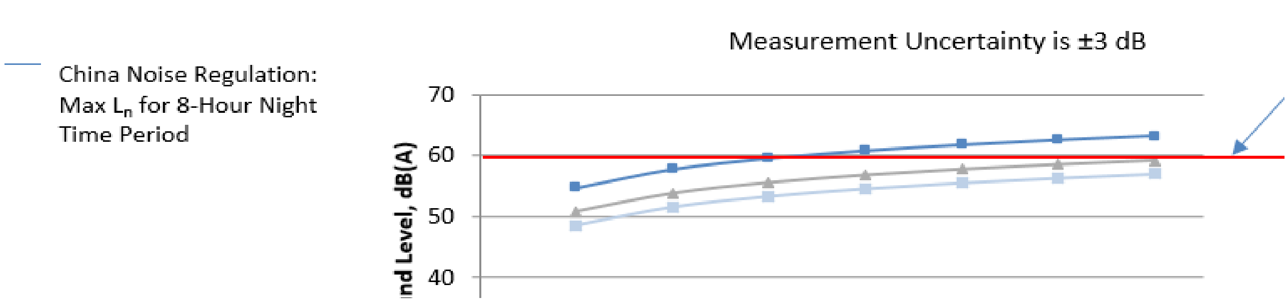
vel (SPL), $L_{pAeq\ (pass\text{-}by)}$ = 84.7 dB(A) for microphone position 4 (30 m from track centerline, 1.2 m above top of rail).

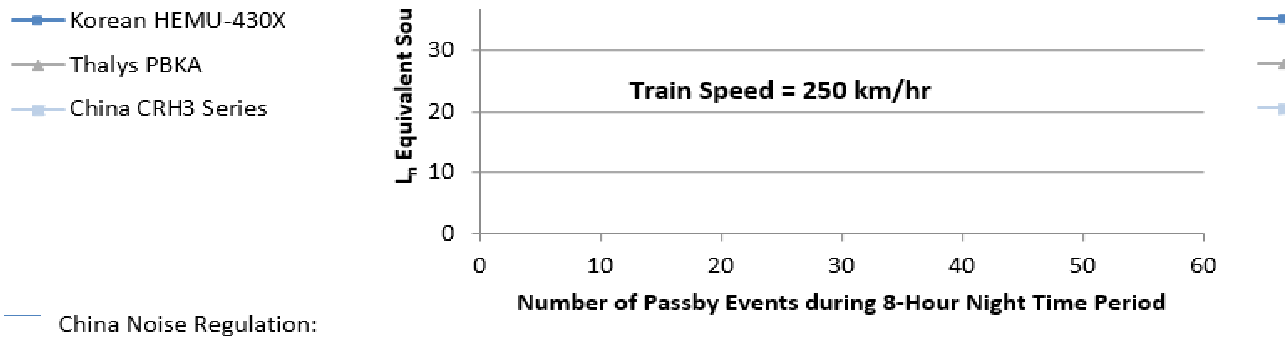
time period, the fraction of time for each pass-by event is equal to 4.2 seconds divided by 8 hours (28,800 seconds)

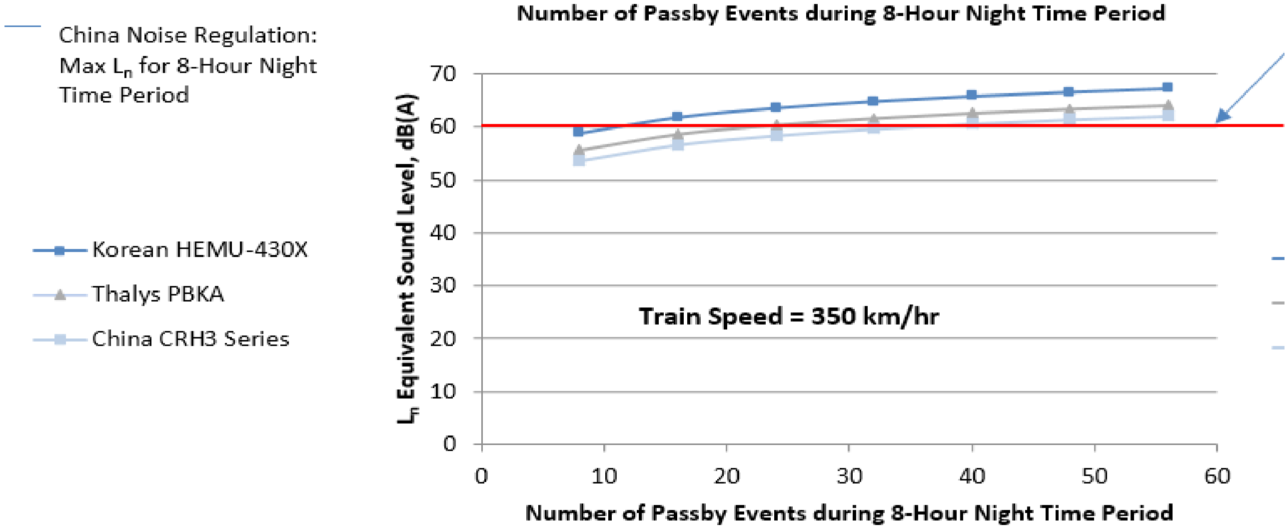
s during the 8 hour time period would be = 10LOG10(2*t(j)*10^(84.7/10)) which is equal to:

The calculation includes all of the pass-by data points from the time recording of the microphone SPL signals starts until the time recording of microphone SPL signals ends.

km/hr	**Train Speed:**	**250**	**km/hr**	**Train Speed:**	**300**
m/sec		**69.44**	**m/sec**		**83.33**
China CRH3 Series	**Korean HEMU-430X**	**Thalys PBKA**	**China CRH3 Series**	**Korean HEMU-430X**	**Thalys PBKA**
9.00	2.12	2.88	2.88	1.77	2.40
0.0003125	0.0000737	0.0001001	0.0001000	0.0000614	0.0000834
65.04	87.06	81.74	79.51	89.89	84.97
L_n (the A-weighted equivalent sound level measured during the night time), dB(A)					
39.02	54.77	50.77	48.54	56.80	53.21
42.03	57.78	53.78	51.55	59.81	56.22
43.79	59.54	55.54	53.31	61.57	57.98
45.04	60.79	56.79	54.56	62.82	59.23
46.01	61.76	57.76	55.53	63.79	60.20
46.80	62.55	58.55	56.32	64.58	61.00
47.47	63.22	59.22	56.99	65.25	61.66



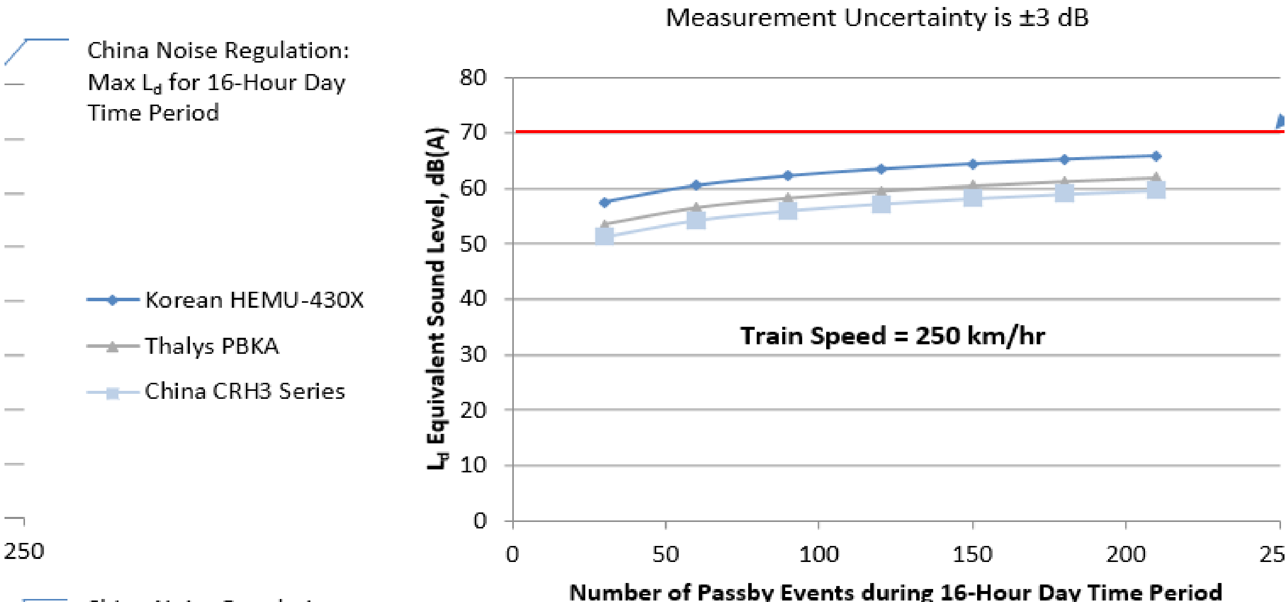


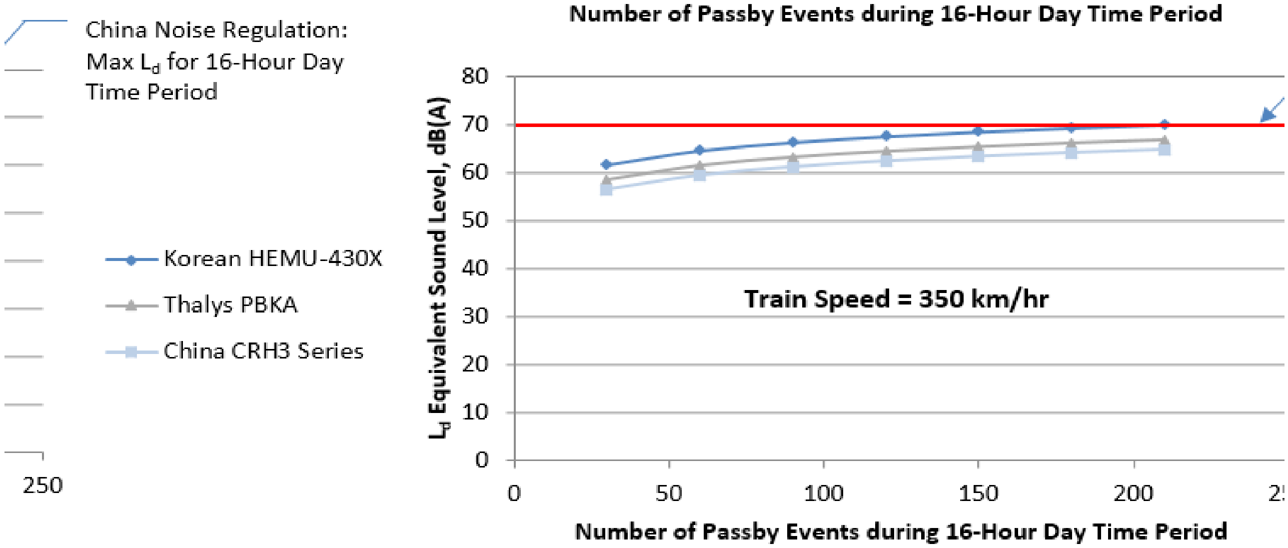


The calculation includes all of the pass-by data points from the time recording of the microphone SPL signals starts until the time recording of microphone SPL signals ends.

km/hr	Train Speed:	250	km/hr	Train Speed:	300
m/sec		69.44	m/sec		83.33
China CRH3 Series	**Korean HEMU-430X**	**Thalys PBKA**	**China CRH3 Series**	**Korean HEMU-430X**	**Thalys PBKA**
9.00	2.12	2.88	2.88	1.77	2.40
0.0001563	0.0000369	0.0000500	0.0000500	0.0000307	0.0000417
65.04	87.06	81.74	79.51	89.89	84.97
L_d (the A-weighted equivalent sound level measured during the day time), dB(A)					
41.75	57.50	53.50	51.27	59.53	55.94
44.76	60.51	56.51	54.28	62.54	58.95
46.52	62.27	58.27	56.04	64.30	60.71
47.77	63.52	59.52	57.29	65.55	61.96
48.74	64.49	60.49	58.26	66.52	62.93
49.53	65.28	61.28	59.05	67.31	63.73

50.20	65.95	61.95	59.72	67.98	64.39





osition 3). Maximum sound pressure levels vary by land use category.

nsen High Speed Rail	
Metric for Noise Measurement	**Measurement Location**
L_{eq}, L_{Amax}	[illegible] centerline at elevation of 1.2 m

ıes

For areas adjacent to Japan's hig

the stricter Environmental Qualit

References:

[1] Ministry of the Environment, G

Notification No. 91," Japan Min

he Shinkansen trains passing in both

noise limits.

[2] Ministry of the Environment, G
https://www.env.go.jp/en/air/r

$^{0}dt]$

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

$L_A(t)$ = A-weighted equivalent continuous sound pressure level produced by the trai
where the 1-hour time interval extends from t_1 to t_2 and $T = t_2 - t_1$ = 1 hour

km/hr and 350 km/hr are included in the following analysis.

since $\Delta t/T = t(j)$ = the fraction of time during which the sound pressurel level $L_A(t)$ occurs during the time period over

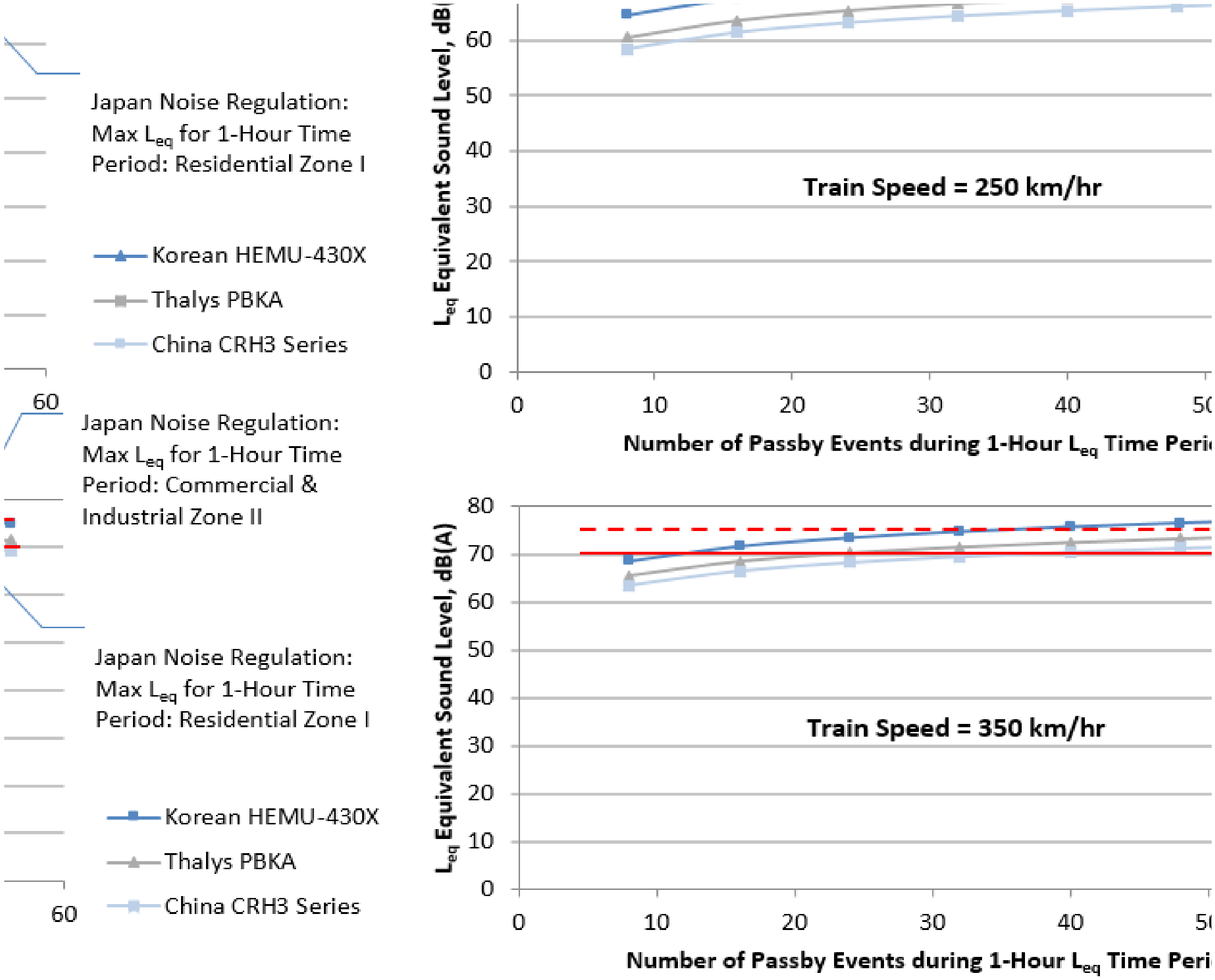
to that for L_d and L_n, except for the time period being equal to 1 hour (3,600 seconds).

ating t(j) is 1 hour (3,600 seconds) and $L_{A(j)} = L(j)$

Microphone Position 3 (25 meters from track centerline, 1.2 meters above top of rail)

The calculation includes all of the passby data points from the time recording of the microphone SPL signals starts until the time recording of microphone SPL signals ends. For the Japan regulation the total time period is 1 hour.

km/hr	Train Speed:	250	km/hr	Train Speed:	300
m/sec		69.44	m/sec		83.33
China CRH3 Series	**Korean HEMU-430X**	**Thalys PBKA**	**China CRH3 Series**	**Korean HEMU-430X**	**Thalys PBKA**
9.00	2.12	2.88	2.88	1.77	2.40
0.0025000	0.0005896	0.0008008	0.0008000	0.0004913	0.0006673
65.83	87.85	82.53	80.30	90.68	85.76
L_{eq} (the A-weighted equivalent sound level measured during a one-hour time period), dB(A)					
48.84	64.59	60.59	58.36	66.62	63.04
51.85	67.60	63.60	61.37	69.63	66.05
53.61	69.36	65.36	63.13	71.40	67.81
54.86	70.61	66.61	64.38	72.64	69.06
55.83	71.58	67.58	65.35	73.61	70.03
56.62	72.37	68.37	66.14	74.41	70.82
57.29	73.04	69.04	66.81	75.08	71.49



is L_{Amax}.

l (L_{pASmax}) of 20 consecutive train passbys, as expressed in the following equation:

ɔoses of comparing noise metrics, we find $L_{Amax} = L_{pASmax}$ as shown below:

$$0^{(L_{pASmax})/10}\Big] = \left[\frac{L_{pASmax}}{10}\right] 10\log_{10}(10) = L_{pASmax}$$

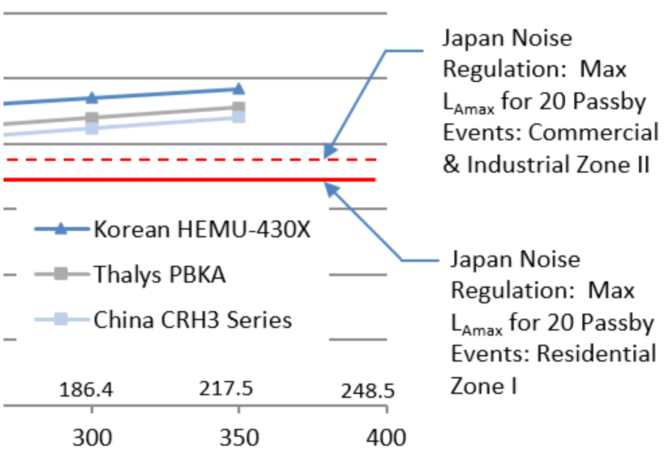
: 1

apan regulations for 20 passby events.

) of rail)

ne Position 3		
(km/hr)		
250	**300**	**350**
91.1	93.9	96.7
83.2	86.4	89.5
81.5	84.9	88.2

: dB



in **ST**andards Program Version: 7 14-Oct-19

L_{90}
98.69
97.48
92.68

L_{90}
86.01
83.41
78.20

ıd levels corresponding to

49.35 dB(A)

km/hr	Train Speed:	350	km/hr
m/sec		97.22	m/sec
China CRH3 Series	Korean HEMU-430X	Thalys PBKA	China CRH3 Series
2.40	1.52	2.06	2.06
0.0000833	0.0000526	0.0000715	0.0000714
82.86	92.64	88.13	86.14
51.10	58.88	55.70	53.71
54.11	61.89	58.71	56.72
55.87	63.65	60.47	58.48
57.12	64.90	61.72	59.73
58.09	65.87	62.69	60.70
58.88	66.66	63.48	61.49
59.55	67.33	64.15	62.16

China Noise Regulation: Max L_n for 8-Hour Night

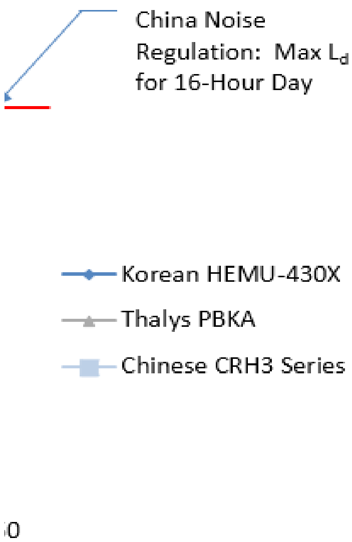
Korean HEMU-430X
Thalys PBKA
China CRH3 Series

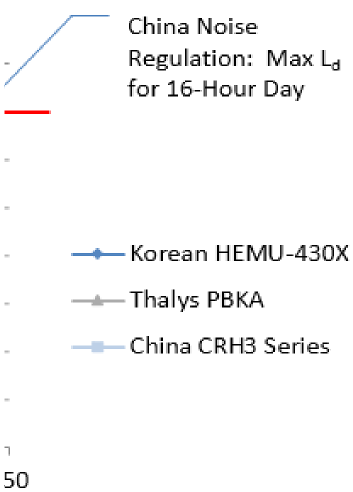
China Noise Regulation: Max L_n for 8-Hour Night

Korean HEMU-430X
Thalys PBKA
China CRH3 Series

km/hr	Train Speed:	350	km/hr
m/sec		97.22	m/sec
China CRH3 Series	Korean HEMU-430X	Thalys PBKA	China CRH3 Series
2.40	1.52	2.06	2.06
0.0000417	0.0000263	0.0000357	0.0000357
82.86	92.64	88.13	86.14
53.83	61.61	58.43	56.44
56.84	64.62	61.44	59.45
58.60	66.38	63.20	61.21
59.85	67.63	64.45	62.46
60.82	68.60	65.42	63.43
61.61	69.39	66.21	64.22

62.28	70.06	66.88	64.89





h speed train lines, the Shinkansen Superexpress Railway Noise regulations[1] apply and supersedes ty standards[2].

overnment of Japan, "Environmental Quality Standards for Shinkansen Superexpress Railway Noise, istry of the Environment, Tokyo, Japan, 1993.

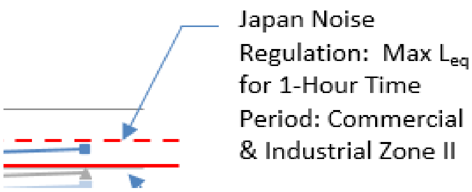
overnment of Japan, "Environmental Quality Standards for Noise, Environmental Agency Notification No. 64,
ıoise/noise.html," Japan Ministry of the Environment, Tokyo, Japan, 1998.

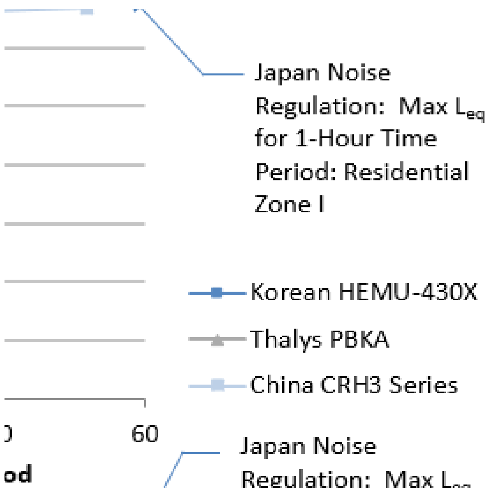
eriod

n as measured during the passby event

which L_{eq} applies, we obtain a relationship similar to

km/hr	Train Speed:	350	km/hr
m/sec		97.22	m/sec
China CRH3 Series	Korean HEMU-430X	Thalys PBKA	China CRH3 Series
2.40	1.52	2.06	2.06
0.0006667	0.0004211	0.0005720	0.0005714
83.66	93.43	88.92	86.93
60.93	68.70	65.52	63.53
63.94	71.71	68.53	66.54
65.70	73.47	70.29	68.30
66.95	74.72	71.54	69.55
67.92	75.69	72.51	70.52
68.71	76.48	73.30	71.31
69.38	77.15	73.97	71.98




Japan Noise Regulation: Max L_{eq} for 1-Hour Time Period: Residential Zone I
Korean HEMU-430X
Thalys PBKA
China CRH3 Series
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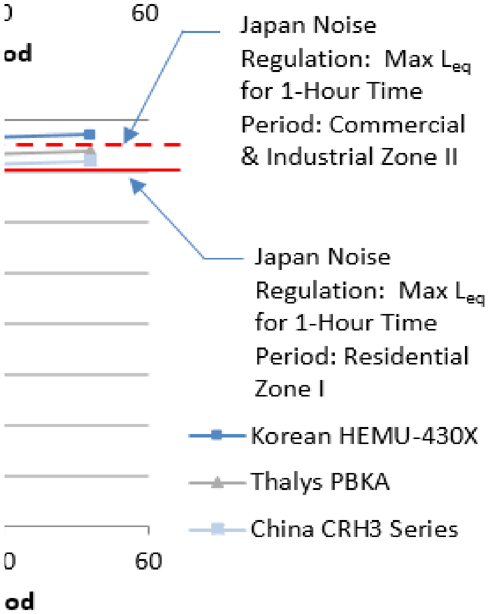
Japan Noise Regulation: Max L_{eq} for 1-Hour Time Period: Commercial & Industrial Zone II
Japan Noise Regulation: Max L_{eq} for 1-Hour Time Period: Residential Zone I
Korean HEMU-430X
Thalys PBKA
China CRH3 Series
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U.S. Department of Transportation
Federal Railroad Administrat

Federal Railroad Administration
High Speed Rail Noise Standards and Regulations

Data Set Number: 1

Data Set Name: Korean HEMU-430X

Korean HEMU-430X

Data Point Number	Passby Data[1Passby Data1Pas]		Sound Pressure (Pa)	Event
	Time (sec)	dB(A)		
1	0	79.1	0.18031	
2	0.05	79.4	0.18665	
3	0.10	79.9	0.19771	
4	0.15	80.2	0.20466	
5	0.20	80.7	0.21679	
6	0.25	81.6	0.24045	
7	0.30	82.1	0.25470	
8	0.35	83.2	0.28909	
9	0.40	84.2	0.32436	
10	0.45	85.2	0.36394	
11	0.50	86.1	0.40367	
12	0.55	86.6	0.42759	
13	0.60	87.2	0.45817	
14	0.65	88.9	0.55722	
15	0.70	90.2	0.64719	
16	0.75	91.3	0.73456	
17	0.80	93.2	0.91418	← 10 dB(A) lower than SPL when Train Nose Passes Microphone
18	0.85	95.2	1.15088	
19	0.90	98.1	1.60705	
20	0.95	100.4	2.09426	

21	1.00	103.2	2.89088
22	1.05	106.4	4.17859
23	1.10	106.2	4.08348
24	1.15	105.7	3.85505
25	1.20	108.2	5.14079
26	1.25	108.6	5.38307
27	1.30	108.2	5.14079
28	1.35	107.5	4.74275
29	1.40	107.2	4.58174
30	1.45	108.8	5.50846
31	1.50	108.9	5.57224
32	1.55	107.3	4.63479
33	1.60	106.2	4.08348
34	1.65	108.3	5.20032
35	1.70	109.9	6.25216
36	1.75	108.3	5.20032
37	1.80	106.8	4.37552
38	1.85	107.5	4.74275
39	1.90	108.7	5.44540
40	1.95	107.5	4.74275
41	2.00	107.2	4.58174
42	2.05	108.7	5.44540
43	2.10	110.4	6.62262
44	2.15	110.2	6.47187
45	2.20	109.3	5.83485
46	2.25	107.4	4.68846
47	2.30	107.2	4.58174
48	2.35	104.2	3.24362
49	2.40	100.5	2.11851
50	2.45	100.3	2.07028
51	2.50	99.1	1.80314
52	2.55	97.2	1.44887
53	2.60	96.4	1.32139
54	2.65	95.3	1.16421
55	2.70	92.6	0.85316
56	2.75	92.3	0.82420
57	2.80	91.2	0.72616
58	2.85	90.7	0.68554
59	2.90	89.7	0.61098

Train Nose Passes Microphone
Start Time for LpASmax Calculat

Maximum Sound Pressure Leve
End Time for LpASmax Calculat
Tail of Train Passes Microphone

10 dB(A) lower than SPL when
Train Tail Passes Microphone

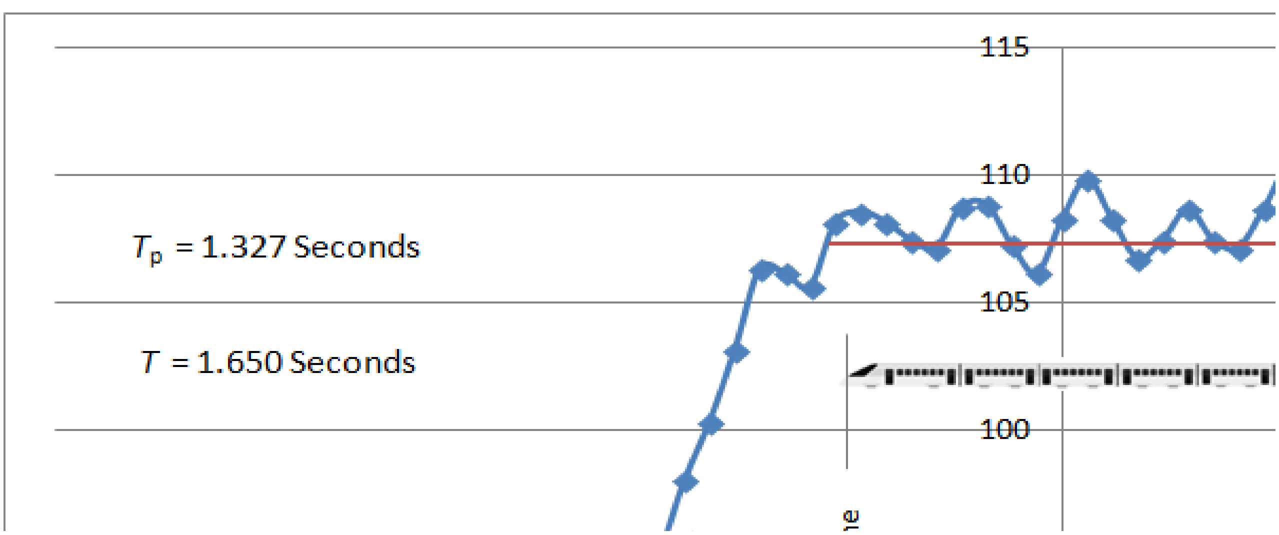
ion

Spreadsheet-Based Tool for Comparing Noise Standards and Regulatio
Conversion Tool for Noise Regulations and Standards to Common Refe

CONTRAST Comparison Of Noise for TRAin STandards

Train Set Information			
Year Data Set was Generated:		2016	[1]SoundView Instrur
Train Set Manufacturer:		Hyundai Rotem	http://www.sour
Operator:		Korail	
Train Set Geometry and Test Conditions			
Parameter	**Value**	**Units**	
Car Lengths			
End Cars:	23.5	m	
Intermediate Cars:	25.1	m	
Number of End Cars:	2		
Number of Intermediate Cars:	4		
Test Train Length:	147.4	m	
Test Train Speed(s):	400	km/hr	
Microphone Position:	2		dB (sound press
Distance from Track Centerline:	7.5	m	where 0.0002 is
Elevation above Top of Rail:	3.5	m	so, Pa = 0.0000
Time Increment for Passby Data, ΔT:Tim	0.05	sec	
Number of Passby Data Points:	59		

