Conversion of existing railway source data to use CNOSSOS-EU

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Summary

The Environmental Noise Directive requires 28 countries to map the noise following a quite precise common noise assessment method that has just been adopted. Concerning railway noise, one challenge is the potential use of existing values to create new databases necessary to implement these new methods, by converting old data, as an alternative to acquiring new ones. The main issues that are tackled in this article concern how to classify the railway vehicles correctly, and how to choose the right parameters; how to classify the right tracks and how to assign to each track the right parameters amongst those required by the new method. Some examples will be given on how existing data can be converted. The key parameters discussed are: rail and wheel roughness, vehicle type, wheel type, rail type, track type. As, following recent work commissioned by the European Commission, where conversion methodologies have been developed, these conversion methodologies will be presented and explained.

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1. Introduction

In July 2014 the Member States of the European Union reached an agreement on a common method for the calculation of railway noise (CNOSSOS-EU), embedded in a new Annex II of Directive 2002/49/EC. This new method splits the calculation of the source sound power from the calculation of the attenuation due to source-receiver propagation.

The introduction of the new method means that existing data needs to be converted to the new format/new categorization, or acquired if necessary. Before entering the details of the different datasets required, it is important to recall that the methodology contains a part called "Quality framework" that requires the use of real data, not defaults, unless costs associated with the data collection are disproportionately high. It proposes that the objective for data collection of each attribute shall be "at least the accuracy corresponding to an uncertainty of ±2dB(A) in the emission level of the source (leaving all other parameters unchanged)". Thus, it means that parameters that are not highly influential on the overall source definition, and disproportionately expensive to measure, can be approximated by defaults. This could also extend to rail vehicles that are rarely seen on a specific track, as these are unlikely to have much influence on the overall source sound power, when energetically added to the sound power of other more frequently-occurring rail vehicles.

2. Overview of the method

The method described may look surprisingly obvious for experts in railway noise emission, whilst it may seem somewhat complex for those used to methods which classify trains by means of commercial names, and who perhaps have not previously needed to consider the effects of different track structures.

2.1 Decoupling vehicles and track sources

The method decouples the trains from the tracks, and foresees to further split trains into vehicles, a vehicle being the minimum piece of a train that "can stand on its wheels", normally a single wagon but, exceptionally, more than a single wagon where bogies are shared. As the method aims to calculate average noise levels, only the overall number of vehicles of a given type is relevant, and not how these are split amongst trains. This implies that information is required not only on the commercial classification of trains, but also on the vehicle types and the number of vehicles that compose each train. It is necessary therefore to collect information on the different types of vehicles circulating on a specific railway line, and on the different types of tracks. Tracks are divided based on a set of acoustic parameters, but usually only a few types exist in each country, and it is therefore a limited set. It is therefore required to develop a matrix of train-track combinations before undertaking a calculation. As it can be sometimes both resource consuming and frustrating to find all possible combinations in the matrix, it is possible to adopt a strategy to focus attention on a minimum set of combinations, explained further in this article.

2.2 Classification of vehicles and tracks

The method foresees the classification of vehicles and tracks into macro groups, where the major acoustic features are described almost in a qualitative manner. Quantitative values necessary to perform a calculation are then given in the annexed tables. As a result of this qualitative classification, sometimes there is no one-to-one relationship between the classification and the tabled parameters (e.g.: for tracks all classified as "ballasted", there are 7 values tabled depending on the sleeper type). This is meant to allow flexible implementation to adapt to local realities, while macroscopically keeping a simple definition for vehicles and tracks (e.g.: simply "ballast" in the given example).

3. Main parameters for vehicles and tracks

3.1 Vehicles

Vehicles are classified following a set of descriptors