Plot of Passby Noise Data, Including Key Time Para



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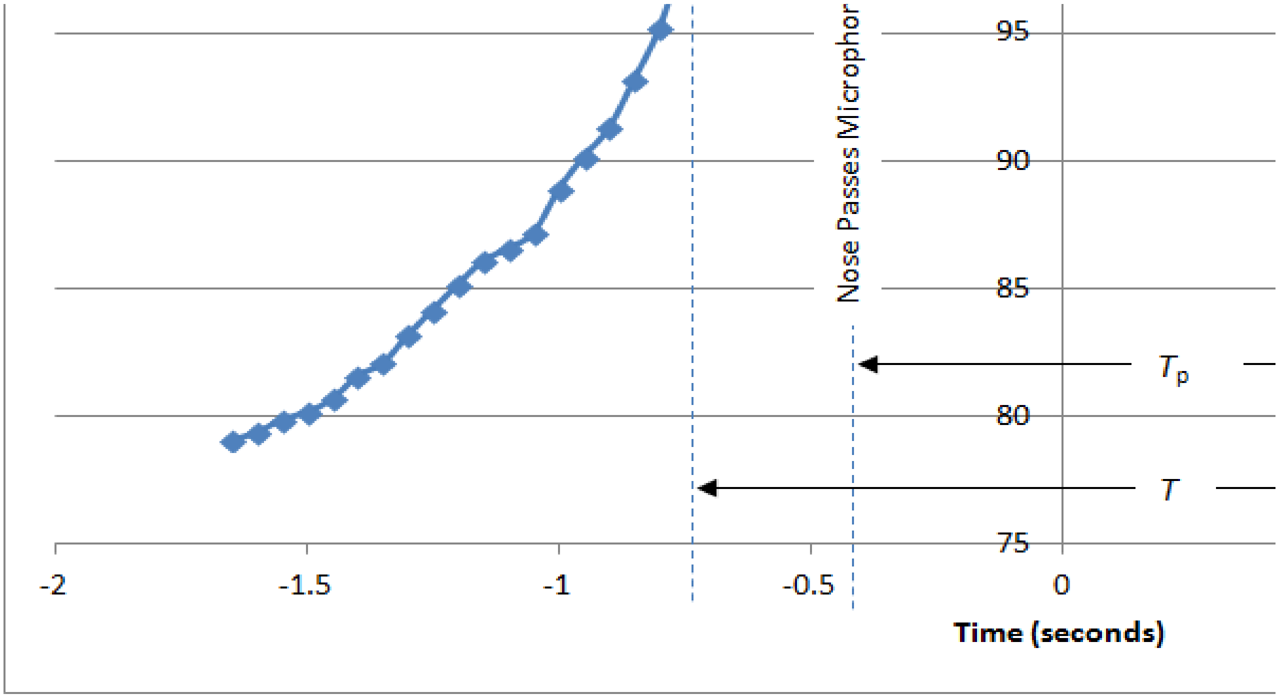

Nose Passes Microphor
95
90
85
80
75
T_p
T
-2
-1.5
-1
-0.5
0
Time (seconds)

el
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rence

Program Version: 7 14-Oct-19

References

nents, High-Speed Train Noise, South Korea HEMU, Virtual Train,2016, [1]SoundView Instruments, High-Speed Train Noise, South Korea

ıdviewinstr.com/high-speed-train-noise/ and http://www.soundviewinstr.com/virtual-train/

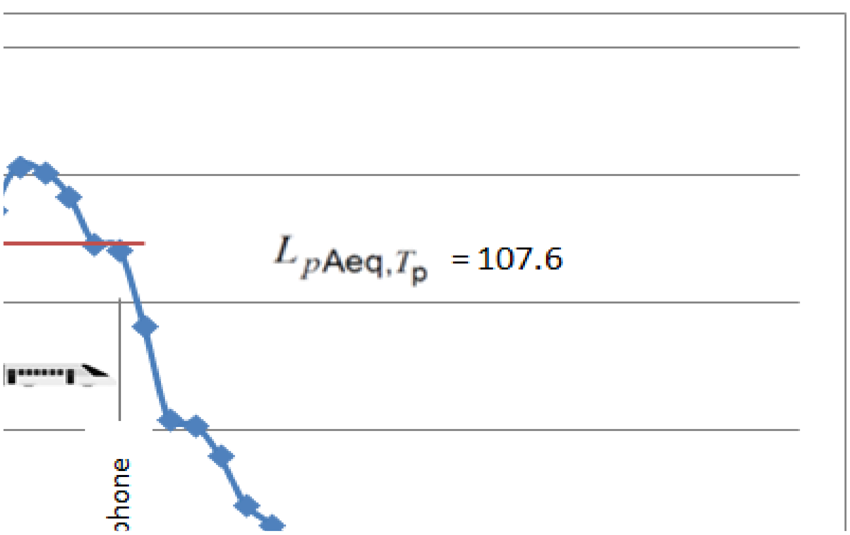
Formula

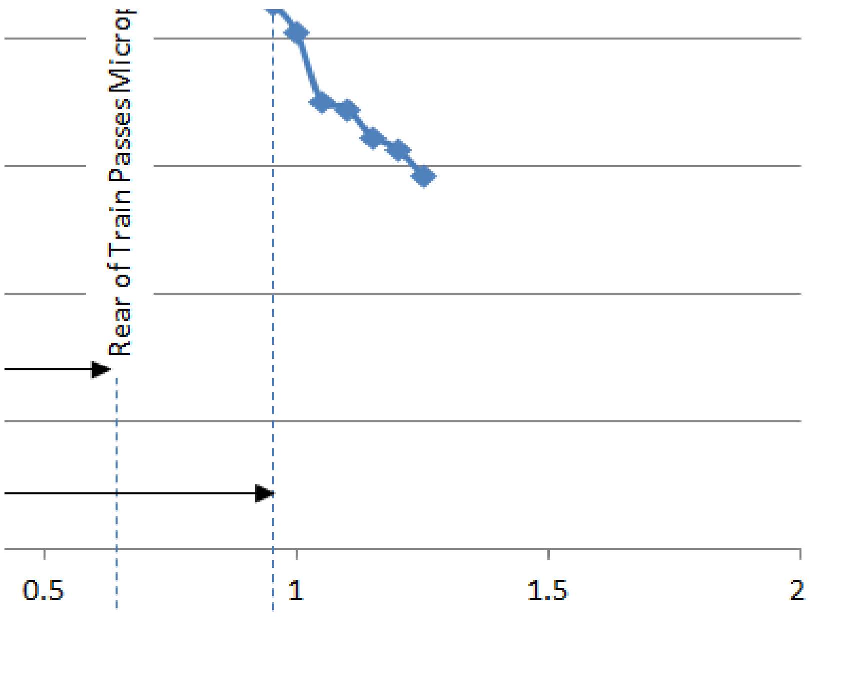
ıure level in decibels) = 20 $\log_{10}$(Pa/0.00002) dB (sound pressure level in decibels) = 20 $\log_{10}$(Pa/0.00002) dB (

; the reference sound pressure level in Pascals

2*10$^{(dB/20)}$so, Pa = 0.00002*10(dB/20)so, Pa = 0.00002*10(dB/20)so, Pa = 0.00002*10(dB/20)so, Pa = 0.00002*10(dB/20)

meters





Rear of Train Passes Microp
0.5
1
1.5
2

a HEMU, Virtual Train,2016, [1]SoundView Instruments, High-Speed Train Noise, South Korea HEMU, Virtual Train,2016, [1]SoundV

sound pressure level in decibels) = 20 $\log_{10}$(Pa/0.00002) dB (sound pressure level in decibels) = 20 $\log_{10}$(

iew Instruments, High-Speed Train Noise, South Korea HEMU, Virtual Train,2016, [1]SoundView Instruments, High-Speed Train N

(Pa/0.00002) dB (sound pressure level in decibels) = 20 $\log_{10}$(Pa/0.00002)

Ioise, South Korea HEMU, Virtual Train,2016,

U.S. Department of Transportation
Federal Railroad Administration

Spreadsheet-Based Tool for Comparing Noise Standards and Regulations
Conversion Tool for Noise Regulations and Standards to Common Reference

RICARDO

Federal Railroad Administration
High Speed Rail Noise Standards and Regulations

CONTRAST Comparison Of Noise for TRAin STandards

Program Version: 7 14-Oct-19

Data Set Number:	1	Passby Noise Calculations
Data Set Name:	Korean HEMU-430X	

Calculate Train Passby Parameters

Train Speed (V):	400	km/hr =	111.11 m/sec
Train Length:	147.4	m	6 cars: 2 end cars and 4 intermediate cars
Time for Passby (T_p)	1.3266	seconds	This is the time increment between nose of train passing microphone and tail of train passing microphone.
Time for TEL (T_{TEL})	1.65	seconds	TEL is the Transit Exposure Limit and represents the equivalent A-weighted SPL over the time period beginning when the instantaneous meter reading is 10 dB(A) less than $L_{pAEq,Tp}$ and continuing through the passby event until the meter reading is again 10 dB(A) less than $L_{pAeq,Tp}$

References

[1]He, et al., Investigation into External Noise of a High-Speed Train at Different Speeds, J Zhejiang Univ-Sci A (Appl Phys & Eng) 2014, 15(12):1019-1033
[2]Paul, et al, High Speed Rail Noise Standards and Regulations, US DOT Federal Railroad Administration, Contract DTFR35-16-C00006, May 2017.
[3]G. Xiaoan and J. Hua, "Application Research on Descending Vibration and Reducing Noise in Accelerating Speed Trains and Express Trains," Chinese Academy of Railway Sciences (CARS) Research Report, Beijing Shi, China, 2003.
[4]Hanson, C.E., et. al., High Speed Ground Transportation Noise and Vibration Impact Assessment, U.S. Department of Transportation, Federal Railroad Administration, Report Number DOT/FRA/ORD-12/15, September 2012.
[5]Gautier, P.E., Poisson, F., and Letourneaux, F., High Speed Trains External Noise: A Review of Measurements and Source Models for TGV Case Up to 360 km/hr, in Proceedings of the 8th World Congress on Railway Research (2008).
[6]European Union, "Commission Regulation Number 1304/2014, on the technical specification for interoperability relating to the subsystem 'rolling stock — noise' amending Decision 2008/232/EC and repealing Decision 2011/229/EU," Official Journal of the European Union, Brussels, Belgium, 2014.

Calculate $L_{pAeq,Tp}$

$L_{pAeq,Tp}$ is the A-weighted equivalent continuous sound pressure level produced by the train as measured during the passby event

$$L_{p\mathrm{Aeq},T_\mathrm{p}} = 10\ \lg\left(\frac{1}{T_2 - T_1}\int_{T_1}^{T_2}\frac{p_\mathrm{A}^2(t)}{p_0^2}\mathrm{d}t\right)\ \mathrm{dB}$$

Microphone Position is 7.5 m from track centerline and 3.5 m above top of rail (Microphone Position 2).

where

- T_p is the passby time interval = time when trail tail passes microphone minus time when train nose passes microphone = $T_2 - T_1$
- T_1 is the time when the train nose passes the microphone
- T_2 is the time when the train tail passes the microphone
- $P_A(t)$ is the A-weighted instantaneous sound pressure in Pa at time t
- P_0 is the reference sound pressure: p_0 = 20μPa = 0.00002 Pa
- Δt_i is the time increment between measured data points = 0.05 seconds
- $P_A(i)$ is the A-weighted instantaneous sound pressure in Pa at pass-by time increment i

$L_{pAeq,Tp}$ can be calculated from the passby data using the following Riemann Sum relationship:

$$\int_{T_1}^{T_2}\frac{p_\mathrm{A}^2(t)}{p_0^2}\mathrm{d}t \approx \sum_{i=1}^{i=n}\left(\frac{\mathrm{Pa}(i)^2}{p_0^2}\right)\Delta t_i$$

An analysis conducted during the current study indicated the integral can be determined numerically, with acceptable accuracy, by employing a midpoint Reimann sum scheme with a mimimum Δti = 0.05 seconds, and the corresponding Pa(i) analog meter values. This approach is described in: Hughes-Hallett, Deborah; McCullum, William G.; et al. (2005). *Calculus (4th ed.)*, Wiley. p. 252.

Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$	Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$	Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$	Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$
1	0.00	79.10	0.180314	8.12831E+07	16	0.75	91.30	0.734565	1.34896E+09	31	1.50	108.90	5.572242	7.76247E+10	46	2.25	107.40	4.688458	5.49541E+10
2	0.05	79.40	0.186651	8.70964E+07	17	0.80	93.20	0.914176	2.08930E+09	32	1.55	107.30	4.634789	5.37032E+10	47	2.30	107.20	4.581735	5.24807E+10
3	0.10	79.90	0.197711	9.77237E+07	18	0.85	95.20	1.150880	3.31131E+09	33	1.60	106.20	4.083476	4.16869E+10	48	2.35	104.20	3.243620	2.63027E+10
4	0.15	80.20	0.204659	1.04713E+08	19	0.90	98.10	1.607052	6.45654E+09	34	1.65	108.30	5.200319	6.76083E+10	49	2.40	100.50	2.118507	1.12202E+10
5	0.20	80.70	0.216785	1.17490E+08	20	0.95	100.40	2.094257	1.09648E+10	35	1.70	109.90	6.252159	9.77237E+10	50	2.45	100.30	2.070284	1.07152E+10
6	0.25	81.60	0.240453	1.44544E+08	21	1.00	103.20	2.890880	2.08930E+10	36	1.75	108.30	5.200319	6.76083E+10	51	2.50	99.10	1.803142	8.12831E+09
7	0.30	82.10	0.254701	1.62181E+08	22	1.05	106.40	4.178592	4.36516E+10	37	1.80	106.80	4.375523	4.78630E+10	52	2.55	97.20	1.448872	5.24807E+09
8	0.35	83.20	0.289088	2.08930E+08	23	1.10	106.20	4.083476	4.16869E+10	38	1.85	107.50	4.742747	5.62341E+10	53	2.60	96.40	1.321387	4.36516E+09
9	0.40	84.20	0.324362	2.63027E+08	24	1.15	105.70	3.855050	3.71535E+10	39	1.90	108.70	5.445403	7.41310E+10	54	2.65	95.30	1.164206	3.38844E+09
10	0.45	85.20	0.363940	3.31131E+08	25	1.20	108.20	5.140792	6.60693E+10	40	1.95	107.50	4.742747	5.62341E+10	55	2.70	92.60	0.853159	1.81970E+09
11	0.50	86.10	0.403673	4.07380E+08	26	1.25	108.60	5.383070	7.24436E+10	41	2.00	107.20	4.581735	5.24807E+10	56	2.75	92.30	0.824195	1.69824E+09
12	0.55	86.60	0.427592	4.57088E+08	27	1.30	108.20	5.140792	6.60693E+10	42	2.05	108.70	5.445403	7.41310E+10	57	2.80	91.20	0.726156	1.31826E+09
13	0.60	87.20	0.458174	5.24807E+08	28	1.35	107.50	4.742747	5.62341E+10	43	2.10	110.40	6.622622	1.09648E+11	58	2.85	90.70	0.685536	1.17490E+09
14	0.65	88.90	0.557224	7.76247E+08	29	1.40	107.20	4.581735	5.24807E+10	44	2.15	110.20	6.471873	1.04713E+11	59	2.90	89.70	0.610984	9.33254E+08
15	0.70	90.20	0.647187	1.04713E+09	30	1.45	108.80	5.508457	7.58578E+10	45	2.20	109.30	5.834854	8.51138E+10					

Data Point Number for Start of Passby Event (time at which train nose passes microphone): 23 i = 1
Data Point Number for End of Passby Event (time at which train tail passes microphone): 45 i - n

thus, $\sum_{i=1}^{i=n}\left(\frac{\mathrm{Pa}(i)^2}{p_0^2}\right)\Delta t_i$ = 7.67250E+10

$$L_{pAeq,Tp} = 10\ \lg\left(\frac{1}{T_2 - T_1}\int_{T_1}^{T_2}\frac{p_\mathrm{A}^2(t)}{p_0^2}\mathrm{d}t\right)$$

$L_{pAeq,Tp}$ = **107.62** **dB(A)**

Measurement Uncertainty is ±3 dB

Impact of Microphone Position

Microphone Position	Distance from Track Centerline (m)	Elevation Above Top of Rail (m)	Applies to Regulations in these Regions[2]				Comment
			US	EU	China	Japan	
1	7.5	1.2		X (TSI 2014)			TSI 1304
2	7.5	3.5		X (TSI 2014)			Also required for speeds > 250 km/hr
3	25	3.5		X (TSI 2008)		X	Reference for pre 2014 train sets
4	30	1.2	X		X		US and China measurement location

Impact of microphone distance is determined from the following equation:[3] $L_d = L_{d0} - 10 \cdot \mathrm{LOG}(d/d0)$, where L_{d0} is the equivalent A-weighted constant sound pressure level for the microphone at distance d0, and d is the distance for Ld.

References:

[A]L. Lu, X. Hu, Y. Zhang and X. Zhou, "Survey and Analysis of the Beijing-Shanghai High Speed Rail Noise," in The 21st International Congress on Sound and Vibration, Beijing, China, 2014.
[B]G. Xiaoan and J. Hua, "Application Research on Descending Vibration and Reducing Noise in Accelerating Speed Trains and Express Trains," Chinese Academy of Railway Sciences (CARS) Research Report, Beijing Shi, China, 2003.
[C]W. Elliott, "Request for Information Reference FOI13-580, Comparison of Measured Sound Levels for High Speed Trains as a Functionof Distance from Track," High Speed Rail Two (HS2), London, England, 2013.

Microphone Position	Distance from Track Centerline (m)	Elevation Above Top of Rail (m)	$L_{pAeq,Tp}$ at 400 km/h dB(A)	$L_{pAeq,Tp}$ at 400 km/h (Pa)
1	7.5	1.2	105.90	3.946
2	7.5	3.5	107.62	4.810
3	25	3.5	94.72	1.089
4	30	1.2	93.93	0.994

To convert dB(A) to Pascals: Pa = 0.00002*(10^(dBA/20))
To convert Pa to dB(A), dB(A) = 20*LOG10(Pa/0.00002)

Note: The simple sound level correction formula underestimates the measured values. Therefore, ratios based on actual measurements were used to adjust for microphone location (table at right).

Sound Pressure Variations for Microphone Positions & Train Speed from Reference 5			
Speed (km/hr)	$L_{pAeq,Tp}$ dB(A)		
	M1	M2	M3
271	93.2	95.8	82.0
341	96.5	98.0	85.5
386	98.5	100.1	88.1

Calculated Noise Metrics: Maximum Recorded Sound Pressure Levels

The following calculations are for Microphone Position 2 — $L_{p(maximum)}$ = maximum recorded pass-by sound pressure level

$L_{p(maximum)}$ = **110.4** dB(A) which occurs at data point 43 at passby time 2.10 seconds

L_{pASmax} is the maximum sound pressure level, slow and A-weighted and L_{pAFmax} = maximum sound pressure level, fast and A-weighted. The time period for the "slow" reading is 1 second. The time period for the "fast" reading is 0.125 seconds.

L_{pASmax} can be calculated as the logarithmic average of the recorded SPLs for the 1 second time interval containing the highest values

The logarithmic average for an Excel array is: {=10*LOG(AVERAGE(10^(ARRAY/10)))} array-entered, i.e. using CTRL-Shift-Enter keys where array is of the form A10:A15. In the current case, the array is Pass-By Data Set 1, C:48:C68

Highest 1-second interval occurs from start time 1.2 to end time 2.2 **Thus, L_{pASmax} = 108.20 dB(A)**

Similarly, L_{pAFmax} can be calculated as the logarithmic average of the recorded SPLs for the 0.125 second time interval containing the highest values

Highest 0.125-second interval occures from start time 2.10 to end time 2.225 **Thus, L_{pAFmax} = 110.40 dB(A)**

Calculated Noise Metrics: Other Standard Parameters

The following calculations are for Microphone Position 2

$L_{pAeq,pass-by}$ is the A-weighted equivalent continuous sound pressure level produced during the entire pass-by event, including approach, T_p, and departure (used for L_d, L_n, etc.)

The calculation includes all of the passby data points.

Data Point Number for Start of Passby Event (time at which microphone begins recording): 1 i = 1

Data Point Number for End of Passby Event (time at which microphone ends recording): 59 i - n thus, $\sum_{i=1}^{i=n} \left(\frac{Pa(i)^2}{p_0^2} \right) \Delta t_i$ = 9.05886E+10 $T_2 - T_1$ = 2.90 seconds

$L_{pAeq,pass-by} = 10 \lg \left(\frac{1}{T_2 - T_1} \int_{T_1}^{T_2} \frac{p_A^2(t)}{p_0^2} dt \right)$ **$L_{pAeq,pass-by}$ = 104.95 dB(A)**

TEL is the Transit Exposure Limit[4]. It is measured over the time interval starting when the SPL is 10 dB(A) lower than $L_{pAeq,Tp}$ and ending when the SPL again reaches a value that is 10 dB(A) lower than $L_{pAeq,Tp}$

TEL is calculated using the followign formula: TEL = $L_{pAeq,Tp}$ + 10*LOG(T_{TEL}/T_p) **TEL = 108.569406 dB(A)**

SEL is the Sound Exposure Limit[4]. Like $L_{pAeq,Tp}$, it integrates the total sound energy over a measurement period, but for SEL, the measurement period is normalized to a duration of 1 second. At a microphone distance of 30 m (100 ft), SEL = $L_{pAeq,Tp}$ + 10*LOG(Tp) + 1

SEL at 30 m: 109.85 dB(A) **SEL at 7.5 m: 115.87 dB(A)** **SEL at 25 m: 110.64 dB(A)** using the distance correction factor: $L_d = L_{d0}$ - 10*LOG(d/d0)

SEL is the cumulative noise exposure (i.e. "dose") for a single noise event normalized over 1 second. The fact that SEL is a cumulative measure means that (1) louder events have higher SELs than quieter ones, and (2) events that last longer in time have higher SELs than shorter ones.[4]

Statistical Parameters

The following parameters are determined by specifying the indicated percentile of the data values using Excel Function PERCENTILE(range,P).
where" range" is the array of values (e.g. K10:K68) and P = the percentile (between 0 and 1, for example, P for the 90th percentile would be entered as 0.9)

L_{10} is the sound pressure level for which 90% of the recorded values are greater. It includes lead-in (prior to nose passing microphone) and trail-off (after tail of train passes) data. **L_{10} = 82.00 dB(A)**

L_{50} is the sound pressure level for which 50% of the recorded values are greater. It includes lead-in (prior to nose passing microphone) and trail-off (after tail of train passes) data. **L_{50} = 100.40 dB(A)**

L_{90} is the sound pressure level for which 10% of the recorded values are greater. It includes lead-in (prior to nose passing microphone) and trail-off (after tail of train passes) data. **L_{90} = 108.72 dB(A)**

Summary of Pass-by Noise Metrics for Each Microphone Position

The noise metrics shown in the following table correspond to the baseline speed of 400 km/hr $L_d = L_{d0}$ - 10*LOG(d/d0), where L_{d0} is the equivalent A-weighted constant sound pressure level for the microphone at distance d0, and d is the distance for L_d.

Microphone Position			Noise Metric: Table Entries are dB(A)							
	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
1	105.9	108.6	106.5	108.6	103.3	106.8	114.0	80.7	98.8	107.0
2	107.6	110.4	108.2	110.4	104.9	108.6	115.9	82.0	100.4	108.7
3	98.8	101.6	99.4	101.6	96.1	99.8	110.6	73.2	91.6	99.9
4	98.0	100.8	98.6	100.8	95.4	99.0	109.8	72.4	90.8	99.1

Microphone Position Adjustment Factors[5]			
Speed (km/hr)	M1	M2	M3
271	0.931	0.957	0.819
341	0.964	0.979	0.854
386	0.984	1.000	0.880

Impact of Train Speed on Noise Levels

Ricardo evaluated several methods for determining the impact of train speed on pass-by noise levels. The approach developed by Gautier, Poisson & Letourneaux[5] provided the highest level of correlation with measured data is the basis for the calculations presented below.

$L_{Aeq,tp}(V) - L_{Aeq,tp}(V_0)$ = K log(V/V_0) where K is an empirical factor — where V= train speed (km/hr), V_0= reference train speed (km/hr)

thus, $L_{Aeq,tp}(V)$ = K log(V/V_0) + $L_{Aeq,tp}(V_0)$

If the SPL is known at train speed V_0, the SPL at train speed V can be determined from this formula

The empirical factor K varies with train speed. This is because the contribution of noise sources (e.g. wheel/rail interaction, propulsion components, aerodynamics) vary with train speed.

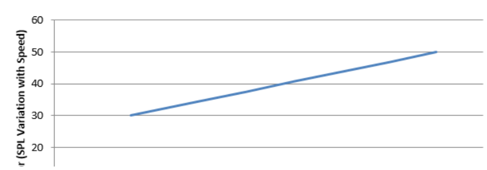
The relationship between the K factor and train speed is provided by the following equation:

K = a*V + b where a= 0.0625 and b= 25.00

V_0 for this train set is: 400 km/hr

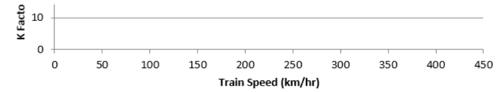
The following tables contain the calculated variation with train speed for the various noise parameters described above:

Ricardo calculated the K factor values for 12 pass-by noise data sets.



Train Speed (km/hr)	K	Microphone Positions 1				Noise Metric: Table Entries are dB(A)					
		$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
80	30.0000	84.9	87.7	85.5	87.7	82.3	85.9	93.0	59.7	77.8	86.0

	150	34.3750	91.3	94.0	91.8	94.0	88.6	92.2	99.4	66.0	84.2	92.3
	200	37.5000	94.6	97.3	95.2	97.3	92.0	95.5	102.7	69.4	87.5	95.7
	250	40.6250	97.6	100.3	98.2	100.3	95.0	98.5	105.7	72.4	90.5	98.7
	300	43.7500	100.4	103.2	101.0	103.2	97.8	101.4	108.6	75.2	93.3	101.5
	350	46.8750	103.2	105.9	103.8	105.9	100.6	104.1	111.3	78.0	96.1	104.3
Test Speed→	400	50.0000	105.9	108.6	106.5	108.6	103.3	106.8	114.0	80.7	98.8	107.0



				Microphone Position 2			Noise Metric: Table Entries are dB(A)					
	Train Speed (km/hr)	K	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
	80	30.0000	86.7	89.4	87.2	89.4	84.0	87.6	94.9	61.0	79.4	87.8
	150	34.3750	93.0	95.8	93.6	95.8	90.3	93.9	101.2	67.4	85.8	94.1
	200	37.5000	96.3	99.1	96.9	99.1	93.7	97.3	104.6	70.7	89.1	97.4
	250	40.6250	99.3	102.1	99.9	102.1	96.7	100.3	107.6	73.7	92.1	100.4
	300	43.7500	102.2	104.9	102.7	104.9	99.5	103.1	110.4	76.5	94.9	103.3
	350	46.8750	104.9	107.7	105.5	107.7	102.2	105.9	113.2	79.3	97.7	106.0
Test Speed→	400	50.0000	107.6	110.4	108.2	110.4	104.9	108.6	115.9	82.0	100.4	108.7

The empirical factor, K, varies with train speed: it is on the order of 30 in speed

range to 300 kph and up to 50 for very high speed trains, for which aerodynamic noise sources are dominant.

K = 0.0625(Train Speed, km/hr) + 25

Measurement Uncertainty is ±3 dB

				Microphone Position 3			Noise Metric: Table Entries are dB(A)					
	Train Speed (km/hr)	K	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
	80	30.0000	77.9	80.6	78.4	80.6	75.2	78.8	89.7	52.2	70.6	78.9
	150	34.3750	84.2	87.0	84.8	87.0	81.5	85.1	96.0	58.6	77.0	85.3
	200	37.5000	87.5	90.3	88.1	90.3	84.9	88.5	99.4	61.9	80.3	88.6
	250	40.6250	90.5	93.3	91.1	93.3	87.9	91.5	102.3	64.9	83.3	91.6
	300	43.7500	93.4	96.1	93.9	96.1	90.7	94.3	105.2	67.7	86.1	94.5
	350	46.8750	96.1	98.9	96.7	98.9	93.4	97.0	107.9	70.5	88.9	97.2
Test Speed→	400	50.0000	98.8	101.6	99.4	101.6	96.1	99.8	110.6	73.2	91.6	99.9

				Microphone Position 4			Noise Metric: Table Entries are dB(A)					
	Train Speed (km/hr)	K	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
	80	30.0000	77.1	79.8	77.6	79.8	74.4	78.0	88.9	51.4	69.8	78.2
	150	34.3750	83.4	86.2	84.0	86.2	80.7	84.3	95.2	57.8	76.2	84.5
	200	37.5000	86.7	89.5	87.3	89.5	84.1	87.7	98.6	61.1	79.5	87.8
	250	40.6250	89.7	92.5	90.3	92.5	87.1	90.7	101.6	64.1	82.5	90.8
	300	43.7500	92.6	95.3	93.1	95.3	89.9	93.5	104.4	66.9	85.3	93.7
	350	46.8750	95.3	98.1	95.9	98.1	92.6	96.3	107.1	69.7	88.1	96.4
Test Speed→	400	50.0000	98.0	100.8	98.6	100.8	95.4	99.0	109.8	72.4	90.8	99.1

The European Technical Standards for Interoperability (TSI) include two normalized values for $L_{pAEq,Tp}$. The values are normalized to 80 km/hr and 250 km/hr.[6]
The measurements are made at a lateral distance of 7.5 m from the rail centerline and 1.2 m above the top of the rail.
Procedures defined within the TSI to allow noise levels to be calculated at various train speeds based on measurements made at 80 km/hr (50 miles/h) and 250 km/hr (155 miles/h).
<u>For the HEMU, no measurements were made at 80 km/hr and 250 km/hr</u>: Thus, the Gautier method was used to calculate these values

From the Microphone Position 1 & 2 Table Above, the normalized values for $L_{pAeq,Tp}$ can be found and are idenfied below:

Values Obtained from Data Analysis			Value from TSI Formula		TSI Formulas
$L_{pAeq,Tp\ (80\ km/hr)}$ =	**84.9**	**dB(A)**	84.9	dB(A)	$L_{pAeq,Tp}$(80 km/h) = $L_{pAeq,Tp}$(vtest) - 30 * log (vtest/80 km/h)
$L_{pAeq,Tp\ (250\ km/hr)}$ =	**97.6**	**dB(A)**	95.7	dB(A)	$L_{pAeq,Tp}$(250 km/h) = $L_{pAeq,Tp}$(vtest) - 50 * log (vtest/250 km/h)

Measurement Uncertainty is ±3 dB

U.S. Department of Transportation
Federal Railroad Administra

Federal Railroad Administration
High Speed Rail Noise Standards and Regulations

Data Set Number: 2
Data Set Name: Thalys PBKA

Thalys PBKA2

Data Point Number	Passby Data[1Passby Data1]		Sound Pressure (Pa)	Event
	Time (sec)	dB(A)		
1	0.00	75.3	0.11642	
2	0.05	76.0	0.12619	
3	0.10	76.0	0.12619	
4	0.15	77.2	0.14489	
5	0.20	77.6	0.15172	
6	0.25	79.3	0.18451	
7	0.30	80.5	0.21185	
8	0.35	81.7	0.24324	
9	0.40	82.5	0.26670	
10	0.45	85.0	0.35566	
11	0.50	86.2	0.40835	←
12	0.55	88.0	0.50238	10 dB(A) lower than SPL when Train Nose Passes Microphone
13	0.60	89.9	0.62522	
14	0.65	91.9	0.78710	←
15	0.70	94.4	1.04961	
16	0.75	96.5	1.33669	Train Nose Passes Microphone
17	0.80	98.0	1.58866	
18	0.85	100.4	2.09426	
19	0.90	100.3	2.07028	
20	0.95	99.1	1.80314	
21	1.00	100.0	2.00000	
22	1.05	99.1	1.80314	

23	1.10	98.8	1.74193	
24	1.15	97.7	1.53472	
25	1.20	96.9	1.39968	
26	1.25	98.7	1.72199	
27	1.30	100.8	2.19296	
28	1.35	100.0	2.00000	
29	1.40	98.0	1.58866	←
30	1.45	97.4	1.48262	
31	1.50	97.9	1.57047	Start Time for LpASmax Calculat
32	1.55	98.3	1.64449	
33	1.60	98.2	1.62566	
34	1.65	96.3	1.30626	
35	1.70	97.1	1.43229	
36	1.75	98.0	1.58866	
37	1.80	99.0	1.78250	
38	1.85	97.5	1.49979	
39	1.90	99.1	1.80314	←
40	1.95	101.3	2.32290	
41	2.00	101.9	2.48903	Maximum Sound Pressure Leve
42	2.05	101.0	2.24404	
43	2.10	99.0	1.78250	
44	2.15	100.0	2.00000	
45	2.20	101.6	2.40453	
46	2.25	102.0	2.51785	
47	2.30	100.5	2.11851	
48	2.35	98.6	1.70228	
49	2.40	100.0	2.00000	←
50	2.45	100.0	2.00000	
51	2.50	99.6	1.90999	End Time for LpASmax Calculati
52	2.55	98.0	1.58866	
53	2.60	97.3	1.46565	
54	2.65	100.0	2.00000	
55	2.70	99.8	1.95447	
56	2.75	98.0	1.58866	
57	2.80	97.3	1.46565	
58	2.85	98.4	1.66353	
59	2.90	100.1	2.02316	
60	2.95	101.6	2.40453	
61	3.00	100.5	2.11851	←
62	3.05	99.0	1.78250	
63	3.10	98.0	1.58866	
64	3.15	96.9	1.39968	Train Tail Passes Microphone
65	3.20	97.0	1.41589	
66	3.25	95.0	1.12468	←
67	3.30	92.1	0.80543	
68	3.35	90.8	0.69347	10 dB(A) lower than SPL when

69	3.40	89.4	0.59024
70	3.45	88.0	0.50238
71	3.50	87.0	0.44774
72	3.55	85.9	0.39448
73	3.60	85.0	0.35566
74	3.65	82.5	0.26670
75	3.70	81.7	0.24324
76	3.75	80.5	0.21185
77	3.80	79.2	0.18240
78	3.85	79.1	0.18031
79	3.90	76.9	0.13997
80	3.95	75.9	0.12475
81	4.00	75.3	0.11642
82	4.05	74.3	0.10376
83	4.10	73.1	0.09037
84	4.15	74.2	0.10257
85	4.20	72.0	0.07962

10 dB(A) lower than SPL when Train Tail Passes Microphone

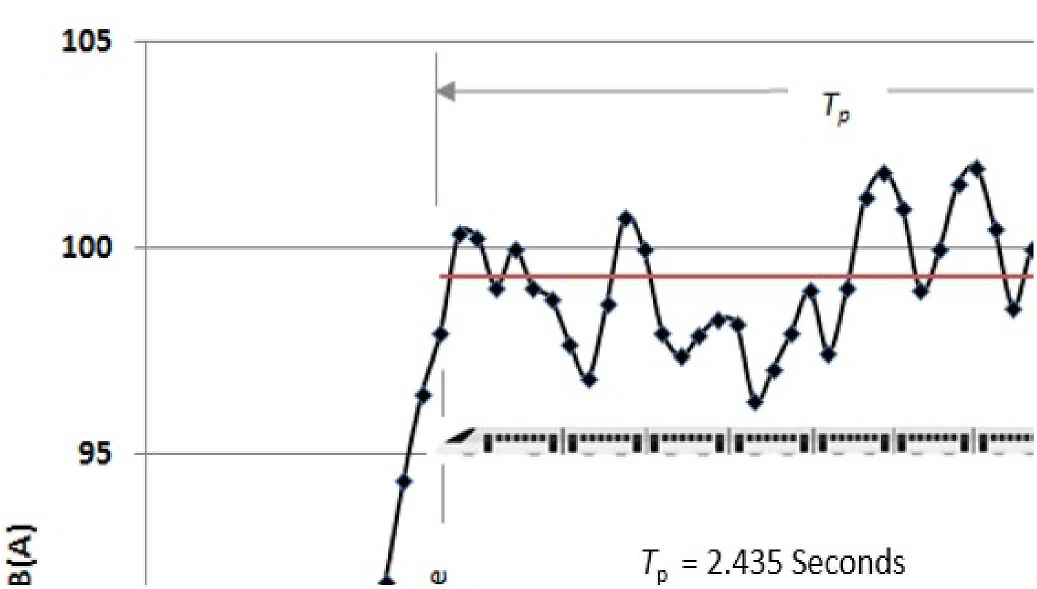
Spreadsheet-Based Tool for Comparing Noise Standards and Re
Conversion Tool for Noise Regulations and Standards to Commo

ation

CONTRAST Comparison Of Noise for TRAin STandards

Train Set Information			
Year Data Set was Generated:		2010	[1]Dittrich, M.G., et
Train Set Manufacturer:		GEC-Alsthom	Thalys treinen op
Operator:		Thalys	trains on HSL Rhe
Train Set Geometry and Test Conditions			Natuurwetenschap
Parameter	**Value**	**Units**	[2]Thalys PBKA image
Car Lengths			Version 1.2 or any l
End Cars:	22.15	m	https://commons.v
Intermediate Cars: two at 21.845 m and six at 18.7 m			
Number of End Cars:	2		
Number of Intermediate Cars:	8		
Test Train Length:	200.19	m	
Test Train Speed(s):	296	km/hr	
Microphone Position:	1		dB (sound press
Distance from Track Centerline:	7.5	m	where 0.0002 is
Elevation above Top of Rail:	1.2	m	so, Pa = 0.0000
Time Increment for Passby Data, ΔT:Time	0.05	sec	
Number of Passby Data Points:	85		

Plot of Passby Noise Data, Including Key Time Parameters



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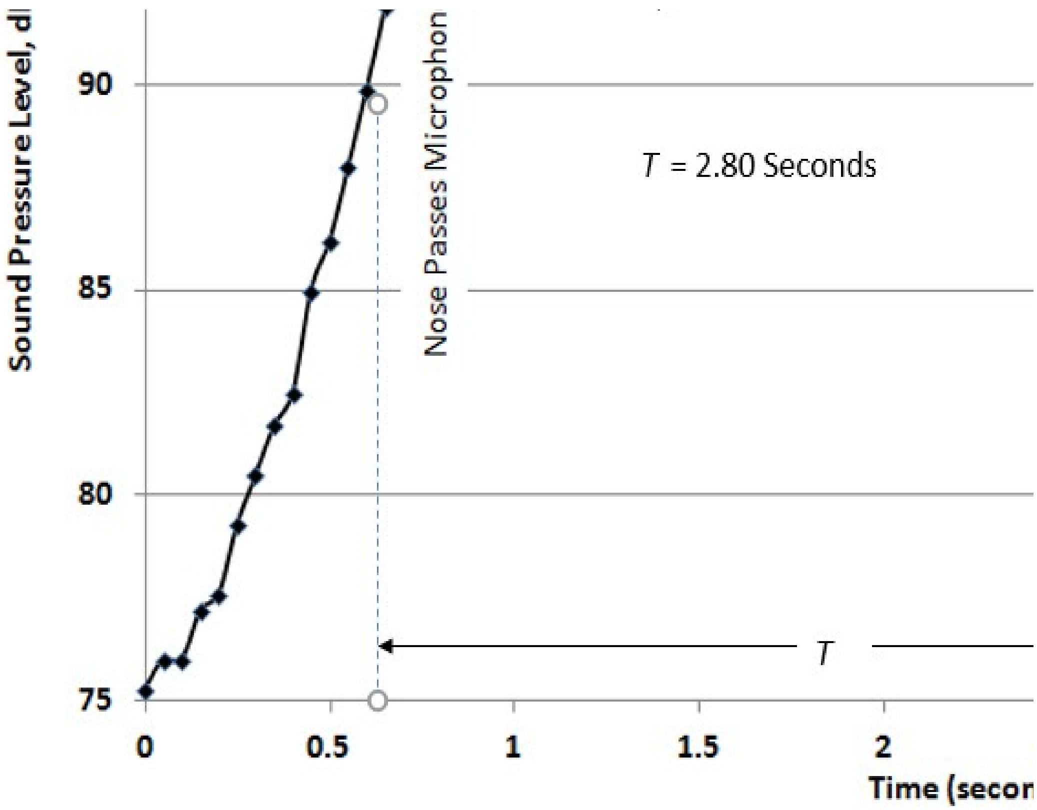
Sound Pressure Level, dl
90
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80
75
Nose Passes Microphon
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on Reference

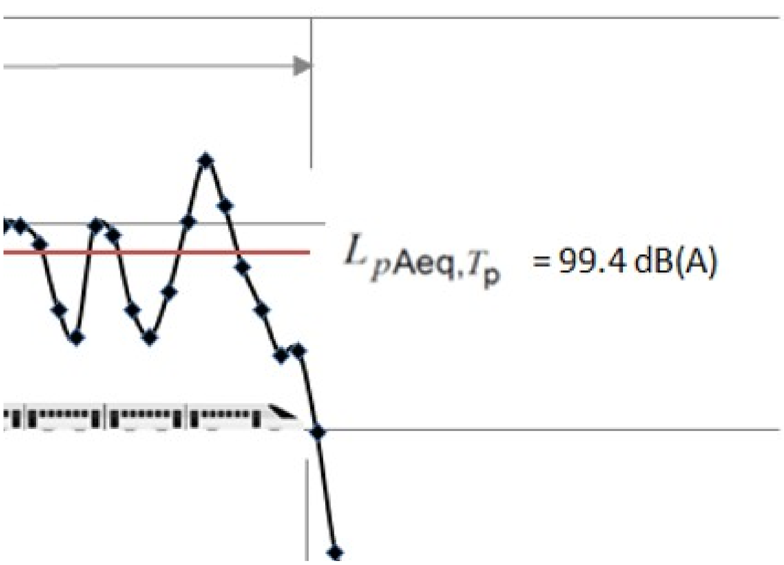
Program Version: 7 14-Oct-19

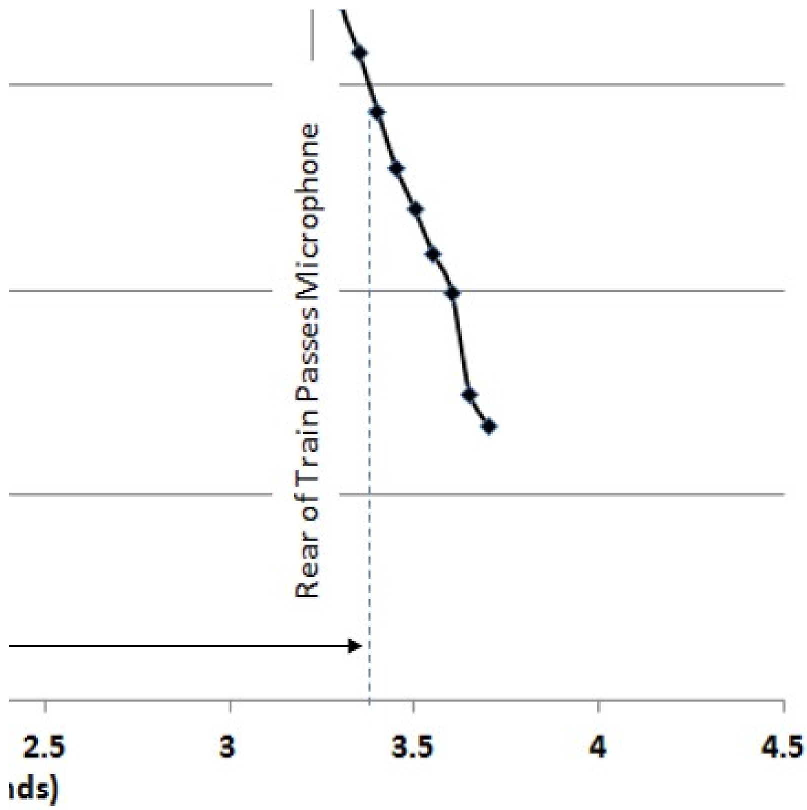
References

:. al., TNO Report MON-RPT-2010-03023, Geluidemissiemetingen aan V250 en[1]Dittrich, M.G., et. al., TNO Report MC
HSL Rheda- en ballastpoor, (Noise emission measurements on V250 and Thalys
eda and ballast track), Nederlandse Organisatie voor Toegepast
pelijk Onderzoek (TNO Industrie en Techniek), 13 December 2010.
used with permission: under the terms of the GNU Free Documentation License, [2]Thalys PBKA image used with permission: unde
ater version published by the Free Software Foundation,
vikimedia.org/wiki/File:Thalys_PBKA_Refurbished_Nederland.jpg

Formulas

sure level in decibels) = 20 $\log_{10}$(Pa/0.00002) dB (sound pressure level in decibels) = 20 $\log_{10}$(Pa/0.00002) d
the reference sound pressure level in Pascals
2*$10^{(dB/20)}$so, Pa = 0.00002*10(dB/20)so, Pa = 0.00002*10(dB/20)so, Pa = 0.00002*10(dB/20)so, Pa = 0.00002*10(dB/20)so, Pa = 0.00002*10(dB/20)




Rear of Train Passes Microphone
2.5
3
3.5
4
4.5
nds)

)N-RPT-2010-03023, Geluidemissiemetingen aan V250 en[1]Dittrich, M.G., et. al., TNO Report MON-RPT-2010-0302

:r the terms of the GNU Free Documentation License, [2]Thalys PBKA image used with permission: under the terms of the GNU F

lB (sound pressure level in decibels) = 20 $\log_{10}$(Pa/0.00002) dB (sound pressure level in decibels) = 20 lo

23, Geluidemissiemetingen aan V250 en [1]Dittrich, M.G., et. al., TNO Report MON-RPT-2010-03023, Geluidemissien

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g$_{10}$(Pa/0.00002) dB (sound pressure level in decibels) = 20 log$_{10}$(Pa/0.00002) dB (sound pressure level in

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decibels) = 20 $\log_{10}$(Pa/0.00002) dB (sound pressure level in decibels) = 20 $\log_{10}$(Pa/0.00002)

0 en[1]Dittrich, M.G., et. al., TNO Report MON-RPT-2010-03023, Geluidemissiemetingen aan V250 en[1]Dittrich, M.G

sed with permission: under the terms of the GNU Free Documentation License, [2]Thalys PBKA image used with permission: unde

i., et. al., TNO Report MON-RPT-2010-03023, Geluidemissiemetingen aan V2

U.S. Department of Transportation
Federal Railroad Administration

Spreadsheet-Based Tool for Comparing Noise Standards and Regulations
Conversion Tool for Noise Regulations and Standards to Common Reference

RICARDO

Federal Railroad Administration
High Speed Rail Noise Standards and Regulations

CONTRAST Comparison Of Noise for TRAin STandards

Program Version: 7 14-Oct-19

Data Set Number: 2
Data Set Name: Thalys PBKA

Pass-By Noise Calculations

Calculate Train Pass-by Parameters

Train Speed (V):	296	km/hr =	82.22	m/sec
Train Length:	200.19	m	10 cars: 2 end cars and 8 intermediate cars	
Time for Pass-By (T_p)	2.434743243	seconds	This is the time increment between nose of train passing microphone and tail of train passing microphone.	
Time for TEL (T_{TEL})	2.80	seconds	TEL is the Transit Exposure Limit and represents the equivalent A-weighted SPL over the time period beginning when the instantaneous meter reading is 10 dB(A) less than $L_{pAEq,Tp}$ and continuing through the pass-by event until the meter reading is again 10 dB(A) less than $L_{pAeq,Tp}$	

References

[1]He, et al., Investigation into External Noise of a High-Speed Train at Different Speeds, J Zhejiang Univ-Sci A (Appl Phys & Eng) 2014, 15(12):1019-1033
[2]Paul, et al, High Speed Rail Noise Standards and Regulations, US DOT Federal Railroad Administration, Contract DTFR35-16-C00006, May 2017.
[3]G. Xiaoan and J. Hua, "Application Research on Descending Vibration and Reducing Noise in Accelerating Speed Trains and Express Trains," Chinese Academy of Railway Sciences (CARS) Research Report, Beijing Shi, China, 2003.
[4]Hanson, C.E., et. al., High Speed Ground Transportation Noise and Vibration Impact Assessment, U.S. Department of Transportation, Federal Railroad Administration, Report Number DOT/FRA/ORD-12/15, September 2012.
[5]Gautier, P.E., Poisson, F., and Letourneaux, F., High Speed Trains External Noise: A Review of Measurements and Source Models for TGV Case Up to 360 km/hr, in Proceedings of the 8th World Congress on Railway Research (2008).
[6]European Union, "Commission Regulation Number 1304/2014, on the technical specification for interoperability relating to the subsystem 'rolling stock — noise' amending Decision 2008/232/EC and repealing Decision 2011/229/EU," Official Journal of the European Union, Brussels, Belgium, 2014.

Calculate $L_{pAeq,Tp}$

$L_{pAeq,Tp}$ is the A-weighted equivalent continuous sound pressure level produced by the train as measured during the pass-by event

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

$L_{pAeq,Tp}$ can be calculated from the pass-by data using the following relationship:

$$\int_{T_1}^{T_2}\frac{p_A^2(t)}{p_0^2}\mathrm{d}t \approx \sum_{i=1}^{i=n}\left(\frac{\mathrm{Pa}(i)^2}{p_0^2}\right)\Delta t_i$$

Microphone Position is 7.5 m from track centerline and 1.5 m above top of rail (Microphone Position 1).

where

T_p	is the pass-by time interval = time when trail tail passes microphone minus time when train nose passes microphone = $T_2 - T_1$			
T_1	is the time when the train nose passes the microphone			
T_2	is the time when the train tail passes the microphone			
$P_A(t)$	is the A-weighted instantaneous sound pressure in Pa at time t			
p_0	is the reference sound pressure:	p_0 = 20μPa =	0.00002	Pa
Δt_i	is the time increment between measured data points =		0.05	seconds
$P_A(i)$	is the A-weighted instantaneous sound pressure in Pa at pass-by time increment i			

An analysis conducted during the current study indicated the integral can be determined numerically, with acceptable accuracy, by employing a midpoint Reimann sum scheme with a mimimum Δti = 0.05 seconds, and the corresponding Pa(i) analog meter values. This approach is described in: Hughes-Hallett, Deborah; McCullum, William G.; et al. (2005). *Calculus (4th ed.)*, Wiley. p. 252.

Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$	Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$	Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$	Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$
1	0.00	75.30	0.116421	3.38844E+07	23	1.10	98.80	1.741927	7.58578E+09	45	2.20	101.60	2.404529	1.44544E+10	67	3.30	92.10	0.805434	1.62181E+09
2	0.05	76.00	0.126191	3.98107E+07	24	1.15	97.70	1.534723	5.88844E+09	46	2.25	102.00	2.517851	1.58489E+10	68	3.35	90.80	0.693474	1.20226E+09
3	0.10	76.00	0.126191	3.98107E+07	25	1.20	96.90	1.399684	4.89779E+09	47	2.30	100.50	2.118507	1.12202E+10	69	3.40	89.40	0.590242	8.70964E+08
4	0.15	77.20	0.144887	5.24807E+07	26	1.25	98.70	1.721988	7.41310E+09	48	2.35	98.60	1.702276	7.24436E+09	70	3.45	88.00	0.502377	6.30957E+08
5	0.20	77.60	0.151716	5.75440E+07	27	1.30	100.80	2.192956	1.20226E+10	49	2.40	100.00	2.000000	1.00000E+10	71	3.50	87.00	0.447744	5.01187E+08
6	0.25	79.30	0.184514	8.51138E+07	28	1.35	100.00	2.000000	1.00000E+10	50	2.45	100.00	2.000000	1.00000E+10	72	3.55	85.90	0.394485	3.89045E+08
7	0.30	80.50	0.211851	1.12202E+08	29	1.40	98.00	1.588656	6.30957E+09	51	2.50	99.60	1.909985	9.12011E+09	73	3.60	85.00	0.355656	3.16228E+08
8	0.35	81.70	0.243237	1.47911E+08	30	1.45	97.40	1.482620	5.49541E+09	52	2.55	98.00	1.588656	6.30957E+09	74	3.65	82.50	0.266704	1.77828E+08
9	0.40	82.50	0.266704	1.77828E+08	31	1.50	97.90	1.570471	6.16595E+09	53	2.60	97.30	1.465649	5.37032E+09	75	3.70	81.70	0.243237	1.47911E+08
10	0.45	85.00	0.355656	3.16228E+08	32	1.55	98.30	1.644485	6.76083E+09	54	2.65	100.00	2.000000	1.00000E+10	76	3.75	80.50	0.211851	1.12202E+08
11	0.50	86.20	0.408348	4.16869E+08	33	1.60	98.20	1.625661	6.60693E+09	55	2.70	99.80	1.954474	9.54993E+09	77	3.80	79.20	0.182402	8.31764E+07
12	0.55	88.00	0.502377	6.30957E+08	34	1.65	96.30	1.306261	4.26580E+09	56	2.75	98.00	1.588656	6.30957E+09	78	3.85	79.10	0.180314	8.12831E+07
13	0.60	89.90	0.625216	9.77237E+08	35	1.70	97.10	1.432287	5.12861E+09	57	2.80	97.30	1.465649	5.37032E+09	79	3.90	76.90	0.139968	4.89779E+07
14	0.65	91.90	0.787100	1.54882E+09	36	1.75	98.00	1.588656	6.30957E+09	58	2.85	98.40	1.663528	6.91831E+09	80	3.95	75.90	0.124747	3.89045E+07
15	0.70	94.40	1.049615	2.75423E+09	37	1.80	99.00	1.782502	7.94328E+09	59	2.90	100.10	2.023159	1.02329E+10	81	4.00	75.30	0.116421	3.38844E+07
16	0.75	96.50	1.336688	4.46684E+09	38	1.85	97.50	1.499788	5.62341E+09	60	2.95	101.60	2.404529	1.44544E+10	82	4.05	74.30	0.103760	2.69153E+07
17	0.80	98.00	1.588656	6.30957E+09	39	1.90	99.10	1.803142	8.12831E+09	61	3.00	100.50	2.118507	1.12202E+10	83	4.10	73.10	0.090371	2.04174E+07
18	0.85	100.40	2.094257	1.09648E+10	40	1.95	101.30	2.322897	1.34896E+10	62	3.05	99.00	1.782502	7.94328E+09	84	4.15	74.20	0.102572	2.63027E+07
19	0.90	100.30	2.070284	1.07152E+10	41	2.00	101.90	2.489029	1.54882E+10	63	3.10	98.00	1.588656	6.30957E+09	85	4.20	72.00	0.079621	1.58489E+07
20	0.95	99.10	1.803142	8.12831E+09	42	2.05	101.00	2.244037	1.25893E+10	64	3.15	96.90	1.399684	4.89779E+09					
21	1.00	100.00	2.000000	1.00000E+10	43	2.10	99.00	1.782502	7.94328E+09	65	3.20	97.00	1.415892	5.01187E+09					
22	1.05	99.10	1.803142	8.12831E+09	44	2.15	100.00	2.000000	1.00000E+10	66	3.25	95.00	1.124683	3.16228E+09					

Data Point Number for Start of Pass-by Event (time at which train nose passes microphone): 16 i = 1
Data Point Number for End of Pass-by Event (time at which train tail passes microphone): 64 i - n

thus, $\sum_{i=1}^{i=n}\left(\frac{\mathrm{Pa}(i)^2}{p_0^2}\right)\Delta t_i$ = 2.08771E+10

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

$L_{pAeq,Tp}$ = 99.33 dB(A)

Impact of Microphone Position

References:

Microphone Position	Distance from Track Centerline (m)	Elevation Above Top of Rail (m)	Applies to Regulations in these Regions[2]				Comment
			US	EU	China	Japan	
1	7.5	1.2		X (TSI 2014)			TSI 1304
2	7.5	3.5		X (TSI 2014)			Also required for speeds > 250 km/hr
3	25	3.5		X (TSI 2008)		X	Reference for pre 2014 train sets
4	30	1.2	X		X		US and China measurement location

Impact of microphone distance is determined from the following equation:[3] $L_d = L_{d0}$ - 10*LOG(d/d0), where L_{d0} is the equivalent A-weighted constant sound pressure level for the microphone at distance d0, and d is the distance for Ld.

Microphone Position	Distance from Track Centerline (m)	Elevation Above Top of Rail (m)	$L_{pAeq,Tp}$ at 296 km/h dB(A)	$L_{pAeq,Tp}$ at 296 km/h (Pa)
1	7.5	1.2	99.33	1.852
2	7.5	3.5	102.10	2.548
3	25	3.5	87.40	0.469
4	30	1.2	86.60	0.428

[A] L. Lu, X. Hu, Y. Zhang and X. Zhou, "Survey and Analysis of the Beijing-Shanghai High Speed Rail Noise," in The 21st International Congress on Sound and Vibration, Beijing, China, 2014.

[B] G. Xiaoan and J. Hua, "Application Research on Descending Vibration and Reducing Noise in Accelerating Speed Trains and Express Trains," Chinese Academy of Railway Sciences (CARS) Research Report, Beijing Shi, China, 2003.

[C] W. Elliott, "Request for Information Reference FOI13-580, Comparison of Measured Sound Levels for High Speed Trains as a Functionof Distance from Track," High Speed Rail Two (HS2), London, England, 2013.

To convert dB(A) to Pascals: Pa = 0.00002*(10^(dBA/20))

To convert Pa to dB(A), dB(A) = 20*LOG10(Pa/0.00002)

Note: The simple sound level correction formula underestimates the measured values. Therefore, ratios based on actual measurements were used to adjust for microphone location (table at right).

Sound Pressure Variations for Microphone Positions & Train Speed from Reference 5

Speed (km/hr)	$L_{pAeq,Tp}$ dB(A)		
	M1	M2	M3
271	93.2	95.8	82.0
341	96.5	98.0	85.5
386	98.5	100.1	88.1

Calculated Noise Metrics: Maximum Recorded Sound Pressure Levels

The following calculations are for Microphone Position 1

$L_{p(maximum)}$ = maximum recorded pass-by sound pressure level

$L_{p(maximum)}$ = **102.0** dB(A) which occurs at data point 46 at pass-by time 2.25 seconds

L_{pASmax} is the maximum sound pressure level, slow and A-weighted and L_{pAFmax} = maximum sound pressure level, fast and A-weighted. The time period for the "slow" reading is 1 second. The time period for the "fast" reading is 0.125 seconds.

L_{pASmax} can be calculated as the logarithmic average of the recorded SPLs for the 1 second time interval containing the highest values

The logarithmic average for an Excel array is: {=10*LOG(AVERAGE(10^(ARRAY/10)))} array-entered, i.e. using CTRL-Shift-Enter keys where array is of the form A10:A15. In the current case, the array is Pass-By Data Set 1, C:48:C68

Highest 1-second interval occurs from start time 1.5 to end time 2.5 **Thus, L_{pASmax} = 97.90 dB(A)**

Similarly, L_{pAFmax} can be calculated as the logarithmic average of the recorded SPLs for the 0.125 second time interval containing the highest values

Highest 0.125-second interval occures from start time 2.15 to end time 2.275 **Thus, L_{pAFmax} = 100.00 dB(A)**

Calculated Noise Metrics: Other Standard Parameters

The following calculations are for Microphone Position 1

$L_{pAeq,pass-by}$ is the A-weighted equivalent continuous sound pressure level produced during the entire pass-by event, including approach, T_p, and departure (used for L_d, L_n, etc.)

The calculation includes all of the pass-by data points.

Data Point Number for Start of Pass-by Event (time pass-by SPLs begin being recorded): 1 i = 1

Data Point Number for End of Pass-by Event (time pass-by SPLs end being recorded): 85 i - n thus, $\sum_{i=1}^{i=n}\left(\frac{Pa(i)^2}{p_0^2}\right)\Delta t_i$ = 2.19727E+10 $T_2 - T_1$ = 4.20 seconds

$$L_{pAeq,pass-by} = 10 \lg \left(\frac{1}{T_2 - T_1} \int_{T_1}^{T_2} \frac{p_A^2(t)}{p_0^2} dt \right)$$

$L_{pAeq,pass-by}$ = 97.19 dB(A)

TEL is the Transit Exposure Limit[4]. It is measured over the time interval starting when the SPL is 10 dB(A) lower than $L_{pAeq,Tp}$ and ending when the SPL again reaches a value that is 10 dB(A) lower than $L_{pAeq,Tp}$

TEL is calculated using the following formula: TEL = $L_{pAeq,Tp}$ + 10*LOG(T_{TEL}/T_p) **TEL = 99.9392281 dB(A)**

SEL is the Sound Exposure Limit[4]. Like $L_{pAeq,Tp}$, it integrates the total sound energy over a measurement period, but for SEL, the measurement period is normalized to a duration of 1 second. At a microphone distance of 30 m (100 ft), SEL = $L_{pAeq,Tp}$ + 10*LOG(Tp) + 1

SEL at 30 m: 104.20 dB(A) **SEL at 7.5 m: 110.22 dB(A)** **SEL at 25 m: 104.99 dB(A)** using the distance correction factor: $L_d = L_{d0}$ - 10*LOG(d/d0)

SEL is the cumulative noise exposure (i.e. "dose") for a single noise event normalized over 1 second. The fact that SEL is a cumulative measure means that (1) louder events have higher SELs than quieter ones, and (2) events that last longer in time have higher SELs than shorter ones.[4]

Statistical Parameters

The following parameters are determined by specifying the indicated percentile of the data values using Excel Function PERCENTILE(range,P).

where" range" is the array of values (e.g. K10:K68) and P = the percentile (between 0 and 1, for example, P for the 90th percentile would be entered as 0.9)

L_{10} is the sound pressure level for which 90% of the recorded values are greater. It includes lead-in (prior to nose passing microphone) and trail-off (after tail of train passes) data. **L_{10} = 76.36 dB(A)**

L_{50} is the sound pressure level for which 50% of the recorded values are greater. It includes lead-in (prior to nose passing microphone) and trail-off (after tail of train passes) data. **L_{50} = 97.30 dB(A)**

L_{90} is the sound pressure level for which 10% of the recorded values are greater. It includes lead-in (prior to nose passing microphone) and trail-off (after tail of train passes) data. **L_{90} = 100.46 dB(A)**

Summary of Pass-by Noise Metrics for Each Microphone Position

The noise metrics shown in the following table correspond to the baseline speed of 296 km/hr $L_d = L_{d0}$ - 10*LOG(d/d0), where L_{d0} is the equivalent A-weighted constant sound pressure level for the microphone at distance d0, and d is the distance for L_d.

Microphone Position			Noise Metric: Table Entries are dB(A)							
	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,pass-by}$	TEL	SEL	L_{10}	L_{50}	L_{90}
1	99.3	102.0	97.9	100.0	97.2	99.9	110.2	76.4	97.3	100.5
2	102.1	104.8	100.6	102.8	99.9	102.7	113.3	78.5	100.0	103.3
3	87.4	89.7	86.1	88.0	85.5	87.9	97.0	67.2	85.6	88.4
4	86.6	89.0	85.3	87.2	84.7	87.1	96.2	66.4	84.8	87.6

Microphone Position Adjustment Factors[5]

Speed (km/hr)	M1	M2	M3
271	1.000	1.028	0.880
341	1.035	1.052	0.917
386	1.057	1.074	0.945

Impact of Train Speed on Noise Levels

Ricardo evaluated several methods for determining the impact of train speed on passby noise levels. The approach developed by Gautier, Poisson & Letourneaux[5] provided the highest level of correlation with measured data is the basis for the calculations presented below.

$L_{Aeq,tp}(V) - L_{Aeq,tp}(V_0) = K \log(V/V_0)$ where K is an empirical factor where V= train speed (km/hr) If the SPL is known at train speed V_0, the SPL at train speed V can be determined from this formula

thus, $L_{Aeq,tp}(V) = K \log(V/V_0) + L_{Aeq,tp}(V_0)$ V_0= reference train speed (km/hr)

The empirical factor K varies with train speed. This is because the contribution of noise sources (e.g. wheel/rail interaction, propulsion components, aerodynamics) vary with train speed.

Ricardo calculated the K factor values for 12 pass-by noise data sets.

The relationship between the K factor and train speed is provided by the following equation:

K = a*V + b where a= 0.0625 and b= 25.00

V_0 for this train set is: 296 km/hr

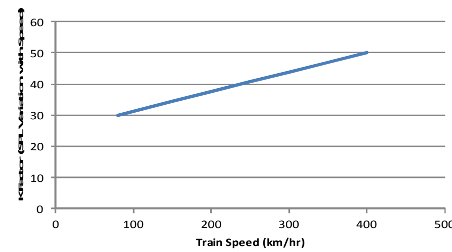
The following tables contain the calculated variation with train speed for the various noise parameters described above:

				Microphone Position 1			Noise Metric: Table Entries are dB(A)					
	Train Speed (km/hr)	K	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
	80	30.0000	82.3	85.0	80.9	83.0	80.1	82.9	93.2	59.3	80.3	83.4
	150	34.3750	89.2	91.9	87.8	89.9	87.0	89.8	100.1	66.2	87.2	90.3
	200	37.5000	92.9	95.6	91.5	93.6	90.8	93.6	103.8	70.0	90.9	94.1
	250	40.6250	96.4	99.0	94.9	97.0	94.2	97.0	107.2	73.4	94.3	97.5
	300	43.7500	99.6	102.3	98.2	100.3	97.4	100.2	110.5	76.6	97.6	100.7
	350	46.8750	102.7	105.4	101.3	103.4	100.6	103.4	113.6	79.8	100.7	103.9
Test Speed→	296	43.5000	99.3	102.0	97.9	100.0	97.2	99.9	110.2	76.4	97.3	100.5

				Microphone Position 2			Noise Metric: Table Entries are dB(A)					
	Train Speed (km/hr)	K	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
	80	30.0000	85.1	87.8	83.6	85.7	82.9	85.7	96.2	61.4	83.0	86.2
	150	34.3750	92.0	94.7	90.5	92.6	89.8	92.6	103.1	68.3	89.9	93.1
	200	37.5000	95.7	98.5	94.2	96.4	93.5	96.3	106.9	72.1	93.6	96.9
	250	40.6250	99.1	101.9	97.7	99.8	96.9	99.7	110.3	75.5	97.0	100.3
	300	43.7500	102.4	105.1	100.9	103.0	100.2	103.0	113.5	78.7	100.3	103.5
	350	46.8750	105.5	108.3	104.0	106.2	103.3	106.1	116.7	81.9	103.4	106.7
Test Speed→	296	43.5000	102.1	104.8	100.6	102.8	99.9	102.7	113.3	78.5	100.0	103.3

				Microphone Position 3			Noise Metric: Table Entries are dB(A)					
	Train Speed (km/hr)	K	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
	80	30.0000	70.3	72.7	69.1	70.9	68.5	70.9	79.9	50.1	68.6	71.3
	150	34.3750	77.2	79.6	76.0	77.8	75.4	77.8	86.8	57.0	75.5	78.2
	200	37.5000	81.0	83.4	79.8	81.6	79.1	81.5	90.6	60.8	79.2	82.0
	250	40.6250	84.4	86.8	83.2	85.0	82.5	84.9	94.0	64.2	82.6	85.4
	300	43.7500	87.7	90.0	86.4	88.2	85.8	88.2	97.2	67.4	85.9	88.6
	350	46.8750	90.8	93.2	89.5	91.4	88.9	91.3	100.4	70.6	89.0	91.8
Test Speed→	296	43.5000	87.4	89.7	86.1	88.0	85.5	87.9	97.0	67.2	85.6	88.4

				Microphone Position 4			Noise Metric: Table Entries are dB(A)					
	Train Speed (km/hr)	K	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
	80	30.0000	69.6	71.9	68.3	70.1	67.7	70.1	79.1	49.3	67.8	70.5
	150	34.3750	76.5	78.8	75.2	77.0	74.6	77.0	86.0	56.2	74.7	77.4
	200	37.5000	80.2	82.6	79.0	80.8	78.3	80.8	89.8	60.0	78.4	81.2
	250	40.6250	83.6	86.0	82.4	84.2	81.7	84.2	93.2	63.4	81.8	84.6
	300	43.7500	86.9	89.2	85.6	87.4	85.0	87.4	96.4	66.6	85.1	87.9
	350	46.8750	90.0	92.4	88.8	90.6	88.1	90.5	99.6	69.8	88.2	91.0
Test Speed→	296	43.5000	86.6	89.0	85.3	87.2	84.7	87.1	96.2	66.4	84.8	87.6



The empirical factor, K, varies with train speed: it is on the order of 30 in speed range to 300 kph and up to 50 for very high speed trains, for which aerodynamic noise sources are dominant.

K = 0.0625(Train Speed, km/hr) + 25

The European Technical Standards for Interoperability (TSI) include two normalized values for $L_{pAEq,Tp}$. The values are normalized to 80 km/hr and 250 km/hr.[6]

The measurements are made at a lateral distance of 7.5 m from the rail centerline and 1.2 m above the top of the rail.

Procedures defined within the TSI to allow noise levels to be calculated at various train speeds based on measurements made at 80 km/hr (50 miles/h) and 250 km/hr (155 miles/h).

<u>For the Thalys PBKA, no measurements were made at 80 km/hr and 250 km/hr</u>: Thus, the Gautier method was used to calculate these values

From the Microphone Position 1 Table Above, the normalized values for $L_{pAeq,Tp}$ can be found and are idenfied below:

Values Obtained from Data Analysis			Value from TSI Formula		TSI Formulas
$L_{pAeq,Tp\ (80\ km/hr)}$ =	**82.3**	**dB(A)**	82.3	dB(A)	$L_{pAeq,Tp}$(80 km/h) = $L_{pAeq,Tp}$(vtest) - 30 * log (vtest/80 km/h)
$L_{pAeq,Tp\ (250\ km/hr)}$ =	**96.4**	**dB(A)**	95.7	dB(A)	$L_{pAeq,Tp}$(250 km/h) = $L_{pAeq,Tp}$(vtest) - 50 * log (vtest/250 km/h)

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Federal Railroad Administration
High Speed Rail Noise Standards and Regulations

Data Set Number: 3
Data Set Name: CRH3 Series (based on Siemens)


China CRH3 Series Train2

Data Point Number	Passby Data[1] Passby Data1		Sound Pressure (Pa)	Event
	Time (sec)	dB(A)		
1	1.00	80.1	0.20232	
2	1.05	82.0	0.25179	
3	1.10	83.9	0.31335	←
4	1.15	85.0	0.35566	10 dB(A) lower than SPL
5	1.20	88.0	0.50238	when Train Nose Passes
6	1.25	90.5	0.66993	← Microphone
7	1.30	93.0	0.89337	
8	1.35	95.0	1.12468	Train Nose Passes Microphone
9	1.40	94.9	1.11181	
10	1.45	95.3	1.16421	
11	1.50	95.3	1.16421	
12	1.55	95.3	1.16421	
13	1.60	96.0	1.26191	
14	1.65	96.1	1.27653	
15	1.70	96.0	1.26191	
16	1.75	95.5	1.19132	
17	1.80	95.1	1.13771	
18	1.85	95.0	1.12468	←
19	1.90	96.2	1.29131	←
20	1.95	96.7	1.36782	Start Time for LpASmax Calculati
21	2.00	97.2	1.44887	Maximum Sound Pressure Leve
22	2.05	97.0	1.41589	

23	2.10	96.6	1.35217	
24	2.15	95.7	1.21907	
25	2.20	96.0	1.26191	
26	2.25	96.8	1.38366	
27	2.30	97.0	1.41589	
28	2.35	96.8	1.38366	
29	2.40	96.1	1.27653	
30	2.45	95.5	1.19132	
31	2.50	95.4	1.17769	
32	2.55	96.2	1.29131	
33	2.60	96.9	1.39968	
34	2.65	97.0	1.41589	
35	2.70	96.6	1.35217	
36	2.75	95.9	1.24747	
37	2.80	96.0	1.26191	
38	2.85	96.2	1.29131	←
39	2.90	96.1	1.27653	
40	2.95	96.4	1.32139	End Time for LpASmax Calculat
41	3.00	96.5	1.33669	
42	3.05	96.9	1.39968	
43	3.10	95.2	1.15088	
44	3.15	95.2	1.15088	
45	3.20	95.3	1.16421	
46	3.25	96.1	1.27653	
47	3.30	96.5	1.33669	
48	3.35	96.5	1.33669	
49	3.40	95.8	1.23319	
50	3.45	95.0	1.12468	
51	3.50	95.0	1.12468	
52	3.55	95.2	1.15088	
53	3.60	95.6	1.20512	
54	3.65	95.8	1.23319	
55	3.70	95.6	1.20512	
56	3.75	94.8	1.09908	
57	3.80	94.8	1.09908	
58	3.85	94.7	1.08650	←
59	3.90	95.9	1.24747	
60	3.95	95.5	1.19132	Train Tail Passes Microphone
61	4.00	94.6	1.07406	
62	4.05	93.2	0.91418	
63	4.10	91.5	0.75167	←
64	4.15	89.8	0.61806	
65	4.20	88.0	0.50238	
66	4.25	86.0	0.39905	10 dB(A) lower than SPL when
67	4.30	84.9	0.35158	Train Tail Passes Microphone
68	4.35	83.1	0.28578	

69	4.40	82.0	0.25179
70	4.45	80.5	0.21185
71	4.50	80.0	0.20000

Spreadsheet-Based Tool for Comparing Noise Standards and Re
Conversion Tool for Noise Regulations and Standards to Commo

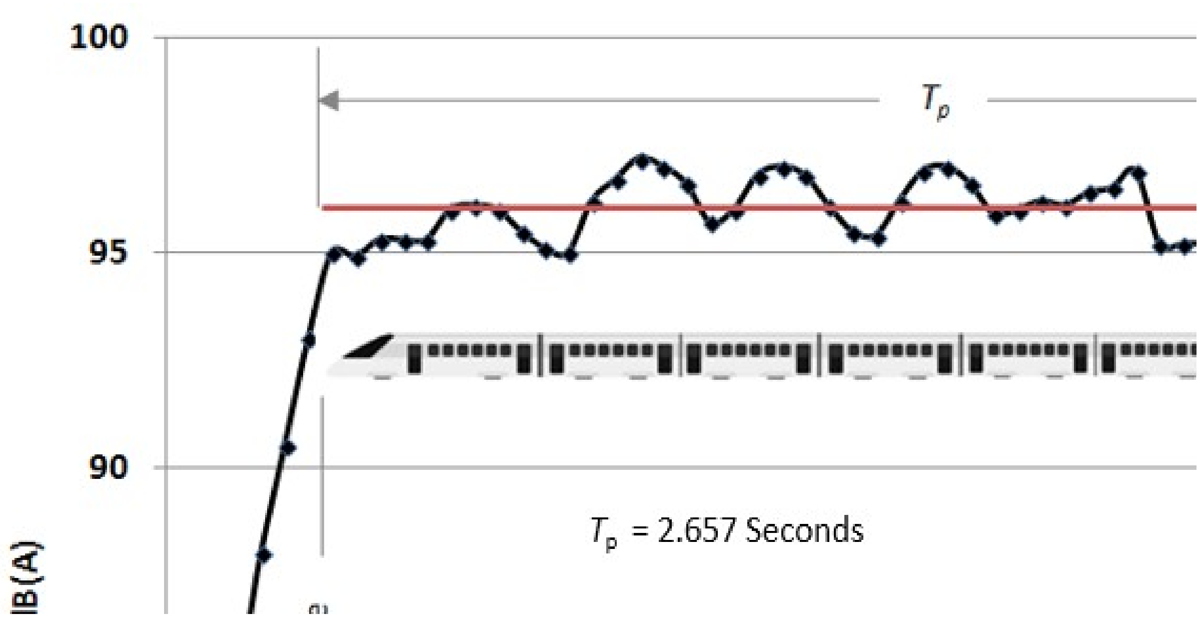
ation

CONTRAST Comparison Of Noise for TRAin STandards

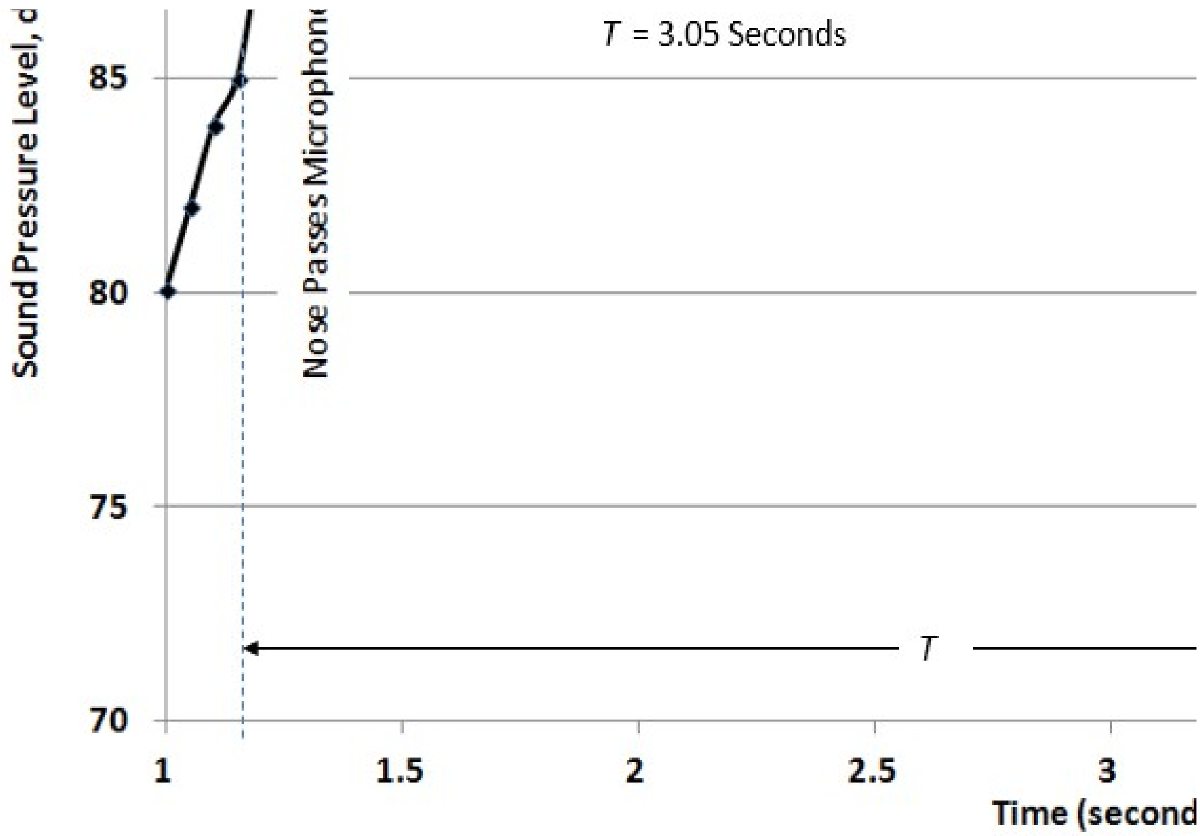
Train Set Information			
Year Data Set was Generated:	2014		[1]He, B., *et. al.*, Inv
Train Set Manufacturer:	Changchun Railway Vehicles, Siemens		J. Zhejang Univ-Sc
Operator:	China Railway Corporation		[2]China CRH3 Series
Train Set Geometry and Test Conditions			https://www.railw
Parameter	**Value**	**Units**	
Car Lengths			
End Cars:	25.641	m	
Intermediate Cars:	24.786	m	
Number of End Cars:	2		
Number of Intermediate Cars:	6		
Test Train Length:	200	m	
Test Train Speed(s):	271	km/hr	
Microphone Position:	2		dB (sound press
Distance from Track Centerline:	7.5	m	where 0.0002 is
Elevation above Top of Rail:	3.5	m	so, Pa = 0.0000
Time Increment for Passby Data, ΔT:Time Inc	0.05	sec	
Number of Passby Data Points:	71		

Plot of Passby Noise Data, Including Key Time Parameters

on
el



ion



Sound Pressure Level, d
85
80
75
70
Nose Passes Microphon
T = 3.05 Seconds
T
1
1.5
2
2.5
3
Time (second

gulations
ɔn Reference

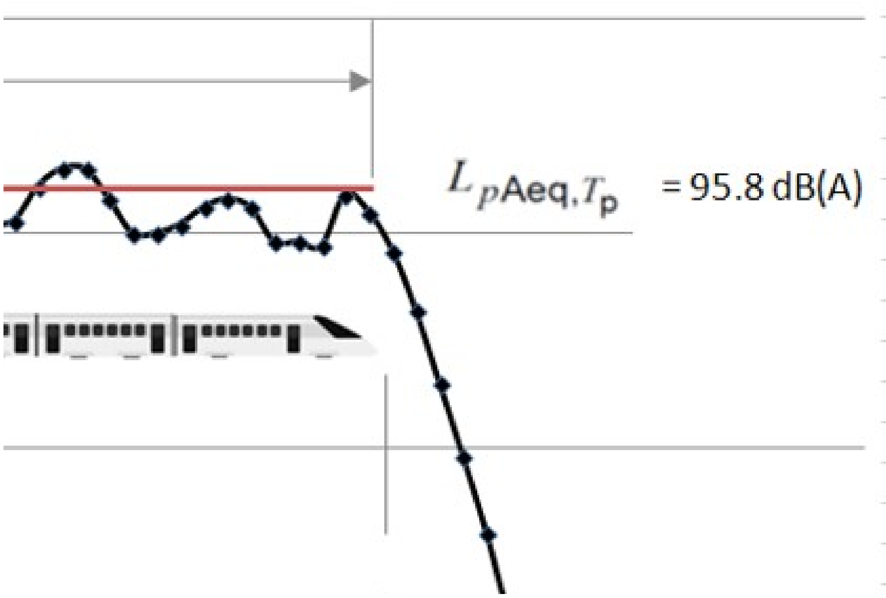
Program Version: 7 14-Oct-19

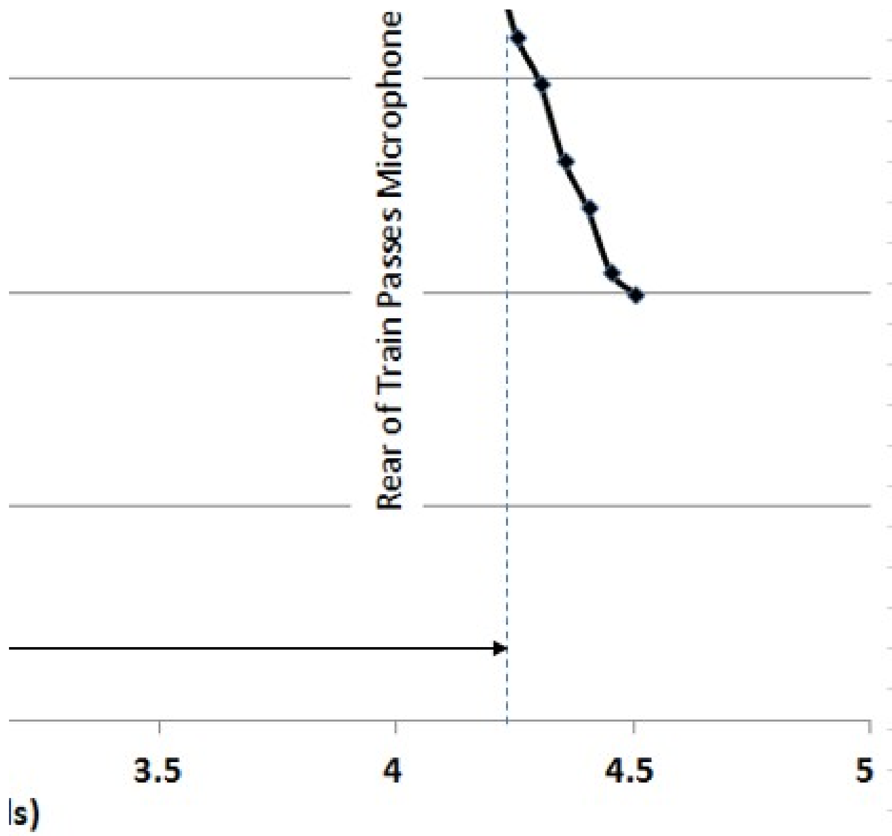
References

/estigation into Exterior Noise of a High-Speed Train at Different Speeds, [1]He, B., *et. al.*, Investigation into Exterior N
ci A (Applied Physics and Enginering), 2014, Vol 15 (12), Pages 1019-1033.
High Speed Train Image; provided by *Railway Technology*, 2019,[2]China CRH3 Series High Speed Train Image; provided by *Railway*
ay-technology.com/projects/beijing-tianjin/

Formulas

;ure level in decibels) = 20 $\log_{10}$(Pa/0.00002) dB (sound pressure level in decibels) = 20 $\log_{10}$(Pa/0.00002) d
; the reference sound pressure level in Pascals
2*10$^{(dB/20)}$so, Pa = 0.00002*10(dB/20)so, Pa = 0.00002*10(dB/20)so, Pa = 0.00002*10(dB/20)so, Pa = 0.00002*10(dB/20)so, Pa = 0.00002*10(dB/20)





Rear of Train Passes Microphone
3.5
4
4.5
5
ls)

oise of a High-Speed Train at Different Speeds, [1]He, B., *et. al.*, Investigation into Exterior Noise of a High-Speed Tr

Technology, 2019,[2]China CRH3 Series High Speed Train Image; provided by *Railway Technology*, 2019,[2]China CRH3 Series High

lB (sound pressure level in decibels) = 20 $\log_{10}$(Pa/0.00002) dB (sound pressure level in decibels) = 20 lo

ain at Different Speeds, [1]He, B., *et. al.*, Investigation into Exterior Noise of a High-Speed Train at Different Speeds

Speed Train Image; provided by *Railway Technology*, 2019,[2]China CRH3 Series High Speed Train Image; provided by *Railway Te*

g$_{10}$(Pa/0.00002) dB (sound pressure level in decibels) = 20 $\log_{10}$(Pa/0.00002) dB (sound pressure level in

, [1]He, B., *et. al.*, Investigation into Exterior Noise of a High-Speed Train at Different Speeds, [1]He, B., *et. al.*, Investi

echnology, 2019,[2]China CRH3 Series High Speed Train Image; provided by *Railway Technology*, 2019,

decibels) = 20 $\log_{10}$(Pa/0.00002)

gation into Exterior Noise of a High-Speed Train at Different Sp

Spreadsheet-Based Tool for Comparing Noise Standards and Regulations
Conversion Tool for Noise Regulations and Standards to Common Reference

Federal Railroad Administration
High Speed Rail Noise Standards and Regulations

CONTRAST Comparison Of Noise for TRAin STandards

Program Version: 3 30-Sep-19

Data Set Number: 3
Data Set Name: CRH3 Series (based on Siemens)

Passby Noise Calculations

Calculate Train Pass-by Parameters

Train Speed (V):	271	km/hr =	75.28 m/sec
Train Length:	200	m	10 cars: 2 end cars and 8 intermediate cars
Time for Passby (T_p)	2.656826568	seconds	This is the time increment between nose of train passing microphone and tail of train passing microphone.
Time for TEL (T_{TEL})	3.05	seconds	TEL is the Transit Exposure Limit and represents the equivalent A-weighted SPL over the time period beginning when the instantaneous meter reading is 10 dB(A) less than $L_{pAEq,Tp}$ and continuing through the pass-by event until the meter reading is again 10 dB(A) less than $L_{pAeq,Tp}$

References

[1]He, et al., Investigation into External Noise of a High-Speed Train at Different Speeds, J Zhejiang Univ-Sci A (Appl Phys & Eng) 2014, 15(12):1019-1033
[2]Paul, et al, High Speed Rail Noise Standards and Regulations, US DOT Federal Railroad Administration, Contract DTFR35-16-C00006, May 2017.
[3]G. Xiaoan and J. Hua, "Application Research on Descending Vibration and Reducing Noise in Accelerating Speed Trains and Express Trains," Chinese Academy of Railway Sciences (CARS) Research Report, Beijing Shi, China, 2003.
[4]Hanson, C.E., et. al., High Speed Ground Transportation Noise and Vibration Impact Assessment, U.S. Department of Transportation, Federal Railroad Administration, Report Number DOT/FRA/ORD-12/15, September 2012.
[5]Gautier, P.E., Poisson, F., and Letourneaux, F., High Speed Trains External Noise: A Review of Measurements and Source Models for TGV Case Up to 360 km/hr, in Proceedings of the 8th World Congress on Railway Research (2008).
[6]European Union, "Commission Regulation Number 1304/2014, on the technical specification for interoperability relating to the subsystem 'rolling stock — noise' amending Decision 2008/232/EC and repealing Decision 2011/229/EU," Official Journal of the European Union, Brussels, Belgium, 2014.

Calculate $L_{pAeq,Tp}$

$L_{pAeq,Tp}$ is the A-weighted equivalent continuous sound pressure level produced by the train as measured during the passby event

$$L_{p\mathrm{Aeq},T_\mathrm{p}} = 10\ \lg\left(\frac{1}{T_2 - T_1}\int_{T_1}^{T_2}\frac{p_\mathrm{A}^2(t)}{p_0^2}\mathrm{d}t\right) \quad \mathrm{dB}$$

Microphone Position is 7.5 m from track centerline and 3.5 m above top of rail (Microphone Position 2).

where

T_p	is the passby time interval = time when trail tail passes microphone minus time when train nose passes microphone = $T_2 - T_1$
T_1	is the time when the train nose passes the microphone
T_2	is the time when the train tail passes the microphone
$P_A(t)$	is the A-weighted instantaneous sound pressure in Pa at time t
p_0	is the reference sound pressure: p_0 = 20μPa = 0.00002 Pa
Δt_i	is the time increment between measured data points = 0.05 seconds
$P_A(i)$	is the A-weighted instantaneous sound pressure in Pa at pass-by time increment i

$L_{pAeq,Tp}$ can be calculated from the passby data using the following relationship:

$$\int_{T_1}^{T_2}\frac{p_\mathrm{A}^2(t)}{p_0^2}\mathrm{d}t \approx \sum_{i=1}^{i=n}\left(\frac{\mathrm{Pa}(i)^2}{p_0^2}\right)\Delta t_i$$

An analysis conducted during the current study indicated the integral can be determined numerically, with acceptable accuracy, by employing a midpoint Reimann sum scheme with a mimimum Δti = 0.05 seconds, and the corresponding Pa(i) analog meter values. This approach is described in: Hughes-Hallett, Deborah; McCullum, William G.; et al. (2005). *Calculus (4th ed.)*, Wiley. p. 252.

Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$	Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$	Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$	Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$
1	1.00	80.10	0.202316	1.02329E+08	19	1.90	96.20	1.291308	4.16869E+09	37	2.80	96.00	1.261915	3.98107E+09	55	3.70	95.60	1.205119	3.63078E+09
2	1.05	82.00	0.251785	1.58489E+08	20	1.95	96.70	1.367823	4.67735E+09	38	2.85	96.20	1.291308	4.16869E+09	56	3.75	94.80	1.099082	3.01995E+09
3	1.10	83.90	0.313350	2.45471E+08	21	2.00	97.20	1.448872	5.24807E+09	39	2.90	96.10	1.276527	4.07380E+09	57	3.80	94.80	1.099082	3.01995E+09
4	1.15	85.00	0.355656	3.16228E+08	22	2.05	97.00	1.415892	5.01187E+09	40	2.95	96.40	1.321387	4.36516E+09	58	3.85	94.70	1.086501	2.95121E+09
5	1.20	88.00	0.502377	6.30957E+08	23	2.10	96.60	1.352166	4.57088E+09	41	3.00	96.50	1.336688	4.46684E+09	59	3.90	95.90	1.247470	3.89045E+09
6	1.25	90.50	0.669931	1.12202E+09	24	2.15	95.70	1.219074	3.71535E+09	42	3.05	96.90	1.399684	4.89779E+09	60	3.95	95.50	1.191324	3.54813E+09
7	1.30	93.00	0.893367	1.99526E+09	25	2.20	96.00	1.261915	3.98107E+09	43	3.10	95.20	1.150880	3.31131E+09	61	4.00	94.60	1.074064	2.88403E+09
8	1.35	95.00	1.124683	3.16228E+09	26	2.25	96.80	1.383662	4.78630E+09	44	3.15	95.20	1.150880	3.31131E+09	62	4.05	93.20	0.914176	2.08930E+09
9	1.40	94.90	1.111809	3.09030E+09	27	2.30	97.00	1.415892	5.01187E+09	45	3.20	95.30	1.164206	3.38844E+09	63	4.10	91.50	0.751675	1.41254E+09
10	1.45	95.30	1.164206	3.38844E+09	28	2.35	96.80	1.383662	4.78630E+09	46	3.25	96.10	1.276527	4.07380E+09	64	4.15	89.80	0.618059	9.54993E+08
11	1.50	95.30	1.164206	3.38844E+09	29	2.40	96.10	1.276527	4.07380E+09	47	3.30	96.50	1.336688	4.46684E+09	65	4.20	88.00	0.502377	6.30957E+08
12	1.55	95.30	1.164206	3.38844E+09	30	2.45	95.50	1.191324	3.54813E+09	48	3.35	96.50	1.336688	4.46684E+09	66	4.25	86.00	0.399052	3.98107E+08
13	1.60	96.00	1.261915	3.98107E+09	31	2.50	95.40	1.177687	3.46737E+09	49	3.40	95.80	1.233190	3.80189E+09	67	4.30	84.90	0.351585	3.09030E+08
14	1.65	96.10	1.276527	4.07380E+09	32	2.55	96.20	1.291308	4.16869E+09	50	3.45	95.00	1.124683	3.16228E+09	68	4.35	83.10	0.285779	2.04174E+08
15	1.70	96.00	1.261915	3.98107E+09	33	2.60	96.90	1.399684	4.89779E+09	51	3.50	95.00	1.124683	3.16228E+09	69	4.40	82.00	0.251785	1.58489E+08
16	1.75	95.50	1.191324	3.54813E+09	34	2.65	97.00	1.415892	5.01187E+09	52	3.55	95.20	1.150880	3.31131E+09	70	4.45	80.50	0.211851	1.12202E+08
17	1.80	95.10	1.137706	3.23594E+09	35	2.70	96.60	1.352166	4.57088E+09	53	3.60	95.60	1.205119	3.63078E+09	71	4.50	80.00	0.200000	1.00000E+08
18	1.85	95.00	1.124683	3.16228E+09	36	2.75	95.90	1.247470	3.89045E+09	54	3.65	95.80	1.233190	3.80189E+09					

Data Point Number for Start of Passby Event (time at which train nose passes microphone): 8 i = 1
Data Point Number for End of Passby Event (time at which train tail passes microphone): 60 i - n

thus, $\sum_{i=1}^{i=n}\left(\frac{\mathrm{Pa}(i)^2}{p_0^2}\right)\Delta t_i$ = 9.39146E+09

$$L_{pAeq,Tp} = 10\ \lg\left(\frac{1}{T_2 - T_1}\int_{T_1}^{T_2}\frac{p_\mathrm{A}^2(t)}{p_0^2}\mathrm{d}t\right)$$

$L_{pAeq,Tp}$ = **95.48** **dB(A)**

Impact of Microphone Position

Microphone Position	Distance from Track Centerline (m)	Elevation Above Top of Rail (m)	Applies to Regulations in these Regions[2]				Comment
			US	EU	China	Japan	
1	7.5	1.2		X (TSI 2014)			TSI 1304
2	7.5	3.5		X (TSI 2014)			Also required for speeds > 250 km/hr

References:

[A]L. Lu, X. Hu, Y. Zhang and X. Zhou, "Survey and Analysis of the Beijing-Shanghai High Speed Rail Noise," in The 21st International Congress on Sound and Vibration, Beijing, China, 2014.
[B]G. Xiaoan and J. Hua, "Application Research on Descending Vibration and Reducing Noise in Accelerating Speed Trains and Express Trains," Chinese Academy of Railway Sciences (CARS)

3	25	3.5		X (TSI 2008)		X	Reference for pre 2014 train sets
4	30	1.2	X		X		US and China measurement location

Research Report, Beijing Shi, China, 2003.

[c]W. Elliott, "Request for Information Reference FOI13-580, Comparison of Measured Sound Levels for High Speed Trains as a Functionof Distance from Track," High Speed Rail Two (HS2), London, England, 2013.

Impact of microphone distance is determined from the following equation:[3] $L_d = L_{d0} - 10*LOG(d/d0)$, where L_{d0} is the equivalent A-weighted constant sound pressure level for the microphone at distance d0, and d is the distance for Ld.

Microphone Position	Distance from Track Centerline (m)	Elevation Above Top of Rail (m)	$L_{pAeq,Tp}$ at 271 km/h dB(A)	$L_{pAeq,Tp}$ at 271 km/h (Pa)
1	7.5	1.2	93.20	0.914
2	7.5	3.5	95.80	1.233
3	25	3.5	82.08	0.254
4	30	1.2	81.29	0.232

To convert dB(A) to Pascals: Pa = 0.00002*(10^(dBA/20))
To convert Pa to dB(A), dB(A) = 20*LOG10(Pa/0.00002)
Note: The simple sound level correction formula underestimates the measured values. Therefore, ratios based on actual measurements were used to adjust for microphone location (table at right).

Sound Pressure Variations for Microphone Positions and Train Speed from Reference 5			
Speed (km/hr)	$L_{pAeq,Tp}$ dB(A)		
	M1	M2	M3
271	93.2	95.8	82.0
341	96.5	98.0	85.5
386	98.5	100.1	88.1

Calculated Noise Metrics: Maximum Recorded Sound Pressure Levels

The following calculations are for Microphone Position 2 — $L_{p(maximum)}$ = maximum recorded passby sound pressure level

$L_{p(maximum)}$ = **97.2** dB(A) which occurs at data point 21 at passby time 2.20 seconds

L_{pASmax} is the maximum sound pressure level, slow and A-weighted and L_{pAFmax} = maximum sound pressure level, fast and A-weighted. The time period for the "slow" reading is 1 second. The time period for the "fast" reading is 0.125 seconds.

L_{pASmax} can be calculated as the logarithmic average of the recorded SPLs for the 1 second time interval containing the highest values

The logarithmic average for an Excel array is: {=10*LOG(AVERAGE(10^(ARRAY/10)))} array-entered, i.e. using CTRL-Shift-Enter keys where array is of the form A10:A15. In the current case, the array is Passby Data Set 1, C:48:C68

Highest 1-second interval occurs from start time 1.95 to end time 2.95 **Thus, L_{pASmax} = 96.42 dB(A)**

Similarly, L_{pAFmax} can be calculated as the logarithmic average of the recorded SPLs for the 0.125 second time interval containing the highest values

Highest 0.125-second interval occures from start time 1.90 to end time 2.025 **Thus, L_{pAFmax} = 96.79 dB(A)**

Calculated Noise Metrics: Other Standard Parameters

The following calculations are for Microphone Position 2

$L_{pAeq,passby}$ is the A-weighted equivalent continuous sound pressure level produced during the entire passby event, including approach, T_p, and departure (used for L_d, L_n, etc.)

The calculation includes all of the pass-by data points.

Data Point Number for Start of Passby Event (time at which train nose passes microphone): 1 i = 1

Data Point Number for End of Passby Event (time at which train tail passes microphone): 71 i - n thus, $\sum_{i=1}^{i=n} \left(\frac{Pa(i)^2}{p_0^2} \right) \Delta t_i$ = 1.10857E+10 $T_2 - T_1$ = 3.50 seconds

$$L_{pAeq,pass\text{-}by} = 10 \lg \left(\frac{1}{T_2 - T_1} \int_{T_1}^{T_2} \frac{p_A^2(t)}{p_0^2} dt \right)$$

$L_{pAeq,pass\text{-}by}$ = 95.01 dB(A)

TEL is the Transit Exposure Limit[4]. It is measured over the time interval starting when the SPL is 10 dB(A) lower than $L_{pAeq,Tp}$ and ending when the SPL again reaches a value that is 10 dB(A) lower than $L_{pAeq,Tp}$

TEL is calculated using the following formula: $TEL = L_{pAeq,Tp} + 10*LOG(T_{TEL}/T_p)$ **TEL = 96.08 dB(A)**

SEL is the Sound Exposure Limit[4]. Like $L_{pAeq,Tp}$, it integrates the total sound energy over a measurement period, but for SEL, the measurement period is normalized to a duration of 1 second. At a microphone distance of 30 m (100 ft), $SEL = L_{pAeq,Tp} + 10*LOG(Tp) + 1$

SEL at 30 m: 100.73 dB(A) **SEL at 7.5 m: 106.75 dB(A)** **SEL at 25 m: 101.52 dB(A)** using the distance correction factor: $L_d = L_{d0} - 10*LOG(d/d0)$

SEL is the cumulative noise exposure (i.e. "dose") for a single noise event normalized over 1 second. The fact that SEL is a cumulative measure means that (1) louder events have higher SELs than quieter ones, and (2) events that last longer in time have higher SELs than shorter ones.[4]

Statistical Parameters

The following parameters are determined by specifying the indicated percentile of the data values using Excel Function PERCENTILE(range,P).
where" range" is the array of values (e.g. K10:K68) and P = the percentile (between 0 and 1, for example, P for the 90th percentile would be entered as 0.9)

L_{10} is the sound pressure level for which 90% of the recorded values are greater. It includes lead-in (prior to nose passing microphone) and trail-off (after tail of train passes) data. **L_{10} = 84.90 dB(A)**

L_{50} is the sound pressure level for which 50% of the recorded values are greater. It includes lead-in (prior to nose passing microphone) and trail-off (after tail of train passes) data. **L_{50} = 95.50 dB(A)**

L_{90} is the sound pressure level for which 10% of the recorded values are greater. It includes lead-in (prior to nose passing microphone) and trail-off (after tail of train passes) data. **L_{90} = 96.80 dB(A)**

Summary of Pass-by Noise Metrics for Each Microphone Position

The noise metrics shown in the following table correspond to the baseline speed of 271 km/hr $L_d = L_{d0} - 10*LOG(d/d0)$, where L_{d0} is the equivalent A-weighted constant sound pressure level for the microphone at distance d0, and d is the distance for L_d.

Microphone Position	Noise Metric: Table Entries are dB(A)									
	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
1	92.9	94.6	93.8	94.2	92.4	93.5	103.9	82.6	92.9	94.2
2	95.5	97.2	96.4	96.8	95.0	96.1	106.7	84.9	95.5	96.8
3	81.7	83.2	82.5	82.8	81.3	82.2	91.4	72.7	81.7	82.9
4	80.9	82.4	81.7	82.1	80.5	81.5	90.6	71.9	81.0	82.1

Microphone Position Adjustment Factors[5]			
Speed (km/hr)	M1	M2	M3
271	1.000	1.028	0.880
341	1.035	1.052	0.917
386	1.057	1.074	0.945

Impact of Train Speed on Noise Levels

Ricardo evaluated several methods for determining the impact of train speed on passby noise levels. The approach developed by Gautier, Poisson & Letourneaux[5] provided the highest level of correlation with measured data is the basis for the calculations presented below.

$L_{Aeq,tp}(V) - L_{Aeq,tp}(V_0) = K \log(V/V_0)$ where K is an empirical factor where V= train speed (km/hr) If the SPL is known at train speed V_0, the SPL at train speed V can be determined from this formula

thus, $L_{Aeq,tp}(V) = K \log(V/V_0) + L_{Aeq,tp}(V_0)$ V_0= reference train speed (km/hr)

The empirical factor K varies with train speed. This is because the contribution of noise sources (e.g. wheel/rail interaction, propulsion components, aerodynamics) vary with train speed. Ricardo calculated the K factor values for 12 passby noise data sets.

The relationship between the K factor and train speed is provided by the following equation:

K = a*V + b where a= 0.0625 and b= 25.00

V_0 for this train set is: 271 km/hr

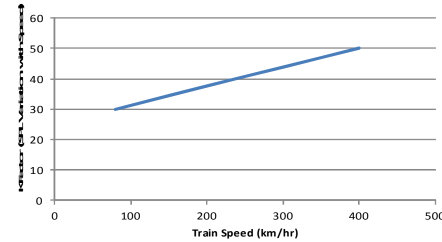
The following tables contain the calculated variation with train speed for the various noise parameters described above:

				Microphone Position 1			Noise Metric: Table Entries are dB(A)					
	Train Speed (km/hr)	K	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
	80	30.0000	77.0	78.7	77.9	78.3	76.5	77.6	88.0	66.7	77.0	78.3
	150	34.3750	84.1	85.7	85.0	85.3	83.6	84.6	95.0	73.8	84.1	85.3
	200	37.5000	87.9	89.6	88.9	89.2	87.5	88.5	98.9	77.6	88.0	89.2
	250	40.6250	91.5	93.1	92.4	92.7	91.0	92.1	102.4	81.2	91.5	92.7
	300	43.7500	94.8	96.5	95.7	96.1	94.4	95.4	105.8	84.5	94.8	96.1
	350	46.8750	98.1	99.8	99.0	99.4	97.6	98.7	109.1	87.8	98.1	99.4
Test Speed→	271	41.9375	92.9	94.6	93.8	94.2	92.4	93.5	103.9	82.6	92.9	94.2

				Microphone Position 2			Noise Metric: Table Entries are dB(A)					
	Train Speed (km/hr)	K	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
	80	30.0000	79.6	81.3	80.5	80.9	79.1	80.2	90.9	69.0	79.6	80.9
	150	34.3750	86.7	88.4	87.6	88.0	86.2	87.3	97.9	76.1	86.7	88.0
	200	37.5000	90.5	92.3	91.5	91.8	90.1	91.1	101.8	80.0	90.6	91.9
	250	40.6250	94.1	95.8	95.0	95.4	93.6	94.7	105.3	83.5	94.1	95.4
	300	43.7500	97.4	99.1	98.3	98.7	96.9	98.0	108.7	86.8	97.4	98.7
	350	46.8750	100.7	102.4	101.6	102.0	100.2	101.3	112.0	90.1	100.7	102.0
Test Speed→	271	41.9375	95.5	97.2	96.4	96.8	95.0	96.1	106.7	84.9	95.5	96.8

				Microphone Position 3			Noise Metric: Table Entries are dB(A)					
	Train Speed (km/hr)	K	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
	80	30.0000	65.8	67.3	66.6	67.0	65.4	66.3	75.5	56.8	65.8	67.0
	150	34.3750	72.9	74.4	73.7	74.0	72.5	73.4	82.5	63.8	72.9	74.0
	200	37.5000	76.8	78.3	77.6	77.9	76.4	77.3	86.4	67.7	76.8	77.9
	250	40.6250	80.3	81.8	81.1	81.4	79.9	80.8	89.9	71.2	80.3	81.4
	300	43.7500	83.7	85.1	84.5	84.8	83.3	84.2	93.3	74.6	83.7	84.8
	350	46.8750	86.9	88.4	87.7	88.1	86.5	87.5	96.6	77.9	87.0	88.1
Test Speed→	271	41.9375	81.7	83.2	82.5	82.8	81.3	82.2	91.4	72.7	81.7	82.9

				Microphone Position 4			Noise Metric: Table Entries are dB(A)					
	Train Speed (km/hr)	K	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
	80	30.0000	65.0	66.5	65.8	66.2	64.6	65.6	74.7	56.0	65.1	66.2
	150	34.3750	72.1	73.6	72.9	73.2	71.7	72.6	81.7	63.0	72.1	73.2
	200	37.5000	76.0	77.5	76.8	77.1	75.6	76.5	85.6	66.9	76.0	77.1
	250	40.6250	79.5	81.0	80.3	80.6	79.1	80.0	89.2	70.5	79.5	80.6
	300	43.7500	82.9	84.3	83.7	84.0	82.5	83.4	92.5	73.8	82.9	84.0
	350	46.8750	86.1	87.6	86.9	87.3	85.7	86.7	95.8	77.1	86.2	87.3
Test Speed→	271	41.9375	80.9	82.4	81.7	82.1	80.5	81.5	90.6	71.9	81.0	82.1



The empirical factor, K, varies with train speed: it is on the order of 30 in speed range to 300 kph and up to 50 for very high speed trains, for which aerodynamic noise sources are dominant.

K = 0.0625(Train Speed, km/hr) + 25

The European Technical Standards for Interoperability (TSI) include two normalized values for $L_{pAEq,Tp}$. The values are normalized to 80 km/hr and 250 km/hr.[6]

The measurements are made at a lateral distance of 7.5 m from the rail centerline and 3.5 m above the top of the rail.

Procedures defined within the TSI to allow noise levels to be calculated at various train speeds based on measurements made at 80 km/hr (50 miles/h) and 250 km/hr (155 miles/hr).

<u>For the CHR3 Series Trains, no measurements were made at 80 km/hr and 250 km/hr</u>: Thus, the Gautier method was used to calculate these values

From the Microphone Position 1 Table Above, the normalized values for $L_{pAeq,Tp}$ can be found and are identified below:

Values Obtained from Data Analysis			Value from TSI Formula		TSI Formulas
$L_{pAeq,Tp\,(80\,km/hr)}$ =	**77.0**	**dB(A)**	77.0	dB(A)	$L_{pAeq,Tp}$(80 km/h) = $L_{pAeq,Tp}$(vtest) - 30 * log (vtest/80 km/h)
$L_{pAeq,Tp\,(250\,km/hr)}$ =	**91.5**	**dB(A)**	91.1	dB(A)	$L_{pAeq,Tp}$(250 km/h) = $L_{pAeq,Tp}$(vtest) - 50 * log (vtest/250 km/h)

U.S. Department of Transportation
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High Speed Rail Noise Standards and Regulations

Data Set Number: 4
Data Set Name: CRH3 Series (based on Siemens)

China CRH3 Series Train2

Data Point Number	Passby Data[1] Passby Data1		Sound Pressure (Pa)	Event
	Time (sec)	dB(A)		
1	1.00	78.8	0.17419	
2	1.05	79.5	0.18881	←
3	1.10	81.3	0.23229	
4	1.15	83.1	0.28578	10 dB(A) lower than SPL when Train Nose Passes Microphone
5	1.20	85.9	0.39448	
6	1.25	88.3	0.52003	←
7	1.30	90.2	0.64719	
8	1.35	92.9	0.88314	Train Nose Passes Microphone
9	1.40	93.0	0.89337	
10	1.45	93.4	0.93547	
11	1.50	93.7	0.96834	
12	1.55	93.4	0.93547	
13	1.60	94.1	1.01398	
14	1.65	93.4	0.93547	
15	1.70	94.3	1.03760	
16	1.75	94.2	1.02572	
17	1.80	93.8	0.97956	←
18	1.85	93.5	0.94630	
19	1.90	94.0	1.00237	Start Time for LpASmax Calcula
20	1.95	93.9	0.99090	
21	2.00	93.8	0.97956	
22	2.05	93.2	0.91418	

23	2.10	93.1	0.90371
24	2.15	92.7	0.86304
25	2.20	92.5	0.84339
26	2.25	93.2	0.91418
27	2.30	93.4	0.93547
28	2.35	93.3	0.92476
29	2.40	93.4	0.93547
30	2.45	93.6	0.95726
31	2.50	93.9	0.99090
32	2.55	93.7	0.96834
33	2.60	94.1	1.01398
34	2.65	94.5	1.06177
35	2.70	94.7	1.08650
36	2.75	94.2	1.02572
37	2.80	93.4	0.93547
38	2.85	93.5	0.94630
39	2.90	93.9	0.99090
40	2.95	93.8	0.97956
41	3.00	93.9	0.99090
42	3.05	94.1	1.01398
43	3.10	93.9	0.99090
44	3.15	93.5	0.94630
45	3.20	93.6	0.95726
46	3.25	93.4	0.93547
47	3.30	93.5	0.94630
48	3.35	93.7	0.96834
49	3.40	93.8	0.97956
50	3.45	93.2	0.91418
51	3.50	93.4	0.93547
52	3.55	94.0	1.00237
53	3.60	93.6	0.95726
54	3.65	94.0	1.00237
55	3.70	94.0	1.00237
56	3.75	93.2	0.91418
57	3.80	92.9	0.88314
58	3.85	92.9	0.88314
59	3.90	93.3	0.92476
60	3.95	93.3	0.92476
61	4.00	92.5	0.84339
62	4.05	91.8	0.77809
63	4.10	90.7	0.68554
64	4.15	89.2	0.57681
65	4.20	87.2	0.45817
66	4.25	86.2	0.40835
67	4.30	84.7	0.34358
68	4.35	83.2	0.28909

← (row 33) Maximum Sound Pressure Leve

← (row 37) End Time for LpASmax Calculat

← (row 58) Train Tail Passes Microphone

← (row 65) 10 dB(A) lower than SPL when

69	4.40	82.2	0.25765
70	4.45	81.2	0.22963
71	4.50	80.2	0.20466

Train Tail Passes Microphone

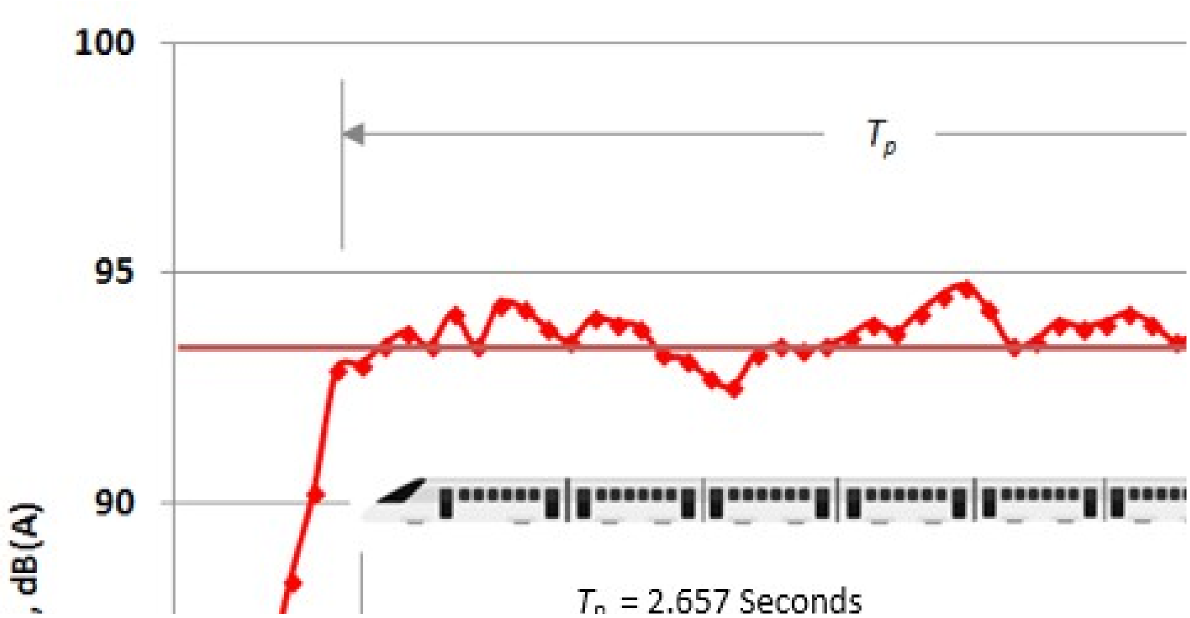
Spreadsheet-Based Tool for Comparing Noise Standards and Re
Conversion Tool for Noise Regulations and Standards to Commo

CONTRAST Comparison Of Noise for TRAin STandards

Train Set Information			
Year Data Set was Generated:	2014		[1]He, B., *et. al.*, Inv
Train Set Manufacturer:	Changchun Railway Vehicles, Siemens		J. Zhejang Univ-S
Operator:	China Railway Corporation		[2]China CRH3 Series
Train Set Geometry and Test Conditions			https://www.railw
Parameter	**Value**	**Units**	
Car Lengths			
End Cars:	25.641	m	
Intermediate Cars:	24.786	m	
Number of End Cars:	2		
Number of Intermediate Cars:	6		
Test Train Length:	200	m	
Test Train Speed(s):	271	km/hr	
Microphone Position:	1		dB (sound press
Distance from Track Centerline:	7.5	m	where 0.0002 is
Elevation above Top of Rail:	1.5	m	so, Pa = 0.0000
Time Increment for Passby Data, ΔT:Time Inc	0.05	sec	
Number of Passby Data Points:	71		

Plot of Passby Noise Data, Including Key Time Parameters

ation



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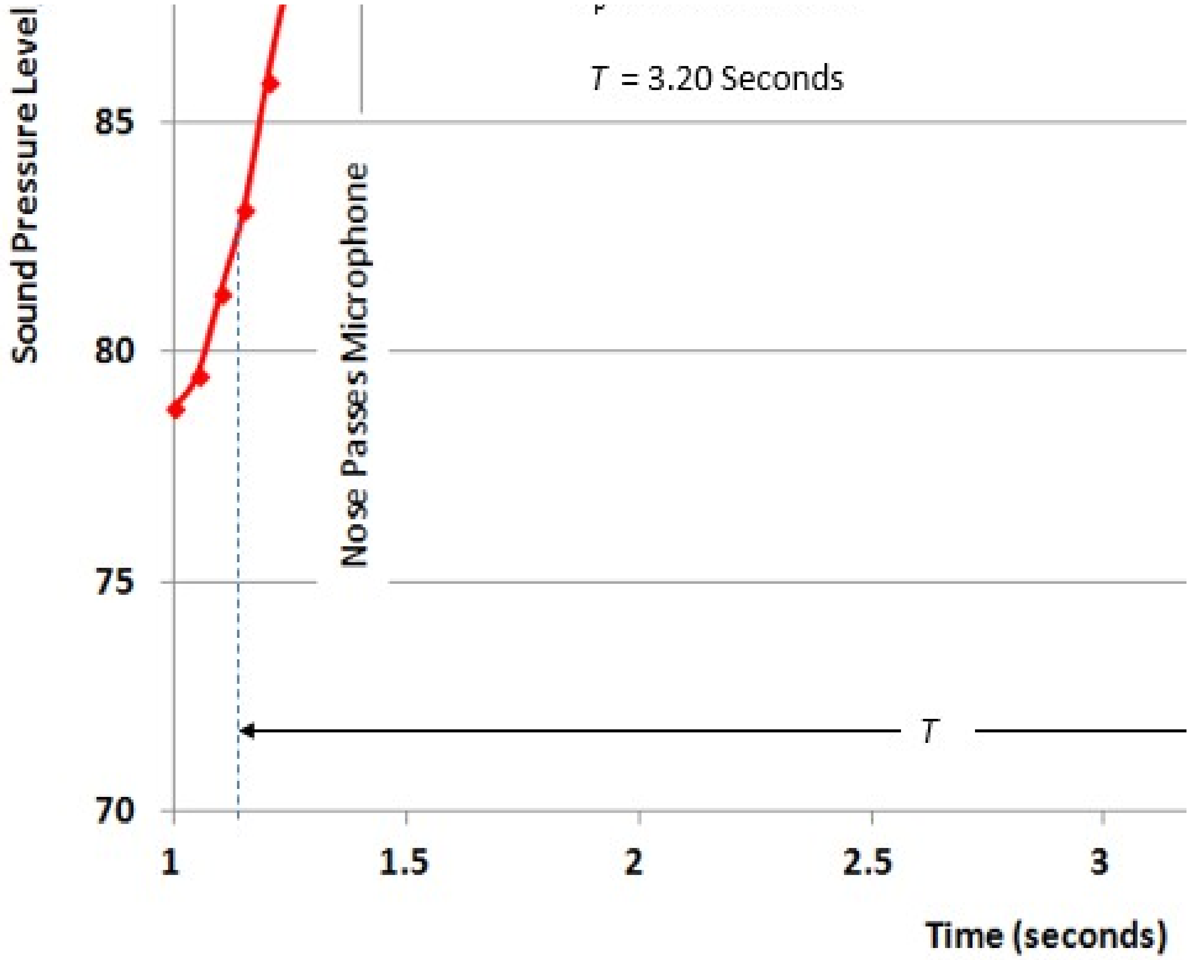

T = 3.20 Seconds
Sound Pressure Level
Nose Passes Microphone
85
80
75
70
T
1
1.5
2
2.5
3
Time (seconds)

gulations
›n Reference

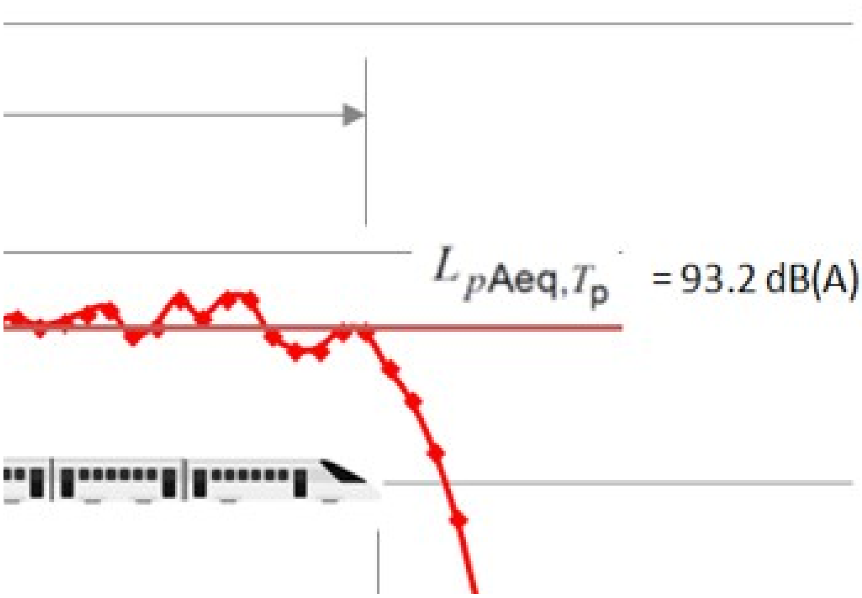
Program Version: 7 14-Oct-19

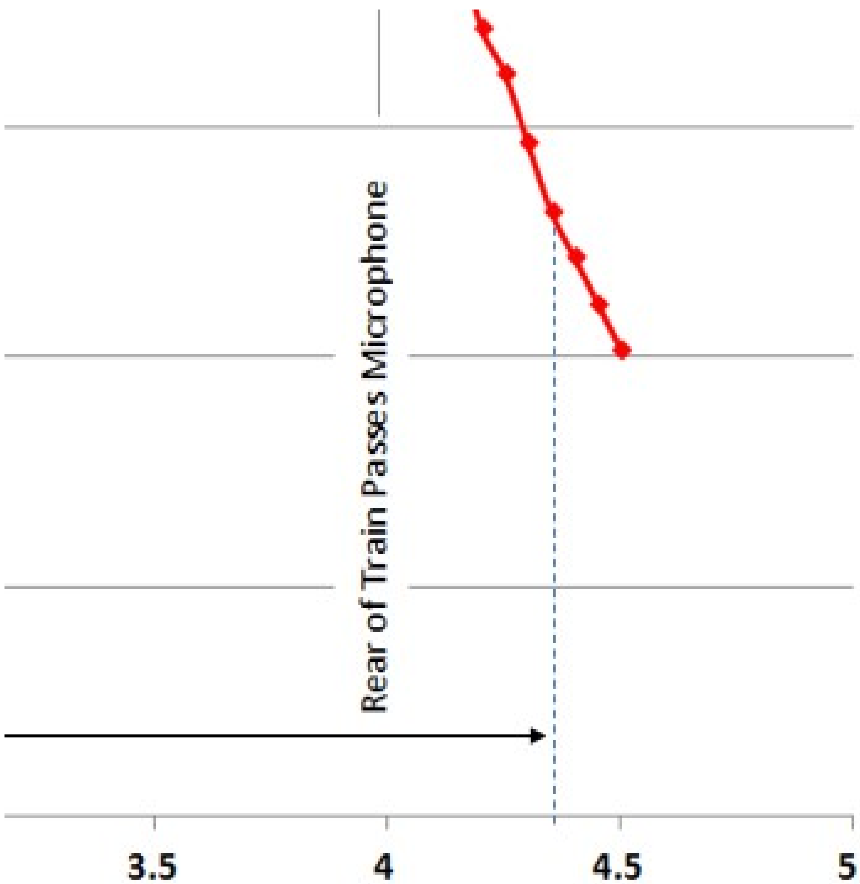
References

›estigation into Exterior Noise of a High-Speed Train at Different Speeds, [1]He, B., *et. al.*, Investigation into Exterior N
ci A (Applied Physics and Enginering), 2014, Vol 15 (12), Pages 1019-1033.
High Speed Train Image; provided by *Railway Technology*, 2019,[2]China CRH3 Series High Speed Train Image; provided by *Railway*
ay-technology.com/projects/beijing-tianjin/

Formulas

›ure level in decibels) = 20 $\log_{10}$(Pa/0.00002) dB (sound pressure level in decibels) = 20 $\log_{10}$(Pa/0.00002) d
› the reference sound pressure level in Pascals
2*$10^{(dB/20)}$so, Pa = 0.00002*10(dB/20)so, Pa = 0.00002*10(dB/20)so, Pa = 0.00002*10(dB/20)so, Pa = 0.00002*10(dB/20)so, Pa = 0.00002*10(dB/20)





Rear of Train Passes Microphone
3.5
4
4.5
5

oise of a High-Speed Train at Different Speeds, [1]He, B., *et. al.*, Investigation into Exterior Noise of a High-Speed Tr

Technology, 2019,[2]China CRH3 Series High Speed Train Image; provided by *Railway Technology*, 2019,[2]China CRH3 Series High

B (sound pressure level in decibels) = 20 $\log_{10}$(Pa/0.00002) dB (sound pressure level in decibels) = 20 lo

ain at Different Speeds, [1]He, B., *et. al.*, Investigation into Exterior Noise of a High-Speed Train at Different Speeds

Speed Train Image; provided by *Railway Technology*, 2019,[2]China CRH3 Series High Speed Train Image; provided by *Railway Te*

g$_{10}$(Pa/0.00002) dB (sound pressure level in decibels) = 20 log$_{10}$(Pa/0.00002) dB (sound pressure level in

, [1]He, B., *et. al.*, Investigation into Exterior Noise of a High-Speed Train at Different Speeds, [1]He, B., *et. al.*, Investi

echnology, 2019,[2]China CRH3 Series High Speed Train Image; provided by *Railway Technology*, 2019,

decibels) = 20 $\log_{10}$(Pa/0.00002)

gation into Exterior Noise of a High-Speed Train at Different Sp

Spreadsheet-Based Tool for Comparing Noise Standards and Regulations
Conversion Tool for Noise Regulations and Standards to Common Reference

Federal Railroad Administration
High Speed Rail Noise Standards and Regulations

CONTRAST Comparison Of Noise for TRAin STandards

Program Version: 7 14-Oct-19

Data Set Number: 4	**Passby Noise Calculations**	**References**
Data Set Name: CRH3 Series (based on Siemens)		

Calculate Train Pass-by Parameters

Train Speed (V):	271	km/hr =	75.28 m/sec
Train Length:	200	m	10 cars: 2 end cars and 8 intermediate cars
Time for Passby (T_p)	2.656826568	seconds	This is the time increment between nose of train passing microphone and tail of train passing microphone.
Time for TEL (T_{TEL})	3.20	seconds	TEL is the Transit Exposure Limit and represents the equivalent A-weighted SPL over the time period beginning when the instantaneous meter reading is 10 dB(A) less than $L_{pAEq,Tp}$ and continuing through the passby event until the meter reading is again 10 dB(A) less than $L_{pAeq,Tp}$

[1]He, et al., Investigation into External Noise of a High-Speed Train at Different Speeds, J Zhejiang Univ-Sci A (Appl Phys & Eng) 2014, 15(12):1019-1033
[2]Paul, et al, High Speed Rail Noise Standards and Regulations, US DOT Federal Railroad Administration, Contract DTFR35-16-C00006, May 2017.
[3]G. Xiaoan and J. Hua, "Application Research on Descending Vibration and Reducing Noise in Accelerating Speed Trains and Express Trains," Chinese Academy of Railway Sciences (CARS) Research Report, Beijing Shi, China, 2003.
[4]Hanson, C.E., et. al., High Speed Ground Transportation Noise and Vibration Impact Assessment, U.S. Department of Transportation, Federal Railroad Administration, Report Number DOT/FRA/ORD-12/15, September 2012.
[5]Gautier, P.E., Poisson, F., and Letourneaux, F., High Speed Trains External Noise: A Review of Measurements and Source Models for TGV Case Up to 360 km/hr, in Proceedings of the 8th World Congress on Railway Research (2008).
[6]European Union, "Commission Regulation Number 1304/2014, on the technical specification for interoperability relating to the subsystem 'rolling stock — noise' amending Decision 2008/232/EC and repealing Decision 2011/229/EU," Official Journal of the European Union, Brussels, Belgium, 2014.

Calculate $L_{pAeq,Tp}$

$L_{pAeq,Tp}$ is the A-weighted equivalent continuous sound pressure level produced by the train as measured during the passby event

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

$L_{pAeq,Tp}$ can be calculated from the passby data using the following relationship:

$$\int_{T_1}^{T_2} \frac{p_A^2(t)}{p_0^2} dt \approx \sum_{i=1}^{i=n} \left(\frac{Pa(i)^2}{p_0^2} \right) \Delta t_i$$

Microphone Position is 7.5 m from track centerline and 1.5 m above top of rail (Microphone Position 1).

where

T_p	is the passby time interval = time when trail tail passes microphone minus time when train nose passes microphone = $T_2 - T_1$
T_1	is the time when the train nose passes the microphone
T_2	is the time when the train tail passes the microphone
$P_A(t)$	is the A-weighted instantaneous sound pressure in Pa at time t
p_0	is the reference sound pressure: p_0 = 20μPa = 0.00002 Pa
Δt_i	is the time increment between measured data points = 0.05 seconds
$P_A(i)$	is the A-weighted instantaneous sound pressure in Pa at passby time increment i

An analysis conducted during the current study indicated the integral can be determined numerically, with acceptable accuracy, by employing a midpoint Reimann sum scheme with a mimimum Δti = 0.05 seconds, and the corresponding Pa(i) analog meter values. This approach is described in: Hughes-Hallett, Deborah; McCullum, William G.; et al. (2005). *Calculus (4th ed.)*, Wiley. p. 252.

Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$	Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$	Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$	Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$
1	1.00	78.80	0.174193	7.58578E+07	19	1.90	94.00	1.002374	2.51189E+09	37	2.80	93.40	0.935470	2.18776E+09	55	3.70	94.00	1.002374	2.51189E+09
2	1.05	79.50	0.188812	8.91251E+07	20	1.95	93.90	0.990900	2.45471E+09	38	2.85	93.50	0.946303	2.23872E+09	56	3.75	93.20	0.914176	2.08930E+09
3	1.10	81.30	0.232290	1.34896E+08	21	2.00	93.80	0.979558	2.39883E+09	39	2.90	93.90	0.990900	2.45471E+09	57	3.80	92.90	0.883141	1.94984E+09
4	1.15	83.10	0.285779	2.04174E+08	22	2.05	93.20	0.914176	2.08930E+09	40	2.95	93.80	0.979558	2.39883E+09	58	3.85	92.90	0.883141	1.94984E+09
5	1.20	85.90	0.394485	3.89045E+08	23	2.10	93.10	0.903712	2.04174E+09	41	3.00	93.90	0.990900	2.45471E+09	59	3.90	93.30	0.924762	2.13796E+09
6	1.25	88.30	0.520032	6.76083E+08	24	2.15	92.70	0.863038	1.86209E+09	42	3.05	94.10	1.013981	2.57040E+09	60	3.95	93.30	0.924762	2.13796E+09
7	1.30	90.20	0.647187	1.04713E+09	25	2.20	92.50	0.843393	1.77828E+09	43	3.10	93.90	0.990900	2.45471E+09	61	4.00	92.50	0.843393	1.77828E+09
8	1.35	92.90	0.883141	1.94984E+09	26	2.25	93.20	0.914176	2.08930E+09	44	3.15	93.50	0.946303	2.23872E+09	62	4.05	91.80	0.778090	1.51356E+09
9	1.40	93.00	0.893367	1.99526E+09	27	2.30	93.40	0.935470	2.18776E+09	45	3.20	93.60	0.957260	2.29087E+09	63	4.10	90.70	0.685536	1.17490E+09
10	1.45	93.40	0.935470	2.18776E+09	28	2.35	93.30	0.924762	2.13796E+09	46	3.25	93.40	0.935470	2.18776E+09	64	4.15	89.20	0.576806	8.31764E+08
11	1.50	93.70	0.968345	2.34423E+09	29	2.40	93.40	0.935470	2.18776E+09	47	3.30	93.50	0.946303	2.23872E+09	65	4.20	87.20	0.458174	5.24807E+08
12	1.55	93.40	0.935470	2.18776E+09	30	2.45	93.60	0.957260	2.29087E+09	48	3.35	93.70	0.968345	2.34423E+09	66	4.25	86.20	0.408348	4.16869E+08
13	1.60	94.10	1.013981	2.57040E+09	31	2.50	93.90	0.990900	2.45471E+09	49	3.40	93.80	0.979558	2.39883E+09	67	4.30	84.70	0.343582	2.95121E+08
14	1.65	93.40	0.935470	2.18776E+09	32	2.55	93.70	0.968345	2.34423E+09	50	3.45	93.20	0.914176	2.08930E+09	68	4.35	83.20	0.289088	2.08930E+08
15	1.70	94.30	1.037600	2.69153E+09	33	2.60	94.10	1.013981	2.57040E+09	51	3.50	93.40	0.935470	2.18776E+09	69	4.40	82.20	0.257650	1.65959E+08
16	1.75	94.20	1.025723	2.63027E+09	34	2.65	94.50	1.061769	2.81838E+09	52	3.55	94.00	1.002374	2.51189E+09	70	4.45	81.20	0.229631	1.31826E+08
17	1.80	93.80	0.979558	2.39883E+09	35	2.70	94.70	1.086501	2.95121E+09	53	3.60	93.60	0.957260	2.29087E+09	71	4.50	80.20	0.204659	1.04713E+08
18	1.85	93.50	0.946303	2.23872E+09	36	2.75	94.20	1.025723	2.63027E+09	54	3.65	94.00	1.002374	2.51189E+09					

Data Point Number for Start of Passby Event (time at which train nose passes microphone): 8 i = 1
Data Point Number for End of Passby Event (time at which train tail passes microphone): 60 i - n

thus, $\sum_{i=1}^{i=n} \left(\frac{Pa(i)^2}{p_0^2} \right) \Delta t_i$ = 5.46164E+09

$L_{pAeq,Tp} = 10 \lg \left(\frac{1}{T_2 - T_1} \int_{T_1}^{T_2} \frac{p_A^2(t)}{p_0^2} dt \right)$ $L_{pAeq,Tp}$ = **93.13** **dB(A)**

Impact of Microphone Position

Microphone Position	Distance from Track Centerline (m)	Elevation Above Top of Rail (m)	Applies to Regulations in these Regions[2]				Comment
			US	EU	China	Japan	
1	7.5	1.2		X (TSI 2014)			TSI 1304
2	7.5	3.5		X (TSI 2014)			Also required for speeds > 250 km/hr

References:

[A]L. Lu, X. Hu, Y. Zhang and X. Zhou, "Survey and Analysis of the Beijing-Shanghai High Speed Rail Noise," in The 21st International Congress on Sound and Vibration, Beijing, China, 2014.
[B]G. Xiaoan and J. Hua, "Application Research on Descending Vibration and Reducing Noise in Accelerating Speed Trains and Express Trains," Chinese Academy of Railway Sciences (CARS)

3	25	3.5		X (TSI 2008)		X	Reference for pre	2014 train sets
4	30	1.2	X		X		US and China measurement location	

Research Report, Beijing Shi, China, 2003.

[c]W. Elliott, "Request for Information Reference FOI13-580, Comparison of Measured Sound Levels for High Speed Trains as a Functionof Distance from Track," High Speed Rail Two (HS2), London, England, 2013.

Impact of microphone distance is determined from the following equation:[3] $L_d = L_{d0}$ - 10*LOG(d/d0), where L_{d0} is the equivalent A-weighted constant sound pressure level for the microphone at distance d0, and d is the distance for Ld.

Microphone Position	Distance from Track Centerline (m)	Elevation Above Top of Rail (m)	$L_{pAeq,Tp}$ at 271 km/h dB(A)	$L_{pAeq,Tp}$ at 271 km/h (Pa)
1	7.5	1.2	93.13	0.907
2	7.5	3.5	95.80	1.233
3	25	3.5	82.08	0.254
4	30	1.2	81.29	0.232

To convert dB(A) to Pascals: Pa = 0.00002*(10^(dBA/20))
To convert Pa to dB(A), dB(A) = 20*LOG10(Pa/0.00002)
Note: The simple sound level correction formula underestimates the measured values. Therefore, ratios based on actual measurements were used to adjust for microphone location (table at right).

Sound Pressure Variations for Microphone Positions and Train Speed from Reference 5

Speed (km/hr)	$L_{pAeq,Tp}$ dB(A)		
	M1	M2	M3
271	93.2	95.8	82.0
341	96.5	98.0	85.5
386	98.5	100.1	88.1

Calculated Noise Metrics: Maximum Recorded Sound Pressure Levels

The following calculations are for Microphone Position 1

$L_{p(maximum)}$ = maximum recorded pass-by sound pressure level

$L_{p(maximum)}$ = **94.7** dB(A) which occurs at data point 35 at pass-by time 2.70 seconds

L_{pASmax} is the maximum sound pressure level, slow and A-weighted and L_{pAFmax} = maximum sound pressure level, fast and A-weighted. The time period for the "slow" reading is 1 second. The time period for the "fast" reading is 0.125 seconds.

L_{pASmax} can be calculated as the logarithmic average of the recorded SPLs for the 1 second time interval containing the highest values

The logarithmic average for an Excel array is: {=10*LOG(AVERAGE(10^(ARRAY/10)))} array-entered, i.e. using CTRL-Shift-Enter keys where array is of the form A10:A15. In the current case, the array is Pass-By Data Set 1, C:48:C68

Highest 1-second interval occurs from start time 1.9 to end time 2.9 **Thus, L_{pASmax} = 93.65 dB(A)**

Similarly, L_{pAFmax} can be calculated as the logarithmic average of the recorded SPLs for the 0.125 second time interval containing the highest values

Highest 0.125-second interval occures from start time 2.60 to end time 2.725 **Thus, L_{pAFmax} = 94.38 dB(A)**

Calculated Noise Metrics: Other Standard Parameters

The following calculations are for Microphone Position 1

$L_{pAeq,pass-by}$ is the A-weighted equivalent continuous sound pressure level produced during the entire pass-by event, including approach, T_p, and departure (used for L_d, L_n, etc.)

The calculation includes all of the pass-by data points.

Data Point Number for Start of Passby Event (time at which train nose passes microphone): 1 i = 1

Data Point Number for End of Passby Event (time at which train tail passes microphone): 71 i - n

thus, $\sum_{i=1}^{i=n} \left(\frac{Pa(i)^2}{p_0^2} \right) \Delta t_i$ = 6.58863E+09 $T_2 - T_1$ = 3.50 seconds

$$L_{pAeq,pass-by} = 10 \lg \left(\frac{1}{T_2 - T_1} \int_{T_1}^{T_2} \frac{p_A^2(t)}{p_0^2} dt \right)$$

$L_{pAeq,passby}$ = 92.75 dB(A)

TEL is the Transit Exposure Limit[4]. It is measured over the time interval starting when the SPL is 10 dB(A) lower than $L_{pAeq,Tp}$ and ending when the SPL again reaches a value that is 10 dB(A) lower than $L_{pAeq,Tp}$

TEL is calculated using the following formula: TEL = $L_{pAeq,Tp}$ + 10*LOG(T_{TEL}/T_p) **TEL = 93.94 dB(A)**

SEL is the Sound Exposure Limit[4]. Like $L_{pAeq,Tp}$, it integrates the total sound energy over a measurement period, but for SEL, the measurement period is normalized to a duration of 1 second. At a microphone distance of 30 m (100 ft), SEL = $L_{pAeq,Tp}$ + 10*LOG(Tp) + 1

SEL at 30 m: 98.37 dB(A) SEL at 7.5 m: 104.39 dB(A) SEL at 25 m: 99.17 dB(A) using the distance correction factor: $L_d = L_{d0}$ - 10*LOG(d/d0)

SEL is the cumulative noise exposure (i.e. "dose") for a single noise event normalized over 1 second. The fact that SEL is a cumulative measure means that (1) louder events have higher SELs than quieter ones, and (2) events that last longer in time have higher SELs than shorter ones.[4]

Statistical Parameters

The following parameters are determined by specifying the indicated percentile of the data values using Excel Function PERCENTILE(range,P).
where" range" is the array of values (e.g. K10:K68) and P = the percentile (between 0 and 1, for example, P for the 90th percentile would be entered as 0.9)

L_{10} is the sound pressure level for which 90% of the recorded values are greater. It includes lead-in (prior to nose passing microphone) and trail-off (after tail of train passes) data. **L_{10} = 83.20 dB(A)**

L_{50} is the sound pressure level for which 50% of the recorded values are greater. It includes lead-in (prior to nose passing microphone) and trail-off (after tail of train passes) data. **L_{50} = 93.40 dB(A)**

L_{90} is the sound pressure level for which 10% of the recorded values are greater. It includes lead-in (prior to nose passing microphone) and trail-off (after tail of train passes) data. **L_{90} = 94.10 dB(A)**

Summary of Pass-by Noise Metrics for Each Microphone Position

The noise metrics shown in the following table correspond to the baseline speed of 271 km/hr $L_d = L_{d0}$ - 10*LOG(d/d0), where L_{d0} is the equivalent A-weighted constant sound pressure level for the microphone at distance d0, and d is the distance for L_d.

Microphone Position			Noise Metric: Table Entries are dB(A)							
	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
1	93.1	94.7	93.7	94.4	92.7	93.9	104.4	83.2	93.4	94.1
2	95.7	97.3	96.3	97.0	95.3	96.6	107.3	85.5	96.0	96.7
3	81.9	83.3	82.4	83.0	81.6	82.6	91.8	73.2	82.2	82.8
4	81.1	82.5	81.6	82.2	80.8	81.9	91.1	72.4	81.4	82.0

Microphone Position Adjustment Factors[5]

Speed (km/hr)	M1	M2	M3
271	1.000	1.028	0.880
341	1.035	1.052	0.917
386	1.057	1.074	0.945

Impact of Train Speed on Noise Levels

Ricardo evaluated several methods for determining the impact of train speed on passby noise levels. The approach developed by Gautier, Poisson & Letourneaux[5] provided the highest level of correlation with measured data is the basis for the calculations presented below.

$L_{Aeq,tp}(V) - L_{Aeq,tp}(V_0) = K \log(V/V_0)$ where K is an empirical factor where V= train speed (km/hr)

thus, $L_{Aeq,tp}(V) = K \log(V/V_0) + L_{Aeq,tp}(V_0)$ V_0= reference train speed (km/hr)

If the SPL is known at train speed V_0, the SPL at train speed V can be determined from this formula

The empirical factor K varies with train speed. This is because the contribution of noise sources (e.g. wheel/rail interaction, propulsion components, aerodynamics) vary with train speed. Ricardo calculated the K factor values for 12 passby noise data sets.

The relationship between the K factor and train speed is provided by the following equation:

K = a*V + b where a= 0.0625 and b= 25.00

V_0 for this train set is: 271 km/hr

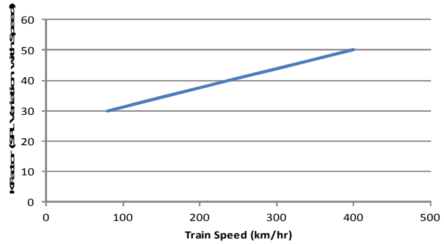
The following tables contain the calculated variation with train speed for the various noise parameters described above:

	Train Speed (km/hr)	K	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
			Microphone Position 1				Noise Metric: Table Entries are dB(A)					
	80	30.0000	77.2	78.8	77.8	78.5	76.9	78.0	88.5	67.3	77.5	78.2
	150	34.3750	84.3	85.9	84.8	85.6	83.9	85.1	95.6	74.4	84.6	85.3
	200	37.5000	88.2	89.8	88.7	89.4	87.8	89.0	99.4	78.3	88.5	89.2
	250	40.6250	91.7	93.3	92.2	93.0	91.3	92.5	103.0	81.8	92.0	92.7
	300	43.7500	95.1	96.6	95.6	96.3	94.7	95.9	106.3	85.1	95.3	96.0
	350	46.8750	98.3	99.9	98.9	99.6	98.0	99.1	109.6	88.4	98.6	99.3
Test Speed→	271	41.9375	93.1	94.7	93.7	94.4	92.7	93.9	104.4	83.2	93.4	94.1

	Train Speed (km/hr)	K	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
			Microphone Position 2				Noise Metric: Table Entries are dB(A)					
	80	30.0000	79.8	81.4	80.4	81.1	79.4	80.7	91.4	69.6	80.1	80.8
	150	34.3750	86.9	88.5	87.4	88.2	86.5	87.7	98.5	76.7	87.2	87.9
	200	37.5000	90.8	92.4	91.3	92.1	90.4	91.6	102.4	80.6	91.1	91.8
	250	40.6250	94.3	95.9	94.8	95.6	93.9	95.1	105.9	84.1	94.6	95.3
	300	43.7500	97.7	99.3	98.2	98.9	97.3	98.5	109.2	87.5	97.9	98.7
	350	46.8750	100.9	102.5	101.5	102.2	100.5	101.8	112.5	90.7	101.2	101.9
Test Speed→	271	41.9375	95.7	97.3	96.3	97.0	95.3	96.6	107.3	85.5	96.0	96.7

	Train Speed (km/hr)	K	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
			Microphone Position 3				Noise Metric: Table Entries are dB(A)					
	80	30.0000	66.0	67.4	66.5	67.1	65.7	66.8	76.0	57.3	66.3	66.9
	150	34.3750	73.1	74.5	73.6	74.2	72.8	73.8	83.0	64.4	73.3	74.0
	200	37.5000	77.0	78.4	77.4	78.1	76.7	77.7	86.9	68.3	77.2	77.8
	250	40.6250	80.5	81.9	81.0	81.6	80.2	81.2	90.4	71.8	80.8	81.4
	300	43.7500	83.9	85.3	84.3	85.0	83.5	84.6	93.8	75.1	84.1	84.7
	350	46.8750	87.1	88.5	87.6	88.2	86.8	87.9	97.1	78.4	87.4	88.0
Test Speed→	271	41.9375	81.9	83.3	82.4	83.0	81.6	82.6	91.8	73.2	82.2	82.8

	Train Speed (km/hr)	K	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
			Microphone Position 4				Noise Metric: Table Entries are dB(A)					
	80	30.0000	65.2	66.6	65.7	66.4	64.9	66.0	75.2	56.5	65.5	66.1
	150	34.3750	72.3	73.7	72.8	73.4	72.0	73.0	82.2	63.6	72.6	73.2
	200	37.5000	76.2	77.6	76.7	77.3	75.9	76.9	86.1	67.5	76.4	77.1
	250	40.6250	79.7	81.1	80.2	80.8	79.4	80.4	89.6	71.0	80.0	80.6
	300	43.7500	83.1	84.5	83.5	84.2	82.7	83.8	93.0	74.3	83.3	83.9
	350	46.8750	86.4	87.7	86.8	87.5	86.0	87.1	96.3	77.6	86.6	87.2
Test Speed→	271	41.9375	81.1	82.5	81.6	82.2	80.8	81.9	91.1	72.4	81.4	82.0



The empirical factor, K, varies with train speed: it is on the order of 30 in speed range to 300 kph and up to 50 for very high speed trains, for which aerodynamic noise sources are dominant.

K = 0.0625(Train Speed, km/hr) + 25

The European Technical Standards for Interoperability (TSI) include two normalized values for $L_{pAEq,Tp}$. The values are normalized to 80 km/hr and 250 km/hr.[6]

The measurements are made at a lateral distance of 7.5 m from the rail centerline and 1.5 m above the top of the rail.

Procedures defined within the TSI to allow noise levels to be calculated at various train speeds based on measurements made at 80 km/hr (50 miles/h) and 250 km/hr (155 miles/h).

For the CHR3 Series Trains, no measurements were made at 80 km/hr and 250 km/hr: Thus, the Gautier method was used to calculate these values

From the Microphone Position 1 Table Above, the normalized values for $L_{pAeq,Tp}$ can be found and are identified below:

Values Obtained from Data Analysis			Value from TSI Formula		TSI Formulas
$L_{pAeq,Tp\ (80\ km/hr)}$ =	**77.2**	**dB(A)**	77.2	dB(A)	$L_{pAeq,Tp}$(80 km/h) = $L_{pAeq,Tp}$(vtest) - 30 * log (vtest/80 km/h)
$L_{pAeq,Tp\ (250\ km/hr)}$ =	**91.7**	**dB(A)**	91.4	dB(A)	$L_{pAeq,Tp}$(250 km/h) = $L_{pAeq,Tp}$(vtest) - 50 * log (vtest/250 km/h)

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Federal Railroad Administration
High Speed Rail Noise Standards and Regulations

Data Set Number: 5
Data Set Name: CRH3 Series (based on Siemens)


China CRH3 Series Train[2]

Data Point Number	Passby Data[1Passby Data1]		Sound Pressure (Pa)	Event
	Time (sec)	dB(A)		
1	1.00	73.6	0.09573	10 dB(A) lower than SPL when Train Nose Passes Microphone
2	1.05	74.6	0.10741	
3	1.10	75.5	0.11913	
4	1.15	76.6	0.13522	
5	1.20	77.3	0.14656	
6	1.25	78.6	0.17023	
7	1.30	79.9	0.19771	
8	1.35	80.7	0.21679	Train Nose Passes Microphone
9	1.40	81.2	0.22963	
10	1.45	81.3	0.23229	
11	1.50	81.7	0.24324	
12	1.55	82.0	0.25179	
13	1.60	82.2	0.25765	
14	1.65	82.3	0.26063	
15	1.70	82.3	0.26063	
16	1.75	82.1	0.25470	
17	1.80	82.7	0.27292	
18	1.85	82.8	0.27608	
19	1.90	82.6	0.26979	
20	1.95	82.5	0.26670	
21	2.00	82.7	0.27292	
22	2.05	82.3	0.26063	

23	2.10	82.1	0.25470	
24	2.15	82.0	0.25179	
25	2.20	82.4	0.26365	
26	2.25	82.4	0.26365	
27	2.30	82.8	0.27608	
28	2.35	83.1	0.28578	
29	2.40	82.9	0.27927	←
30	2.45	82.9	0.27927	
31	2.50	83.0	0.28251	Start Time for LpASmax Calculat
32	2.55	82.8	0.27608	
33	2.60	82.7	0.27292	
34	2.65	82.6	0.26979	
35	2.70	82.9	0.27927	
36	2.75	82.9	0.27927	
37	2.80	82.9	0.27927	
38	2.85	83.3	0.29244	←
39	2.90	83.1	0.28578	
40	2.95	83.4	0.29582	Maximum Sound Pressure Lev
41	3.00	83.2	0.28909	
42	3.05	82.8	0.27608	
43	3.10	82.8	0.27608	
44	3.15	82.8	0.27608	
45	3.20	82.9	0.27927	
46	3.25	83.0	0.28251	
47	3.30	83.0	0.28251	
48	3.35	82.8	0.27608	
49	3.40	82.8	0.27608	←
50	3.45	83.2	0.28909	
51	3.50	83.1	0.28578	End Time for LpASmax Calculat
52	3.55	82.5	0.26670	
53	3.60	82.3	0.26063	
54	3.65	82.6	0.26979	
55	3.70	82.2	0.25765	
56	3.75	82.2	0.25765	
57	3.80	81.7	0.24324	
58	3.85	81.4	0.23498	←
59	3.90	81.3	0.23229	
60	3.95	81.3	0.23229	Train Tail Passes Microphone
61	4.00	80.7	0.21679	
62	4.05	79.4	0.18665	
63	4.10	78.4	0.16635	
64	4.15	77.6	0.15172	
65	4.20	77.1	0.14323	
66	4.25	77.1	0.14323	
67	4.30	76.1	0.12765	
68	4.35	75.4	0.11777	←

69	4.40	74.9	0.11118
70	4.45	73.8	0.09796
71	4.50	73.2	0.09142

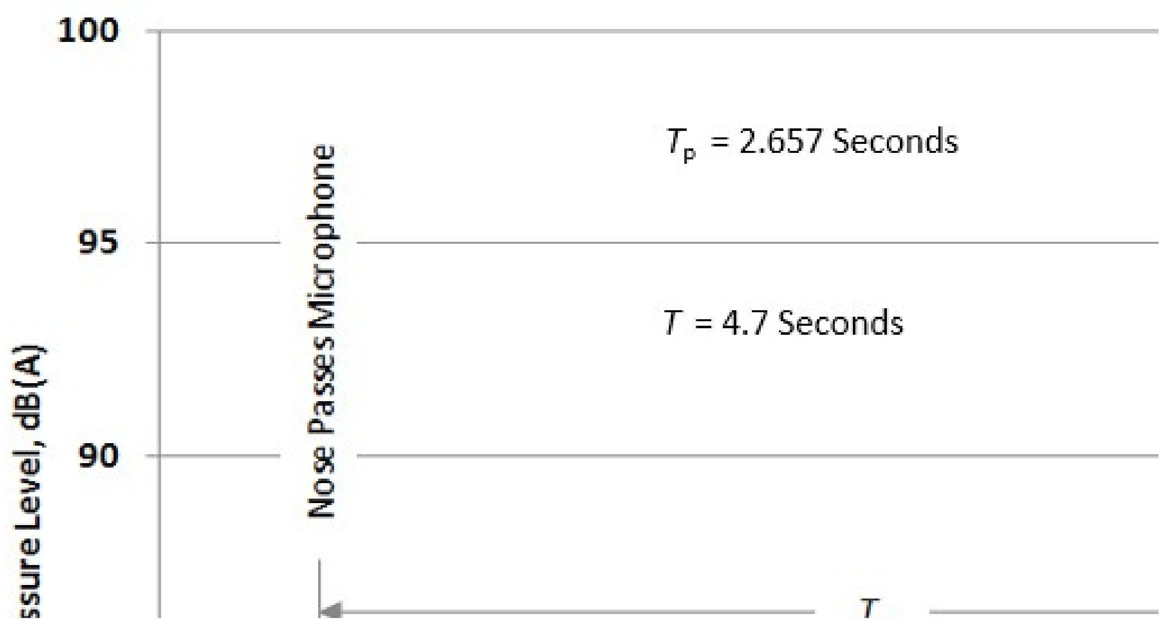
10 dB(A) lower than SPL when Train Tail Passes Microphone

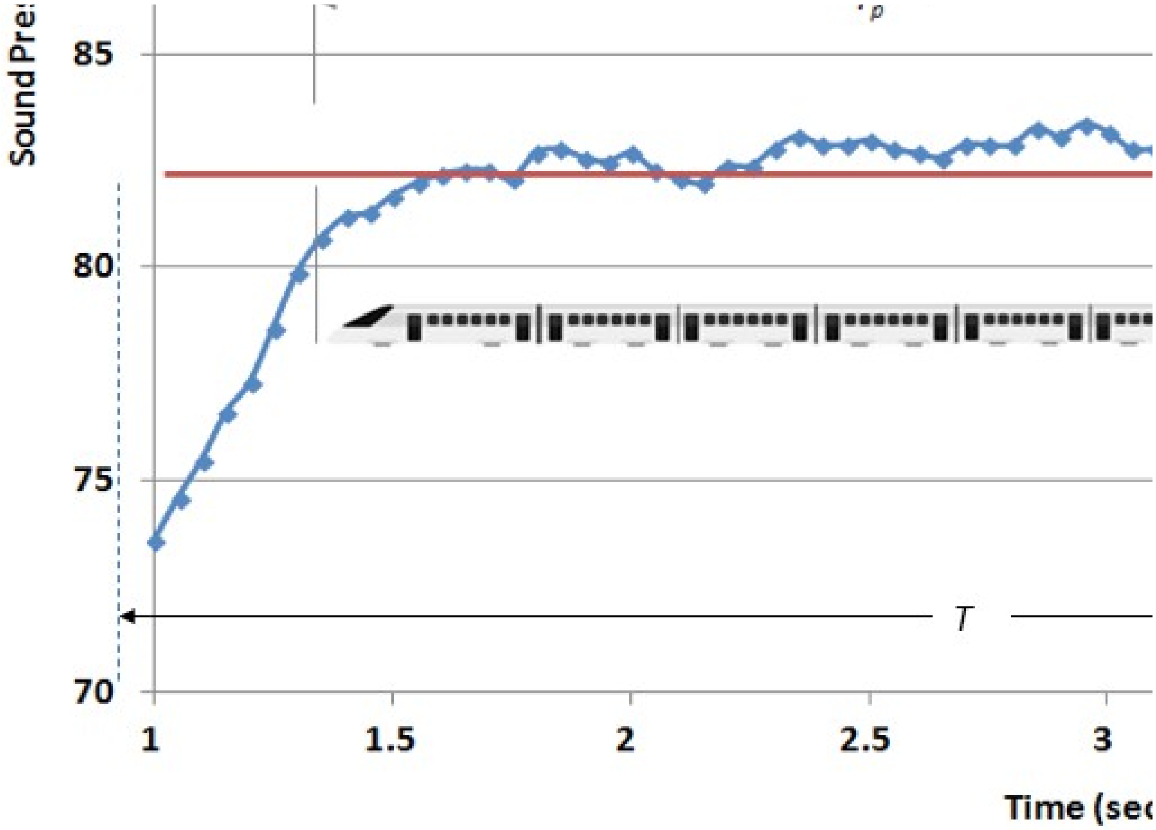
Spreadsheet-Based Tool for Comparing Noise Standards and Re
Conversion Tool for Noise Regulations and Standards to Commo

CONTRAST Comparison Of Noise for TRAin STandards

Train Set Information			
Year Data Set was Generated:	2014		[1]He, B., *et. al.*, Inv
Train Set Manufacturer:	Changchun Railway Vehicles, Siemens		J. Zhejang Univ-Sc
Operator:	China Railway Corporation		[2]China CRH3 Series
Train Set Geometry and Test Conditions			https://www.railw
Parameter	**Value**	**Units**	
Car Lengths			
End Cars:	25.641	m	
Intermediate Cars:	24.786	m	
Number of End Cars:	2		
Number of Intermediate Cars:	6		
Test Train Length:	200	m	
Test Train Speed(s):	271	km/hr	
Microphone Position:	3		dB (sound press
Distance from Track Centerline:	25	m	where 0.0002 is
Elevation above Top of Rail:	3.5	m	so, Pa = 0.00002
Time Increment for Pass-By Data, ΔT:Time In	0.05	sec	
Number of Pass-By Data Points:	71		

Plot of Passby Noise Data, Including Key Time Parameters





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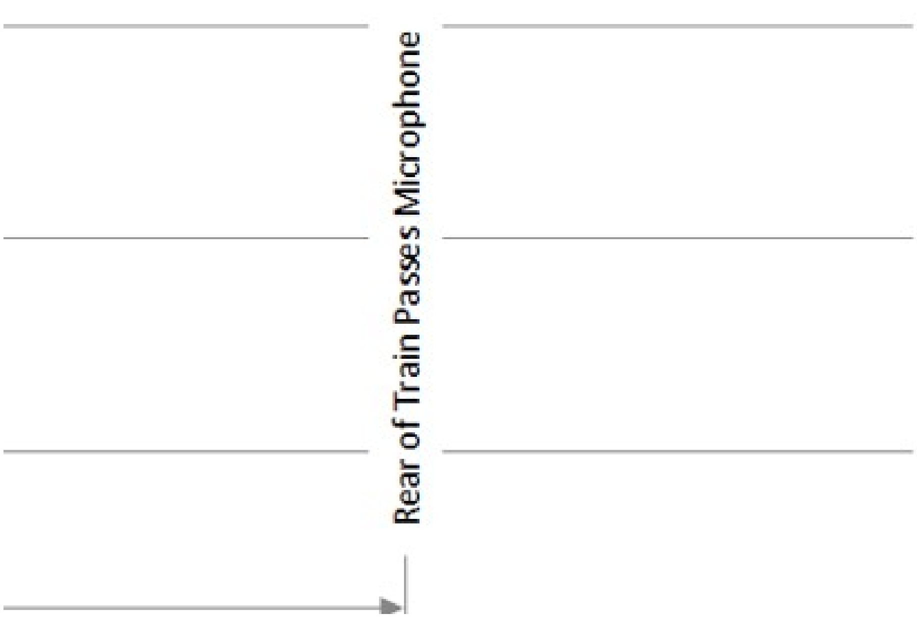
Program Version: 7 14-Oct-19

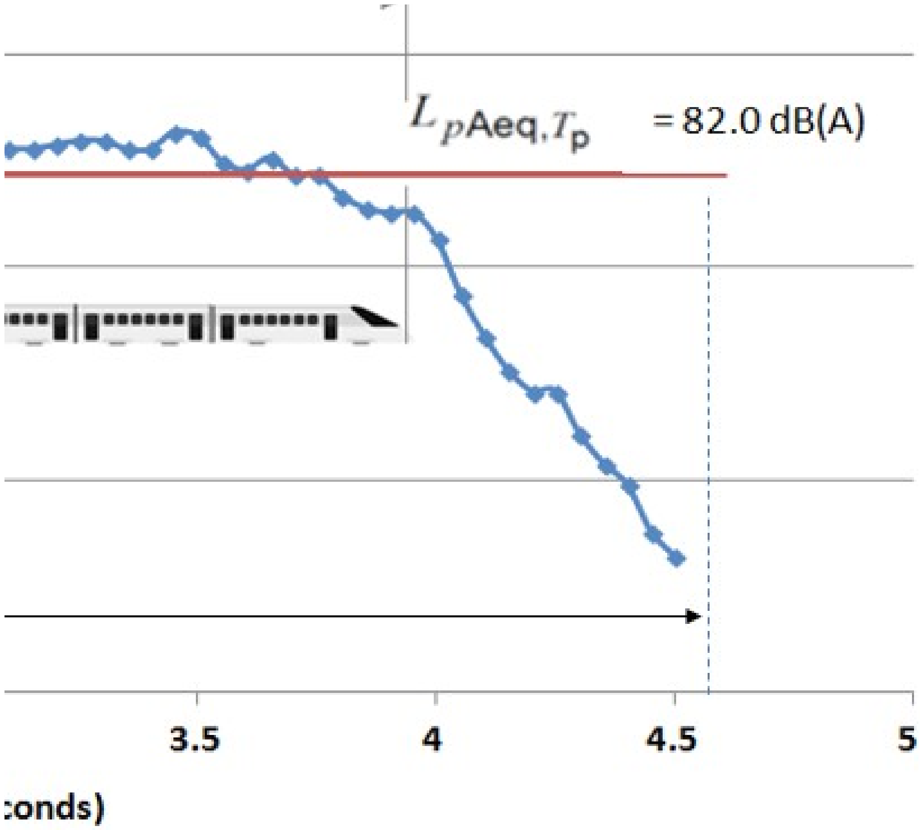
References

/estigation into Exterior Noise of a High-Speed Train at Different Speeds, [1]He, B., *et. al.*, Investigation into Exterior N
ci A (Applied Physics and Enginering), 2014, Vol 15 (12), Pages 1019-1033.
High Speed Train Image; provided by *Railway Technology*, 2019,[2]China CRH3 Series High Speed Train Image; provided by *Railway*
ay-technology.com/projects/beijing-tianjin/

Formulas

;ure level in decibels) = 20 $\log_{10}$(Pa/0.00002) dB (sound pressure level in decibels) = 20 $\log_{10}$(Pa/0.00002) d
; the reference sound pressure level in Pascals
2*10^(dB/20)so, Pa = 0.00002*10(dB/20)so, Pa = 0.00002*10(dB/20)so, Pa = 0.00002*10(dB/20)so, Pa = 0.00002*10(dB/20)so, Pa = 0.00002*10(dB/20)





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decibels) = 20 $\log_{10}$(Pa/0.00002)

gation into Exterior Noise of a High-Speed Train at Different Sp

U.S. Department of Transportation
Federal Railroad Administration

Spreadsheet-Based Tool for Comparing Noise Standards and Regulations
Conversion Tool for Noise Regulations and Standards to Common Reference

RICARDO

Federal Railroad Administration
High Speed Rail Noise Standards and Regulations

CONTRAST Comparison Of Noise for TRAin STandards

Program Version: 7 14-Oct-19

Data Set Number:	5	Passby Noise Calculations	References
Data Set Name:	CRH3 Series (based on Siemens)		

Calculate Train Passby Parameters

Train Speed (V):	271	km/hr =	75.28	m/sec
Train Length:	200	m	10 cars: 2 end cars and 8 intermediate cars	
Time for Passby (T_p)	2.656826568	seconds	This is the time increment between nose of train passing microphone and tail of train passing microphone.	
Time for TEL (T_{TEL})	4.70	seconds	TEL is the Transit Exposure Limit and represents the equivalent A-weighted SPL over the time period beginning when the instantaneous meter reading is 10 dB(A) less than $L_{pAEq,Tp}$ and continuing through the passby event until the meter reading is again 10 dB(A) less than $L_{pAeq,Tp}$	

References

[1] He, et al., Investigation into External Noise of a High-Speed Train at Different Speeds, J Zhejiang Univ-Sci A (Appl Phys & Eng) 2014, 15(12):1019-1033

[2] Paul, et al, High Speed Rail Noise Standards and Regulations, US DOT Federal Railroad Administration, Contract DTFR35-16-C00006, May 2017.

[3] G. Xiaoan and J. Hua, "Application Research on Descending Vibration and Reducing Noise in Accelerating Speed Trains and Express Trains," Chinese Academy of Railway Sciences (CARS) Research Report, Beijing Shi, China, 2003.

[4] Hanson, C.E., et. al., High Speed Ground Transportation Noise and Vibration Impact Assessment, U.S. Department of Transportation, Federal Railroad Administration, Report Number DOT/FRA/ORD-12/15, September 2012.

[5] Gautier, P.E., Poisson, F., and Letourneaux, F., High Speed Trains External Noise: A Review of Measurements and Source Models for TGV Case Up to 360 km/hr, in Proceedings of the 8th World Congress on Railway Research (2008).

[6] European Union, "Commission Regulation Number 1304/2014, on the technical specification for interoperability relating to the subsystem 'rolling stock — noise' amending Decision 2008/232/EC and repealing Decision 2011/229/EU," Official Journal of the European Union, Brussels, Belgium, 2014.

Calculate $L_{pAeq,Tp}$

$L_{pAeq,Tp}$ is the A-weighted equivalent continuous sound pressure level produced by the train as measured during the passby event

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

$L_{pAeq,Tp}$ can be calculated from the passby data using the following relationship:

$$\int_{T_1}^{T_2}\frac{p_A^2(t)}{p_0^2}dt \approx \sum_{i=1}^{i=n}\left(\frac{Pa(i)^2}{p_0^2}\right)\Delta t_i$$

Microphone Position is 25 m from track centerline and 3.5 m above top of rail (Microphone Position 3).

where

T_p	is the passby time interval = time when trail tail passes microphone minus time when train nose passes microphone = $T_2 - T_1$			
T_1	is the time when the train nose passes the microphone			
T_2	is the time when the train tail passes the microphone			
$P_A(t)$	is the A-weighted instantaneous sound pressure in Pa at time t			
p_0	is the reference sound pressure:	$p_0 = 20\mu Pa$ =	0.00002	Pa
Δt_i	is the time increment between measured data points =		0.05	seconds
$P_A(i)$	is the A-weighted instantaneous sound pressure in Pa at passby time increment i			

An analysis conducted during the current study indicated the integral can be determined numerically, with acceptable accuracy, by employing a midpoint Reimann sum scheme with a mimimum Δti = 0.05 seconds, and the corresponding Pa(i) analog meter values. This approach is described in: Hughes-Hallett, Deborah; McCullum, William G.; et al. (2005). *Calculus (4th ed.)*, Wiley. p. 252.

Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$	Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$	Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$	Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$
1	1.00	73.60	0.095726	2.29087E+07	19	1.90	82.60	0.269793	1.81970E+08	37	2.80	82.90	0.279274	1.94984E+08	55	3.70	82.20	0.257650	1.65959E+08
2	1.05	74.60	0.107406	2.88403E+07	20	1.95	82.50	0.266704	1.77828E+08	38	2.85	83.30	0.292435	2.13796E+08	56	3.75	82.20	0.257650	1.65959E+08
3	1.10	75.50	0.119132	3.54813E+07	21	2.00	82.70	0.272917	1.86209E+08	39	2.90	83.10	0.285779	2.04174E+08	57	3.80	81.70	0.243237	1.47911E+08
4	1.15	76.60	0.135217	4.57088E+07	22	2.05	82.30	0.260633	1.69824E+08	40	2.95	83.40	0.295822	2.18776E+08	58	3.85	81.40	0.234980	1.38038E+08
5	1.20	77.30	0.146565	5.37032E+07	23	2.10	82.10	0.254701	1.62181E+08	41	3.00	83.20	0.289088	2.08930E+08	59	3.90	81.30	0.232290	1.34896E+08
6	1.25	78.60	0.170228	7.24436E+07	24	2.15	82.00	0.251785	1.58489E+08	42	3.05	82.80	0.276077	1.90546E+08	60	3.95	81.30	0.232290	1.34896E+08
7	1.30	79.90	0.197711	9.77237E+07	25	2.20	82.40	0.263651	1.73780E+08	43	3.10	82.80	0.276077	1.90546E+08	61	4.00	80.70	0.216785	1.17490E+08
8	1.35	80.70	0.216785	1.17490E+08	26	2.25	82.40	0.263651	1.73780E+08	44	3.15	82.80	0.276077	1.90546E+08	62	4.05	79.40	0.186651	8.70964E+07
9	1.40	81.20	0.229631	1.31826E+08	27	2.30	82.80	0.276077	1.90546E+08	45	3.20	82.90	0.279274	1.94984E+08	63	4.10	78.40	0.166353	6.91831E+07
10	1.45	81.30	0.232290	1.34896E+08	28	2.35	83.10	0.285779	2.04174E+08	46	3.25	83.00	0.282508	1.99526E+08	64	4.15	77.60	0.151716	5.75440E+07
11	1.50	81.70	0.243237	1.47911E+08	29	2.40	82.90	0.279274	1.94984E+08	47	3.30	83.00	0.282508	1.99526E+08	65	4.20	77.10	0.143229	5.12861E+07
12	1.55	82.00	0.251785	1.58489E+08	30	2.45	82.90	0.279274	1.94984E+08	48	3.35	82.80	0.276077	1.90546E+08	66	4.25	77.10	0.143229	5.12861E+07
13	1.60	82.20	0.257650	1.65959E+08	31	2.50	83.00	0.282508	1.99526E+08	49	3.40	82.80	0.276077	1.90546E+08	67	4.30	76.10	0.127653	4.07380E+07
14	1.65	82.30	0.260633	1.69824E+08	32	2.55	82.80	0.276077	1.90546E+08	50	3.45	83.20	0.289088	2.08930E+08	68	4.35	75.40	0.117769	3.46737E+07
15	1.70	82.30	0.260633	1.69824E+08	33	2.60	82.70	0.272917	1.86209E+08	51	3.50	83.10	0.285779	2.04174E+08	69	4.40	74.90	0.111181	3.09030E+07
16	1.75	82.10	0.254701	1.62181E+08	34	2.65	82.60	0.269793	1.81970E+08	52	3.55	82.50	0.266704	1.77828E+08	70	4.45	73.80	0.097956	2.39883E+07
17	1.80	82.70	0.272917	1.86209E+08	35	2.70	82.90	0.279274	1.94984E+08	53	3.60	82.30	0.260633	1.69824E+08	71	4.50	73.20	0.091418	2.08930E+07
18	1.85	82.80	0.276077	1.90546E+08	36	2.75	82.90	0.279274	1.94984E+08	54	3.65	82.60	0.269793	1.81970E+08					

Data Point Number for Start of Passby Event (time at which train nose passes microphone): 8 i = 1

Data Point Number for End of Passby Event (time at which train tail passes microphone): 60 i - n

thus, $\sum_{i=1}^{i=n}\left(\frac{Pa(i)^2}{p_0^2}\right)\Delta t_i$ = 4.29114E+08

$$L_{pAeq,Tp} = 10\ \lg\left(\frac{1}{T_2 - T_1}\int_{T_1}^{T_2}\frac{p_A^2(t)}{p_0^2}dt\right)$$

$L_{pAeq,Tp}$ = 82.08 dB(A)

Impact of Microphone Position

Microphone Position	Distance from Track Centerline (m)	Elevation Above Top of Rail (m)	Applies to Regulations in these Regions[2]				Comment
			US	EU	China	Japan	
1	7.5	1.2		X (TSI 2014)			TSI 1304
2	7.5	3.5		X (TSI 2014)			Also required for speeds > 250 km/hr
3	25	3.5		X (TSI 2008)		X	Reference for pre 2014 train sets
4	30	1.2	X		X		US and China measurement location

References:

[a] L. Lu, X. Hu, Y. Zhang and X. Zhou, "Survey and Analysis of the Beijing-Shanghai High Speed Rail Noise," in The 21st International Congress on Sound and Vibration, Beijing, China, 2014.

[b] G. Xiaoan and J. Hua, "Application Research on Descending Vibration and Reducing Noise in Accelerating Speed Trains and Express Trains," Chinese Academy of Railway Sciences (CARS) Research Report, Beijing Shi, China, 2003.

[c] W. Elliott, "Request for Information Reference FOI13-580, Comparison of Measured Sound

Impact of microphone distance is determined from the following equation:[3] $L_d = L_{d0} - 10*LOG(d/d0)$, where L_{d0} is the equivalent A-weighted constant sound pressure level for the microphone at distance d0, and d is the distance for Ld.

Levels for High Speed Trains as a Functionof Distance from Track," High Speed Rail Two (HS2), London, England, 2013.

Microphone Position	Distance from Track Centerline (m)	Elevation Above Top of Rail (m)	$L_{pAeq,Tp}$ at 271 km/h dB(A)	$L_{pAeq,Tp}$ at 271 km/h (Pa)
1	7.5	1.2	93.20	0.914
2	7.5	3.5	95.80	1.233
3	25	3.5	82.08	0.254
4	30	1.2	81.29	0.232

To convert dB(A) to Pascals: Pa = 0.00002*(10^(dBA/20))

To convert Pa to dB(A), dB(A) = 20*LOG10(Pa/0.00002)

Note: The simple sound level correction formula underestimates the measured values. Therefore, ratios based on actual measurements were used to adjust for microphone location (table at right).

Sound Pressure Variations for Microphone Positions and Train Speed from Reference 5			
Speed (km/hr)	$L_{pAeq,Tp}$ dB(A)		
	M1	M2	M3
271	93.2	95.8	82.0
341	96.5	98.0	85.5
386	98.5	100.1	88.1

Calculated Noise Metrics: Maximum Recorded Sound Pressure Levels

The following calculations are for Microphone Position 3 $L_{p(maximum)}$ = maximum recorded passby sound pressure level

$L_{p(maximum)}$ = **83.4** dB(A) which occurs at data point 40 at pass-by time 2.95 seconds

L_{pASmax} is the maximum sound pressure level, slow and A-weighted and L_{pAFmax} = maximum sound pressure level, fast and A-weighted. The time period for the "slow" reading is 1 second. The time period for the "fast" reading is 0.125 seconds.

L_{pASmax} can be calculated as the logarithmic average of the recorded SPLs for the 1 second time interval containing the highest values

The logarithmic average for an Excel array is: {=10*LOG(AVERAGE(10^(ARRAY/10)))} array-entered, i.e. using CTRL-Shift-Enter keys where array is of the form A10:A15. In the current case, the array is Pass-By Data Set 1, C:48:C68

Highest 1-second interval occurs from start time 2.5 to end time 3.5 **Thus, L_{pASmax} = 82.96 dB(A)**

Similarly, L_{pAFmax} can be calculated as the logarithmic average of the recorded SPLs for the 0.125 second time interval containing the highest values

Highest 0.125-second interval occures from start time 2.85 to end time 2.975 **Thus, L_{pAFmax} = 83.25 dB(A)**

Calculated Noise Metrics: Other Standard Parameters

The following calculations are for Microphone Position 3

$L_{pAeq,passby}$ is the A-weighted equivalent continuous sound pressure level produced during the entire pass-by event, including approach, T_p, and departure (used for L_d, L_n, etc.)

The calculation includes all of the pass-by data points.

Data Point Number for Start of Passby Event (time at which train nose passes microphone): 1 i = 1

Data Point Number for End of Passby Event (time at which train tail passes microphone): 71 i - n thus, $\sum_{i=1}^{i=n}\left(\frac{Pa(i)^2}{p_0^2}\right)\Delta t_i$ = 5.20591E+08 $T_2 - T_1$ = 3.50 seconds

$L_{pAeq,passby} = 10\ lg\left(\frac{1}{T_2-T_1}\int_{T_1}^{T_2}\frac{p_A^2(t)}{p_0^2}dt\right)$ **$L_{pAeq,passby}$ = 81.72 dB(A)**

TEL is the Transit Exposure Limit[4]. It is measured over the time interval starting when the SPL is 10 dB(A) lower than $L_{pAeq,Tp}$ and ending when the SPL again reaches a value that is 10 dB(A) lower than $L_{pAeq,Tp}$

TEL is calculated using the following formula: $TEL = L_{pAeq,Tp} + 10*LOG(T_{TEL}/T_p)$ **TEL = 84.56 dB(A)**

SEL is the Sound Exposure Limit[4]. Like $L_{pAeq,Tp}$, it integrates the total sound energy over a measurement period, but for SEL, the measurement period is normalized to a duration of 1 second. At a microphone distance of 30 m (100 ft), SEL = $L_{pAeq,Tp} + 10*LOG(Tp) + 1$

SEL at 30 m: 87.33 dB(A) SEL at 7.5 m: 93.35 dB(A) SEL at 25 m: 88.12 dB(A) using the distance correction factor: $L_d = L_{d0} - 10*LOG(d/d0)$

SEL is the cumulative noise exposure (i.e. "dose") for a single noise event normalized over 1 second. The fact that SEL is a cumulative measure means that (1) louder events have higher SELs than quieter ones, and (2) events that last longer in time have higher SELs than shorter ones.[4]

Statistical Parameters

The following parameters are determined by specifying the indicated percentile of the data values using Excel Function PERCENTILE(range,P).

where" range" is the array of values (e.g. K10:K68) and P = the percentile (between 0 and 1, for example, P for the 90th percentile would be entered as 0.9)

L_{10} is the sound pressure level for which 90% of the recorded values are greater. It includes lead-in (prior to nose passing microphone) and trail-off (after tail of train passes) data. L_{10} = **76.10 dB(A)**

L_{50} is the sound pressure level for which 50% of the recorded values are greater. It includes lead-in (prior to nose passing microphone) and trail-off (after tail of train passes) data. L_{50} = **82.30 dB(A)**

L_{90} is the sound pressure level for which 10% of the recorded values are greater. It includes lead-in (prior to nose passing microphone) and trail-off (after tail of train passes) data. L_{90} = **83.00 dB(A)**

Summary of Passby Noise Metrics for Each Microphone Position

The noise metrics shown in the following table correspond to the baseline speed of 271 km/hr $L_d = L_{d0} - 10*LOG(d/d0)$, where L_{d0} is the equivalent A-weighted constant sound pressure level for the microphone at distance d0, and d is the distance for L_d.

Microphone Position			Noise Metric: Table Entries are dB(A)							
	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
1	93.3	94.8	94.3	94.6	92.9	96.1	100.2	86.5	93.5	94.3
2	95.9	97.4	96.9	97.3	95.5	98.8	102.9	88.9	96.2	97.0
3	82.1	83.4	83.0	83.3	81.7	84.6	88.1	76.1	82.3	83.0
4	81.3	82.6	82.2	82.5	80.9	83.8	87.3	75.3	81.5	82.2

Microphone Position Adjustment Factors[5]			
Speed (km/hr)	M1	M2	M3
271	1.000	1.028	0.880
341	1.035	1.052	0.917
386	1.057	1.074	0.945

Impact of Train Speed on Noise Levels

Ricardo evaluated several methods for determining the impact of train speed on passby noise levels. The approach developed by Gautier, Poisson & Letourneaux[5] provided the highest level of correlation with measured data is the basis for the calculations presented below.

$L_{Aeq,tp}(V) - L_{Aeq,tp}(V_0) = K\ log(V/V_0)$ where K is an empirical factor where V= train speed (km/hr) If the SPL is known at train speed V_0, the SPL at train speed V can be determined from this formula

thus, $L_{Aeq,tp}(V) = K\ log(V/V_0) + L_{Aeq,tp}(V_0)$ V_0= reference train speed (km/hr)

The empirical factor K varies with train speed. This is because the contribution of noise sources (e.g. wheel/rail interaction, propulsion components, aerodynamics) vary with train speed. Ricardo calculated the K factor values for 12 passby noise data sets.

The relationship between the K factor and train speed is provided by the following equation:

K = a*V + b where a= 0.0625 and b= 25.00

V_0 for this train set is: 271 km/hr

The following tables contain the calculated variation with train speed for the various noise parameters described above:

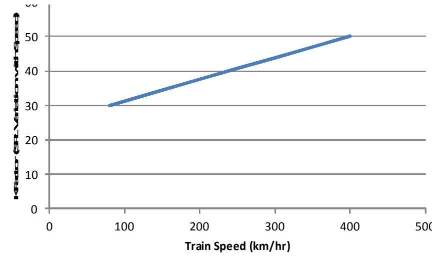
			Microphone Position 1		Noise Metric: Table Entries are dB(A)

Train Speed (km/hr)	K	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
80	30.0000	77.4	78.9	78.4	78.7	77.0	80.2	84.3	70.6	77.6	78.4
150	34.3750	84.5	86.0	85.5	85.8	84.1	87.3	91.3	77.7	84.7	85.5
200	37.5000	88.3	89.8	89.3	89.7	87.9	91.2	95.2	81.5	88.6	89.4
250	40.6250	91.9	93.4	92.9	93.2	91.5	94.7	98.7	85.1	92.1	92.9
300	43.7500	95.2	96.7	96.2	96.6	94.8	98.0	102.1	88.4	95.5	96.3
350	46.8750	98.5	100.0	99.5	99.8	98.1	101.3	105.4	91.7	98.7	99.5
Test Speed→ 271	41.9375	93.3	94.8	94.3	94.6	92.9	96.1	100.2	86.5	93.5	94.3

			Microphone Position 2			Noise Metric: Table Entries are dB(A)					
Train Speed (km/hr)	K	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
80	30.0000	80.0	81.5	81.0	81.4	79.6	82.9	87.1	73.0	80.3	81.1
150	34.3750	87.1	88.6	88.1	88.4	86.6	90.0	94.1	80.1	87.3	88.1
200	37.5000	90.9	92.5	92.0	92.3	90.5	93.8	98.0	84.0	91.2	92.0
250	40.6250	94.5	96.0	95.5	95.8	94.1	97.4	101.5	87.5	94.7	95.5
300	43.7500	97.8	99.4	98.8	99.2	97.4	100.7	104.9	90.8	98.1	98.9
350	46.8750	101.1	102.6	102.1	102.5	100.7	104.0	108.2	94.1	101.4	102.2
Test Speed→ 271	41.9375	95.9	97.4	96.9	97.3	95.5	98.8	102.9	88.9	96.2	97.0

			Microphone Position 3			Noise Metric: Table Entries are dB(A)					
Train Speed (km/hr)	K	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
80	30.0000	66.2	67.5	67.1	67.4	65.8	68.7	72.2	60.2	66.4	67.1
150	34.3750	73.3	74.6	74.1	74.4	72.9	75.7	79.3	67.3	73.5	74.2
200	37.5000	77.1	78.5	78.0	78.3	76.8	79.6	83.2	71.2	77.4	78.1
250	40.6250	80.7	82.0	81.5	81.8	80.3	83.1	86.7	74.7	80.9	81.6
300	43.7500	84.0	85.3	84.9	85.2	83.7	86.5	90.0	78.0	84.2	84.9
350	46.8750	87.3	88.6	88.2	88.5	86.9	89.8	93.3	81.3	87.5	88.2
Test Speed→ 271	41.9375	82.1	83.4	83.0	83.3	81.7	84.6	88.1	76.1	82.3	83.0

			Microphone Position 4			Noise Metric: Table Entries are dB(A)					
Train Speed (km/hr)	K	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
80	30.0000	65.4	66.7	66.3	66.6	65.0	67.9	71.4	59.4	65.6	66.3
150	34.3750	72.5	73.8	73.3	73.6	72.1	74.9	78.5	66.5	72.7	73.4
200	37.5000	76.3	77.7	77.2	77.5	76.0	78.8	82.4	70.4	76.6	77.3
250	40.6250	79.9	81.2	80.7	81.0	79.5	82.3	85.9	73.9	80.1	80.8
300	43.7500	83.2	84.5	84.1	84.4	82.9	85.7	89.3	77.2	83.4	84.1
350	46.8750	86.5	87.8	87.4	87.7	86.1	89.0	92.5	80.5	86.7	87.4
Test Speed→ 271	41.9375	81.3	82.6	82.2	82.5	80.9	83.8	87.3	75.3	81.5	82.2



The empirical factor, K, varies with train speed: it is on the order of 30 in speed range to 300 kph and up to 50 for very high speed trains, for which aerodynamic noise sources are dominant.

K = 0.0625(Train Speed, km/hr) + 25

The European Technical Standards for Interoperability (TSI) include two normalized values for $L_{pAEq,Tp}$. The values are normalized to 80 km/hr and 250 km/hr.[6]

The measurements are made at a lateral distance of 7.5 m from the rail centerline and 1.5 m above the top of the rail.

Procedures defined within the TSI to allow noise levels to be calculated at various train speeds based on measurements made at 80 km/hr (50 miles/h) and 250 km/hr (155 miles/h).

<u>For the CRH3 Series Trains, no measurements were made at 80 km/hr and 250 km/hr</u>: Thus, the Gautier method was used to calculate these values

From the Microphone Position 1 Table Above, the normalized values for $L_{pAeq,Tp}$ can be found and are identified below:

Values Obtained from Data Analysis			Value from TSI Formula		TSI Formulas
$L_{pAeq,Tp\ (80\ km/hr)}$ =	**77.4**	**dB(A)**	77.4	dB(A)	$L_{pAeq,Tp}$(80 km/h) = $L_{pAeq,Tp}$(vtest) - 30 * log (vtest/80 km/h)
$L_{pAeq,Tp\ (250\ km/hr)}$ =	**91.9**	**dB(A)**	91.5	dB(A)	$L_{pAeq,Tp}$(250 km/h) = $L_{pAeq,Tp}$(vtest) - 50 * log (vtest/250 km/h)

Federal Railroad Administration
High Speed Rail Noise Standards and Regulations

Data Set Number: 6
Data Set Name: Common Reference

The Common Reference Data Set is a Scaled Version of the Thalys PBKA (see Data Set 2).

Data Point Number	Passby Data[1Passby Data1]		Sound Pressure (Pa)	Event
	Time (sec)	dB(A)		
1	0.00	73.9	0.09909	
2	0.05	74.6	0.10741	
3	0.10	74.6	0.10741	
4	0.15	75.8	0.12332	
5	0.20	76.2	0.12913	
6	0.25	77.9	0.15705	
7	0.30	79.1	0.18031	
8	0.35	80.3	0.20703	
9	0.40	81.1	0.22700	
10	0.45	83.6	0.30271	
11	0.50	84.8	0.34756	←
12	0.55	86.6	0.42759	10 dB(A) lower than SPL when
13	0.60	88.5	0.53215	Train Nose Passes Microphone
14	0.65	90.5	0.66993	←
15	0.70	93.0	0.89337	
16	0.75	95.1	1.13771	Train Nose Passes Microphone
17	0.80	96.6	1.35217	
18	0.85	99.0	1.78250	
19	0.90	98.9	1.76210	
20	0.95	97.7	1.53472	
21	1.00	98.6	1.70228	

22	1.05	97.7	1.53472	
23	1.10	97.4	1.48262	
24	1.15	96.3	1.30626	
25	1.20	95.5	1.19132	
26	1.25	97.3	1.46565	
27	1.30	99.4	1.86651	
28	1.35	98.6	1.70228	
29	1.40	96.6	1.35217	←
30	1.45	96.0	1.26191	
31	1.50	96.5	1.33669	Start Time for LpASmax Calculat
32	1.55	96.9	1.39968	
33	1.60	96.8	1.38366	
34	1.65	94.9	1.11181	
35	1.70	95.7	1.21907	
36	1.75	96.6	1.35217	
37	1.80	97.6	1.51716	
38	1.85	96.1	1.27653	
39	1.90	97.7	1.53472	←
40	1.95	99.9	1.97711	
41	2.00	100.5	2.11851	Maximum Sound Pressure Leve
42	2.05	99.6	1.90999	
43	2.10	97.6	1.51716	
44	2.15	98.6	1.70228	
45	2.20	100.2	2.04659	
46	2.25	100.6	2.14304	
47	2.30	99.1	1.80314	
48	2.35	97.2	1.44887	
49	2.40	98.6	1.70228	←
50	2.45	98.6	1.70228	
51	2.50	98.2	1.62566	End Time for LpASmax Calculati
52	2.55	96.6	1.35217	
53	2.60	95.9	1.24747	
54	2.65	98.6	1.70228	
55	2.70	98.4	1.66353	
56	2.75	96.6	1.35217	
57	2.80	95.9	1.24747	
58	2.85	97.0	1.41589	
59	2.90	98.7	1.72199	
60	2.95	100.2	2.04659	
61	3.00	99.1	1.80314	←
62	3.05	97.6	1.51716	
63	3.10	96.6	1.35217	
64	3.15	95.5	1.19132	Train Tail Passes Microphone
65	3.20	95.6	1.20512	
66	3.25	93.6	0.95726	←
67	3.30	90.7	0.68554	

68	3.35	89.4	0.59024
69	3.40	88.0	0.50238
70	3.45	86.6	0.42759
71	3.50	85.6	0.38109
72	3.55	84.5	0.33576
73	3.60	83.6	0.30271
74	3.65	81.1	0.22700
75	3.70	80.3	0.20703
76	3.75	79.1	0.18031
77	3.80	77.8	0.15525
78	3.85	76.7	0.13678
79	3.90	75.5	0.11913
80	3.95	74.5	0.10618
81	4.00	73.9	0.09909
82	4.05	72.9	0.08831
83	4.10	71.7	0.07692
84	4.15	71.0	0.07096
85	4.20	70.6	0.06777

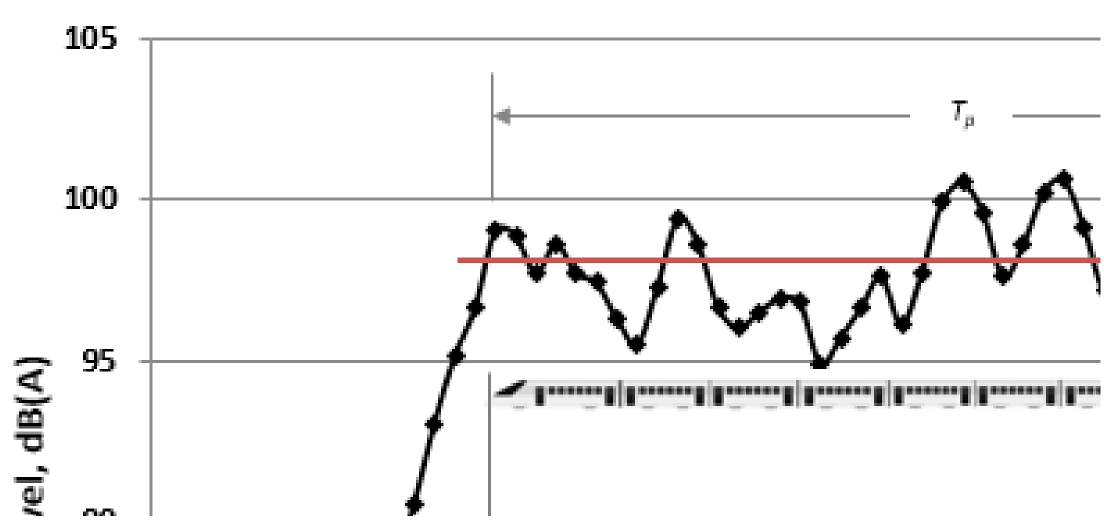
10 dB(A) lower than SPL when
Train Tail Passes Microphone

Spreadsheet-Based Tool for Comparing Noise Standards and Re
Conversion Tool for Noise Regulations and Standards to Commc

CONTRAST Comparison **O**f **N**oise for **TRA**in **ST**andards

Train Set Information			
Year Data Set was Generated:		2010	[1]Dittrich, M.G., et
Train Set Manufacturer:		GEC-Alsthom	Thalys treinen op
Operator:		Thalys	trains on HSL Rhe
Train Set Geometry and Test Conditions			Natuurwetenschap
Parameter	**Value**	**Units**	[2]Thalys PBKA image
Car Lengths			Version 1.2 or any l
End Cars:	22.15	m	https://commons.v
Intermediate Cars: two at 21.845 m and six at 18.7 m			
Number of End Cars:	2		
Number of Intermediate Cars:	8		
Test Train Length:	200.19	m	
Test Train Speed(s):	296	km/hr	
Microphone Position:	1		dB (sound press
Distance from Track Centerline:	7.5	m	where 0.0002 is
Elevation above Top of Rail:	1.2	m	so, Pa = 0.0000:
Time Increment for Passby Data, ΔT:Time	0.05	sec	
Number of Passby Data Points:	85		

Plot of Passby Noise Data, Including Key Time Parameters



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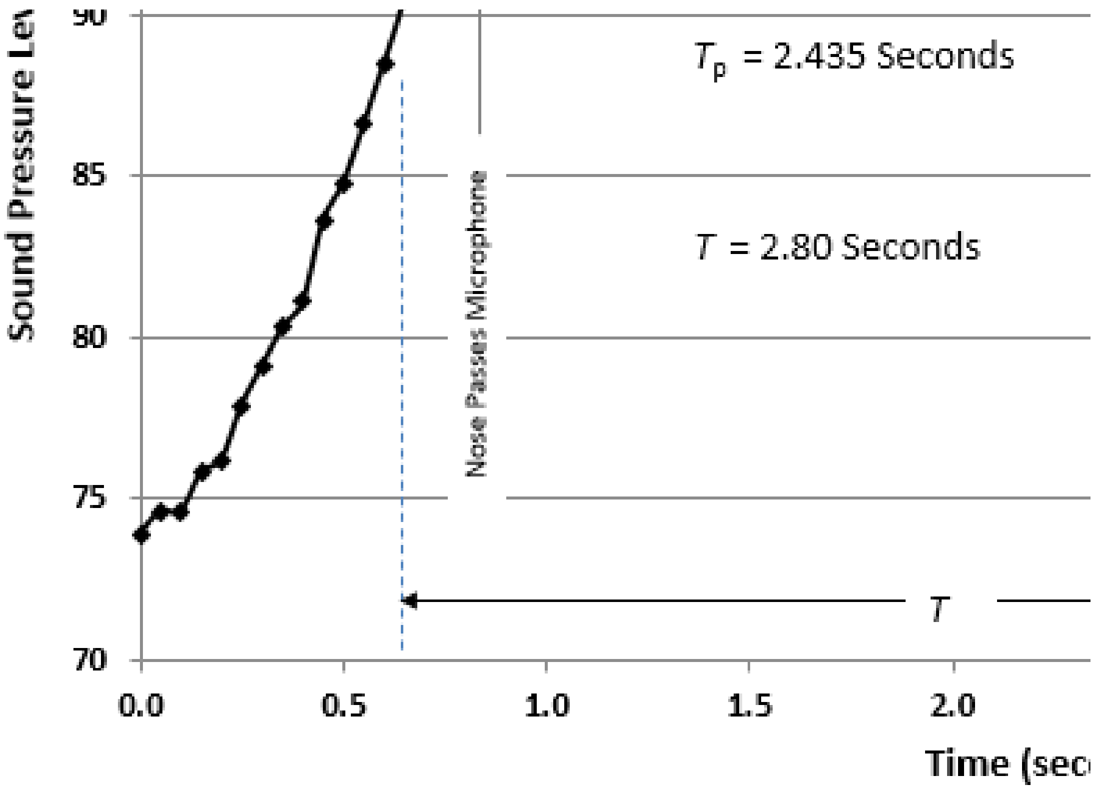

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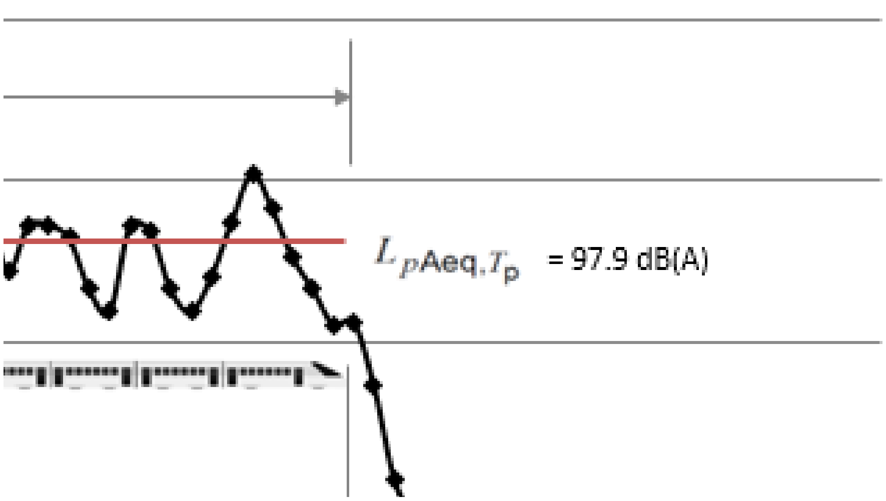
Program Version: 7 14-Oct-19

References

:. al., TNO Report MON-RPT-2010-03023, Geluidemissiemetingen aan V250 en [1]Dittrich, M.G., et. al., TNO Report MC
HSL Rheda- en ballastpoor, (Noise emission measurements on V250 and Thalys
:da and ballast track), Nederlandse Organisatie voor Toegepast
pelijk Onderzoek (TNO Industrie en Techniek), 13 December 2010.
: used with permission: under the terms of the GNU Free Documentation License, [2]Thalys PBKA image used with permission: unde
ater version published by the Free Software Foundation,
vikimedia.org/wiki/File:Thalys_PBKA_Refurbished_Nederland.jpg

Formulas

ure level in decibels) = 20 $\log_{10}$(Pa/0.00002) dB (sound pressure level in decibels) = 20 $\log_{10}$(Pa/0.00002) d
; the reference sound pressure level in Pascals
2*$10^{(dB/20)}$so, Pa = 0.00002*10(dB/20)so, Pa = 0.00002*10(dB/20)so, Pa = 0.00002*10(dB/20)so, Pa = 0.00002*10(dB/20)so, Pa = 0.00002*10(dB/20)



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Data Point Number
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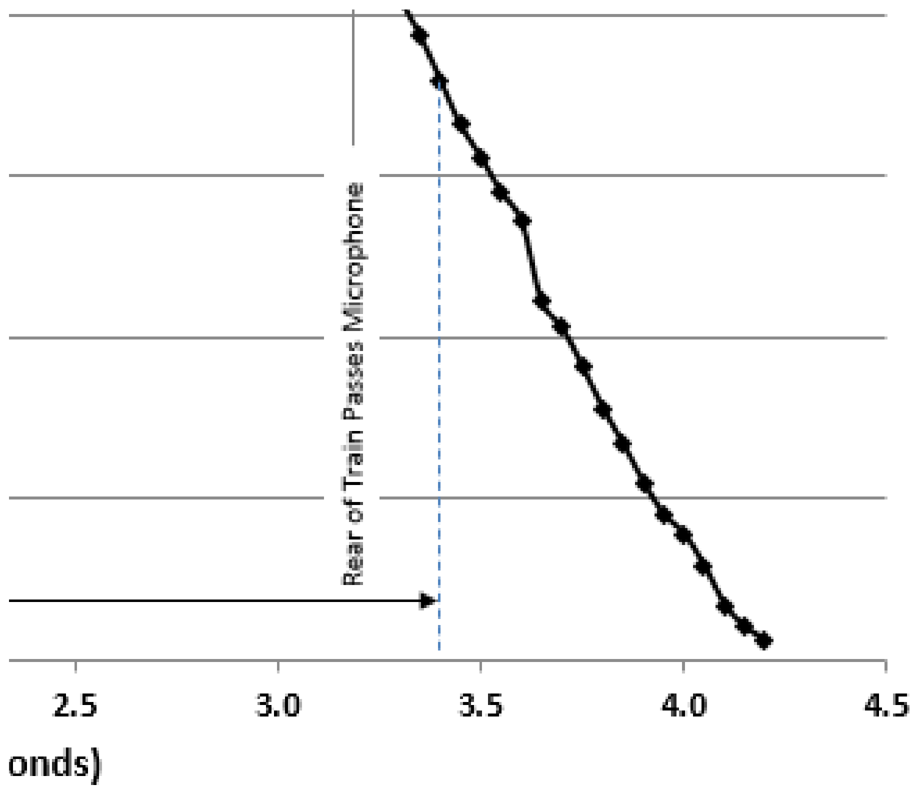

assby Data Set

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ON-RPT-2010-03023, Geluidemissiemetingen aan V250 en [1]Dittrich, M.G., et. al., TNO Report MON-RPT-2010-0302

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al Thalys PBKA Data Set		
Passby Data (see Passby		Sound Pressure (Pa)
Time (sec)	dB(A)	
0.00	75.3	0.11642
0.05	76.0	0.12619
0.10	76.0	0.12619
0.15	77.2	0.14489
0.20	77.6	0.15172
0.25	79.3	0.18451
0.30	80.5	0.21185
0.35	81.7	0.24324
0.40	82.5	0.26670
0.45	85.0	0.35566
0.50	86.2	0.40835
0.55	88.0	0.50238
0.60	89.9	0.62522
0.65	91.9	0.78710
0.70	94.4	1.04961
0.75	96.5	1.33669
0.80	98.0	1.58866
0.85	100.4	2.09426
0.90	100.3	2.07028
0.95	99.1	1.80314
1.00	100.0	2.00000

1.05	99.1	1.80314
1.10	98.8	1.74193
1.15	97.7	1.53472
1.20	96.9	1.39968
1.25	98.7	1.72199
1.30	100.8	2.19296
1.35	100.0	2.00000
1.40	98.0	1.58866
1.45	97.4	1.48262
1.50	97.9	1.57047
1.55	98.3	1.64449
1.60	98.2	1.62566
1.65	96.3	1.30626
1.70	97.1	1.43229
1.75	98.0	1.58866
1.80	99.0	1.78250
1.85	97.5	1.49979
1.90	99.1	1.80314
1.95	101.3	2.32290
2.00	101.9	2.48903
2.05	101.0	2.24404
2.10	99.0	1.78250
2.15	100.0	2.00000
2.20	101.6	2.40453
2.25	102.0	2.51785
2.30	100.5	2.11851
2.35	98.6	1.70228
2.40	100.0	2.00000
2.45	100.0	2.00000
2.50	99.6	1.90999
2.55	98.0	1.58866
2.60	97.3	1.46565
2.65	100.0	2.00000
2.70	99.8	1.95447
2.75	98.0	1.58866
2.80	97.3	1.46565
2.85	98.4	1.66353
2.90	100.1	2.02316
2.95	101.6	2.40453
3.00	100.5	2.11851
3.05	99.0	1.78250
3.10	98.0	1.58866
3.15	96.9	1.39968
3.20	97.0	1.41589
3.25	95.0	1.12468
3.30	92.1	0.80543

3.35	90.8	0.69347
3.40	89.4	0.59024
3.45	88.0	0.50238
3.50	87.0	0.44774
3.55	85.9	0.39448
3.60	85.0	0.35566
3.65	82.5	0.26670
3.70	81.7	0.24324
3.75	80.5	0.21185
3.80	79.2	0.18240
3.85	79.1	0.18031
3.90	76.9	0.13997
3.95	75.9	0.12475
4.00	75.3	0.11642
4.05	74.3	0.10376
4.10	73.1	0.09037
4.15	74.2	0.10257
4.20	72.0	0.07962

3, Geluidemissiemetingen aan V250 en[1]Dittrich, M.G., et. al., TNO Report MON-RPT-2010-03023, Geluidemissiem

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) en[1]Dittrich, M.G., et. al., TNO Report MON-RPT-2010-03023, Geluidemissiemetingen aan V250 en[1]Dittrich, M.G.

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, et. al., TNO Report MON-RPT-2010-03023, Geluidemissiemetingen aan V2

U.S. Department of Transportation
Federal Railroad Administration

Spreadsheet-Based Tool for Comparing Noise Standards and Regulations
Conversion Tool for Noise Regulations and Standards to Common Reference

RICARDO

Federal Railroad Administration
High Speed Rail Noise Standards and Regulations

CONTRAST — Comparison Of Noise for TRAin STandards — Program Version: 7 — 14-Oct-19

Data Set Number: 6	Passby Noise Calculations	References
Data Set Name: Common Reference		

Calculate Train Passby Parameters

Train Speed (V):	296	km/hr = 82.22	m/sec
Train Length:	200.19	m	10 cars: 2 end cars and 8 intermediate cars
Time for PassBy (T_p)	2.434743243	seconds	This is the time increment between nose of train passing microphone and tail of train passing microphone.
Time for TEL (T_{TEL})	2.80	seconds	TEL is the Transit Exposure Limit and represents the equivalent A-weighted SPL over the time period beginning when the instantaneous meter reading is 10 dB(A) less than $L_{pAEq,Tp}$ and continuing through the passby event until the meter reading is again 10 dB(A) less than $L_{pAeq,Tp}$

[1]He, et al., Investigation into External Noise of a High-Speed Train at Different Speeds, J Zhejiang Univ-Sci A (Appl Phys & Eng) 2014, 15(12):1019-1033
[2]Paul, et al, High Speed Rail Noise Standards and Regulations, US DOT Federal Railroad Administration, Contract DTFR35-16-C00006, May 2017.
[3]G. Xiaoan and J. Hua, "Application Research on Descending Vibration and Reducing Noise in Accelerating Speed Trains and Express Trains," Chinese Academy of Railway Sciences (CARS) Research Report, Beijing Shi, China, 2003.
[4]Hanson, C.E., et. al., High Speed Ground Transportation Noise and Vibration Impact Assessment, U.S. Department of Transportation, Federal Railroad Administration, Report Number DOT/FRA/ORD-12/15, September 2012.
[5]Gautier, P.E., Poisson, F., and Letourneaux, F., High Speed Trains External Noise: A Review of Measurements and Source Models for TGV Case Up to 360 km/hr, in Proceedings of the 8th World Congress on Railway Research (2008).
[6]European Union, "Commission Regulation Number 1304/2014, on the technical specification for interoperability relating to the subsystem 'rolling stock — noise' amending Decision 2008/232/EC and repealing Decision 2011/229/EU," Official Journal of the European Union, Brussels, Belgium, 2014.

Calculate $L_{pAeq,Tp}$

$L_{pAeq,Tp}$ is the A-weighted equivalent continuous sound pressure level produced by the train as measured during the passby event

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

$L_{pAeq,Tp}$ can be calculated from the passby data using the following relationship:

$$\int_{T_1}^{T_2}\frac{p_A^2(t)}{p_0^2}\mathrm{d}t \approx \sum_{i=1}^{i=n}\left(\frac{Pa(i)^2}{p_0^2}\right)\Delta t_i$$

Microphone Position is 7.5 m from track centerline and 1.5 m above top of rail (Microphone Position 1).

where

- T_p is the passby time interval = time when trail tail passes microphone minus time when train nose passes microphone = $T_2 - T_1$
- T_1 is the time when the train nose passes the microphone
- T_2 is the time when the train tail passes the microphone
- $P_A(t)$ is the A-weighted instantaneous sound pressure in Pa at time t
- p_0 is the reference sound pressure: p_0 = 20μPa = 0.00002 Pa
- Δt_i is the time increment between measured data points = 0.05 seconds
- $P_A(i)$ is the A-weighted instantaneous sound pressure in Pa at passby time increment i

An analysis conducted during the current study indicated the integral can be determined numerically, with acceptable accuracy, by employing a midpoint Reimann sum scheme with a minimum Δti = 0.05 seconds, and the corresponding Pa(i) analog meter values. This approach is described in: Hughes-Hallett, Deborah; McCullum, William G.; et al. (2005). *Calculus (4th ed.)*, Wiley. p. 252.

Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$	Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$	Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$	Data Point Number	Time (sec)	SPL dB(A)	SPL Pascals (Pa)	$P_A(i)^2/p_0^2$
1	0.00	73.90	0.099090	2.45471E+07	23	1.10	97.40	1.482620	5.49541E+09	45	2.20	100.20	2.046586	1.04713E+10	67	3.30	90.70	0.685536	1.17490E+09
2	0.05	74.60	0.107406	2.88403E+07	24	1.15	96.30	1.306261	4.26580E+09	46	2.25	100.60	2.143039	1.14815E+10	68	3.35	89.40	0.590242	8.70964E+08
3	0.10	74.60	0.107406	2.88403E+07	25	1.20	95.50	1.191324	3.54813E+09	47	2.30	99.10	1.803142	8.12831E+09	69	3.40	88.00	0.502377	6.30957E+08
4	0.15	75.80	0.123319	3.80189E+07	26	1.25	97.30	1.465649	5.37032E+09	48	2.35	97.20	1.448872	5.24807E+09	70	3.45	86.60	0.427592	4.57088E+08
5	0.20	76.20	0.129131	4.16869E+07	27	1.30	99.40	1.866509	8.70964E+09	49	2.40	98.60	1.702276	7.24436E+09	71	3.50	85.60	0.381092	3.63078E+08
6	0.25	77.90	0.157047	6.16595E+07	28	1.35	98.60	1.702276	7.24436E+09	50	2.45	98.60	1.702276	7.24436E+09	72	3.55	84.50	0.335761	2.81838E+08
7	0.30	79.10	0.180314	8.12831E+07	29	1.40	96.60	1.352166	4.57088E+09	51	2.50	98.20	1.625661	6.60693E+09	73	3.60	83.60	0.302712	2.29087E+08
8	0.35	80.30	0.207028	1.07152E+08	30	1.45	96.00	1.261915	3.98107E+09	52	2.55	96.60	1.352166	4.57088E+09	74	3.65	81.10	0.227002	1.28825E+08
9	0.40	81.10	0.227002	1.28825E+08	31	1.50	96.50	1.336688	4.46684E+09	53	2.60	95.90	1.247470	3.89045E+09	75	3.70	80.30	0.207028	1.07152E+08
10	0.45	83.60	0.302712	2.29087E+08	32	1.55	96.90	1.399684	4.89779E+09	54	2.65	98.60	1.702276	7.24436E+09	76	3.75	79.10	0.180314	8.12831E+07
11	0.50	84.80	0.347560	3.01995E+08	33	1.60	96.80	1.383662	4.78630E+09	55	2.70	98.40	1.663528	6.91831E+09	77	3.80	77.80	0.155249	6.02560E+07
12	0.55	86.60	0.427592	4.57088E+08	34	1.65	94.90	1.111809	3.09030E+09	56	2.75	96.60	1.352166	4.57088E+09	78	3.85	76.70	0.136782	4.67735E+07
13	0.60	88.50	0.532145	7.07946E+08	35	1.70	95.70	1.219074	3.71535E+09	57	2.80	95.90	1.247470	3.89045E+09	79	3.90	75.50	0.119132	3.54813E+07
14	0.65	90.50	0.669931	1.12202E+09	36	1.75	96.60	1.352166	4.57088E+09	58	2.85	97.00	1.415892	5.01187E+09	80	3.95	74.50	0.106177	2.81838E+07
15	0.70	93.00	0.893367	1.99526E+09	37	1.80	97.60	1.517155	5.75440E+09	59	2.90	98.70	1.721988	7.41310E+09	81	4.00	73.90	0.099090	2.45471E+07
16	0.75	95.10	1.137706	3.23594E+09	38	1.85	96.10	1.276527	4.07380E+09	60	2.95	100.20	2.046586	1.04713E+10	82	4.05	72.90	0.088314	1.94984E+07
17	0.80	96.60	1.352166	4.57088E+09	39	1.90	97.70	1.534723	5.88844E+09	61	3.00	99.10	1.803142	8.12831E+09	83	4.10	71.70	0.076918	1.47911E+07
18	0.85	99.00	1.782502	7.94328E+09	40	1.95	99.90	1.977106	9.77237E+09	62	3.05	97.60	1.517155	5.75440E+09	84	4.15	71.00	0.070963	1.25893E+07
19	0.90	98.90	1.762098	7.76247E+09	41	2.00	100.50	2.118507	1.12202E+10	63	3.10	96.60	1.352166	4.57088E+09	85	4.20	70.60	0.067769	1.14815E+07
20	0.95	97.70	1.534723	5.88844E+09	42	2.05	99.60	1.909985	9.12011E+09	64	3.15	95.50	1.191324	3.54813E+09					
21	1.00	98.60	1.702276	7.24436E+09	43	2.10	97.60	1.517155	5.75440E+09	65	3.20	95.60	1.205119	3.63078E+09					
22	1.05	97.70	1.534723	5.88844E+09	44	2.15	98.60	1.702276	7.24436E+09	66	3.25	93.60	0.957260	2.29087E+09					

Data Point Number for Start of Passby Event (time at which train nose passes microphone): 16 — i = 1

Data Point Number for End of Passby Event (time at which train tail passes microphone): 64 — i - n

thus, $\sum_{i=1}^{i=n}\left(\frac{Pa(i)^2}{p_0^2}\right)\Delta t_i$ = 1.51242E+10

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

$L_{pAeq,Tp}$ = **97.93** **dB(A)**

Impact of Microphone Position

Microphone Position	Distance from Track Centerline (m)	Elevation Above Top of Rail (m)	Applies to Regulations in these Regions[2]				Comment
			US	EU	China	Japan	

References:

[4]L. Lu, X. Hu, Y. Zhang and X. Zhou, "Survey and Analysis of the Beijing-Shanghai High Speed Rail Noise," in The 21st International Congress on Sound and Vibration, Beijing, China, 2014.

1	7.5	1.2		X (TSI 2014)			TSI 1304		
2	7.5	3.5		X (TSI 2014)			Also required for	speeds > 250	km/hr
3	25	3.5		X (TSI 2008)		X	Reference for pre	2014 train se	ts
4	30	1.2	X		X		US and China me	asurement loc	ation

[B]G. Xiaoan and J. Hua, "Application Research on Descending Vibration and Reducing Noise in Accelerating Speed Trains and Express Trains," Chinese Academy of Railway Sciences (CARS) Research Report, Beijing Shi, China, 2003.

[C]W. Elliott, "Request for Information Reference FOI13-580, Comparison of Measured Sound Levels for High Speed Trains as a Functionof Distance from Track," High Speed Rail Two (HS2), London, England, 2013.

Impact of microphone distance is determined from the following equation:[3] $L_d = L_{d0}$ - 10*LOG(d/d0), where L_{d0} is the equivalent A-weighted constant sound pressure level for the microphone at distance d0, and d is the distance for Ld.

Microphone Position	Distance from Track Centerline (m)	Elevation Above Top of Rail (m)	$L_{pAeq,Tp}$ at 296 km/h dB(A)	$L_{pAeq,Tp}$ at 296 km/h (Pa)
1	7.5	1.2	97.93	1.576
2	7.5	3.5	100.66	2.159
3	25	3.5	86.16	0.407
4	30	1.2	85.37	0.371

To convert dB(A) to Pascals: Pa = 0.00002*(10^(dBA/20))

To convert Pa to dB(A), dB(A) = 20*LOG10(Pa/0.00002)

Note: The simple sound level correction formula underestimates the measured values. Therefore, ratios based on actual measurements were used to adjust for microphone location (table at right).

Sound Pressure Variations for Microphone Positions and Train Speed from Reference 5			
Speed (km/hr)	**$L_{pAeq,Tp}$ dB(A)**		
	M1	**M2**	**M3**
271	93.2	95.8	82.0
341	96.5	98.0	85.5
386	98.5	100.1	88.1

Calculated Noise Metrics: Maximum Recorded Sound Pressure Levels

The following calculations are for Microphone Position 1

$L_{p(maximum)}$ = maximum recorded passby sound pressure level

$L_{p(maximum)}$ = **102.0** dB(A) which occurs at data point 46 at passby time 2.25 seconds

L_{pASmax} is the maximum sound pressure level, slow and A-weighted and L_{pAFmax} = maximum sound pressure level, fast and A-weighted. The time period for the "slow" reading is 1 second. The time period for the "fast" reading is 0.125 seconds.

L_{pASmax} can be calculated as the logarithmic average of the recorded SPLs for the 1 second time interval containing the highest values

The logarithmic average for an Excel array is: {=10*LOG(AVERAGE(10^(ARRAY/10)))} array-entered, i.e. using CTRL-Shift-Enter keys where array is of the form A10:A15. In the current case, the array is Pass-By Data Set 1, C:48:C68

Highest 1-second interval occurs from start time 1.5 to end time 2.5 **Thus, L_{pASmax} = 97.90 dB(A)**

Similarly, L_{pAFmax} can be calculated as the logarithmic average of the recorded SPLs for the 0.125 second time interval containing the highest values

Highest 0.125-second interval occurs from start time 2.15 to end time 2.275 **Thus, L_{pAFmax} = 100.00 dB(A)**

Calculated Noise Metrics: Other Standard Parameters

The following calculations are for Microphone Position 1

$L_{pAeq,passby}$ is the A-weighted equivalent continuous sound pressure level produced during the entire passby event, including approach, T_p, and departure (used for L_d, L_n, etc.)

The calculation includes all of the passby data points.

Data Point Number for Start of Passby Event (time passby SPLs begin being recorded): 1 i = 1

Data Point Number for End of Passby Event (time passby SPLs end being recorded): 85 i - n thus, $\sum_{i=1}^{i=n} \left(\frac{Pa(i)^2}{p_0^2} \right) \Delta t_i$ = 1.59169E+10 $T_2 - T_1$ = 4.20 seconds

$L_{pAeq,passby} = 10 \lg \left(\frac{1}{T_2 - T_1} \int_{T_1}^{T_2} \frac{p_A^2(t)}{p_0^2} dt \right)$ **$L_{pAeq,passby}$ = 95.79 dB(A)**

TEL is the Transit Exposure Limit[4]. It is measured over the time interval starting when the SPL is 10 dB(A) lower than $L_{pAeq,Tp}$ and ending when the SPL again reaches a value that is 10 dB(A) lower than $L_{pAeq,Tp}$

TEL is calculated using the following formula: TEL = $L_{pAeq,Tp}$ + 10*LOG(T_{TEL}/T_p) **TEL = 98.5392281 dB(A)**

SEL is the Sound Exposure Limit[4]. Like $L_{pAeq,Tp}$, it integrates the total sound energy over a measurement period, but for SEL, the measurement period is normalized to a duration of 1 second. At a microphone distance of 30 m (100 ft), SEL = $L_{pAeq,Tp}$ + 10*LOG(Tp) + 1

SEL at 30 m: 102.80 dB(A) SEL at 7.5 m: 108.82 dB(A) SEL at 25 m: 103.59 dB(A) using the distance correction factor: $L_d = L_{d0}$ - 10*LOG(d/d0)

SEL is the cumulative noise exposure (i.e. "dose") for a single noise event normalized over 1 second. The fact that SEL is a cumulative measure means that (1) louder events have higher SELs than quieter ones, and (2) events that last longer in time have higher SELs than shorter ones.[4]

Statistical Parameters

The following parameters are determined by specifying the indicated percentile of the data values using Excel Function PERCENTILE(range,P).

where" range" is the array of values (e.g. K10:K68) and P = the percentile (between 0 and 1, for example, P for the 90th percentile would be entered as 0.9)

L_{10} is the sound pressure level for which 90% of the recorded values are greater. It includes lead-in (prior to nose passing microphone) and trail-off (after tail of train passes) data. **L_{10} = 76.36 dB(A)**

L_{50} is the sound pressure level for which 50% of the recorded values are greater. It includes lead-in (prior to nose passing microphone) and trail-off (after tail of train passes) data. **L_{50} = 97.30 dB(A)**

L_{90} is the sound pressure level for which 10% of the recorded values are greater. It includes lead-in (prior to nose passing microphone) and trail-off (after tail of train passes) data. **L_{90} = 100.46 dB(A)**

Summary of Passby Noise Metrics for Each Microphone Position

The noise metrics shown in the following table correspond to the baseline speed of 296 km/hr $L_d = L_{d0}$ - 10*LOG(d/d0), where L_{d0} is the equivalent A-weighted constant sound pressure level for the microphone at distance d0, and d is the distance for L_d.

Microphone Position			Noise Metric: Table Entries are dB(A)							
	$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
1	97.9	102.0	97.9	100.0	95.8	98.5	108.8	76.4	97.3	100.5
2	100.7	104.8	100.6	102.8	98.5	101.3	111.9	78.5	100.0	103.3
3	86.2	89.7	86.1	88.0	84.3	86.7	95.7	67.2	85.6	88.4
4	85.4	89.0	85.3	87.2	83.5	85.9	94.9	66.4	84.8	87.6

Microphone Position Adjustment Factors[5]			
Speed (km/hr)	**M1**	**M2**	**M3**
271	1.000	1.028	0.880
341	1.035	1.052	0.917
386	1.057	1.074	0.945

Impact of Train Speed on Noise Levels

Ricardo evaluated several methods for determining the impact of train speed on passby noise levels. The approach developed by Gautier, Poisson & Letourneaux[5] provided the highest level of correlation with measured data is the basis for the calculations presented below.

$L_{Aeq,tp}(V) - L_{Aeq,tp}(V_0)$ = K log(V/V_0) where K is an empirical factor where V= train speed (km/hr)

thus, $L_{Aeq,tp}(V)$ = K log(V/V_0) + $L_{Aeq,tp}(V_0)$ V_0= reference train speed (km/hr)

If the SPL is known at train speed V_0, the SPL at train speed V can be determined from this formula

The empirical factor K varies with train speed. This is because the contribution of noise sources (e.g. wheel/rail interaction, propulsion components, aerodynamics) vary with train speed. Ricardo calculated the K factor values for 12 passby noise data sets.

The relationship between the K factor and train speed is provided by the following equation:

K = a*V + b where a= 0.0625 and b= 25.00

Scale K factor for 80 mph so $L_{pAeq,Tp}$ = (17.93218/17.0460517)*30.000 where 30.000 is the original K factor for the Thalys at 80 km/hr.

V_0 for this train set is: 296 km/hr

D146*Log(C146/D141) = -17.932180023 and it should be = -17.93218 to ensure $L_{pAeq,Tp}$ = 80 dB(A)

=$D$146*LOG(C146/$D$141)+$E$152

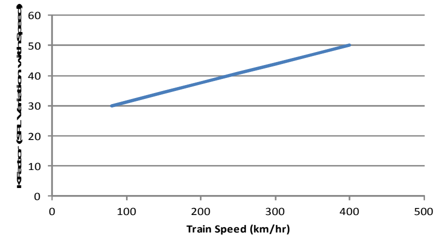
The following tables contain the calculated variation with train speed for the various noise parameters described above:

	Train Speed (km/hr)	K		Microphone Position 1			Noise Metric: Table Entries are dB(A)					
			$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
	80	31.5595	80.0	84.1	80.0	82.1	77.9	80.6	90.9	58.4	79.4	82.5
	150	34.3750	87.8	91.9	87.8	89.9	85.6	88.4	98.7	66.2	87.2	90.3
	200	37.5000	91.5	95.6	91.5	93.6	89.4	92.2	102.4	70.0	90.9	94.1
	250	40.6250	95.0	99.0	94.9	97.0	92.8	95.6	105.8	73.4	94.3	97.5
	300	43.7500	98.2	102.3	98.2	100.3	96.0	98.8	109.1	76.6	97.6	100.7
	350	46.8750	101.3	105.4	101.3	103.4	99.2	102.0	112.2	79.8	100.7	103.9
Test Speed→	296	43.5000	97.9	102.0	97.9	100.0	95.8	98.5	108.8	76.4	97.3	100.5

	Train Speed (km/hr)	K		Microphone Position 2			Noise Metric: Table Entries are dB(A)					
			$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
	80	31.5595	82.7	86.9	82.7	84.9	80.5	83.4	93.9	60.6	82.1	85.3
	150	34.3750	90.5	94.7	90.5	92.6	88.3	91.1	101.7	68.3	89.9	93.1
	200	37.5000	94.3	98.5	94.2	96.4	92.1	94.9	105.5	72.1	93.6	96.9
	250	40.6250	97.7	101.9	97.7	99.8	95.5	98.3	108.9	75.5	97.0	100.3
	300	43.7500	100.9	105.1	100.9	103.0	98.7	101.5	112.1	78.7	100.3	103.5
	350	46.8750	104.1	108.3	104.0	106.2	101.9	104.7	115.3	81.9	103.4	106.7
Test Speed→	296	43.5000	100.7	104.8	100.6	102.8	98.5	101.3	111.9	78.5	100.0	103.3

	Train Speed (km/hr)	K		Microphone Position 3			Noise Metric: Table Entries are dB(A)					
			$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
	80	31.5595	68.2	71.8	68.2	70.1	66.3	68.8	77.8	49.3	67.7	70.5
	150	34.3750	76.0	79.6	76.0	77.8	74.1	76.6	85.6	57.0	75.5	78.2
	200	37.5000	79.8	83.4	79.8	81.6	77.9	80.3	89.4	60.8	79.2	82.0
	250	40.6250	83.2	86.8	83.2	85.0	81.3	83.7	92.8	64.2	82.6	85.4
	300	43.7500	86.4	90.0	86.4	88.2	84.5	87.0	96.0	67.4	85.9	88.6
	350	46.8750	89.6	93.2	89.5	91.4	87.7	90.1	99.2	70.6	89.0	91.8
Test Speed→	296	43.5000	86.2	89.7	86.1	88.0	84.3	86.7	95.7	67.2	85.6	88.4

	Train Speed (km/hr)	K		Microphone Position 4			Noise Metric: Table Entries are dB(A)					
			$L_{pAeq,Tp}$	$L_{p(maximum)}$	L_{pASmax}	L_{pAFmax}	$L_{pAeq,passby}$	TEL	SEL	L_{10}	L_{50}	L_{90}
	80	31.5595	67.4	71.0	67.4	69.3	65.6	68.0	77.0	48.5	66.9	69.7
	150	34.3750	75.2	78.8	75.2	77.0	73.3	75.8	84.8	56.2	74.7	77.4
	200	37.5000	79.0	82.6	79.0	80.8	77.1	79.5	88.6	60.0	78.4	81.2
	250	40.6250	82.4	86.0	82.4	84.2	80.5	82.9	92.0	63.4	81.8	84.6
	300	43.7500	85.6	89.2	85.6	87.4	83.7	86.2	95.2	66.6	85.1	87.9
	350	46.8750	88.8	92.4	88.8	90.6	86.9	89.3	98.4	69.8	88.2	91.0
Test Speed→	296	43.5000	85.4	89.0	85.3	87.2	83.5	85.9	94.9	66.4	84.8	87.6



The empirical factor, K, varies with train speed: it is on the order of 30 in speed range to 300 kph and up to 50 for very high speed trains, for which aerodynamic noise sources are dominant.

K = 0.0625(Train Speed, km/hr) + 25

The European Technical Standards for Interoperability (TSI) include two normalized values for $L_{pAEq,Tp}$. The values are normalized to 80 km/hr and 250 km/hr.[6]

The measurements are made at a lateral distance of 7.5 m from the rail centerline and 1.2 m above the top of the rail.

Procedures defined within the TSI to allow noise levels to be calculated at various train speeds based on measurements made at 80 km/hr (50 miles/h) and 250 km/hr (155 miles/h).

<u>For the Thalys PBKA, no measurements were made at 80 km/hr and 250 km/hr</u>: Thus, the Gautier method was used to calculate these values

From the Microphone Position 1 table above, the normalized values for $L_{pAeq,Tp}$ can be found and are identified below:

Values Obtained from Data Analysis			Value from TSI Formula		TSI Formulas
$L_{pAeq,Tp\ (80\ km/hr)}$ =	**80.0**	**dB(A)**	80.9	dB(A)	$L_{pAeq,Tp}$(80 km/h) = $L_{pAeq,Tp}$(vtest) - 30 * log (vtest/80 km/h)
$L_{pAeq,Tp\ (250\ km/hr)}$ =	**95.0**	**dB(A)**	94.3	dB(A)	$L_{pAeq,Tp}$(250 km/h) = $L_{pAeq,Tp}$(vtest) - 50 * log (vtest/250 km/h)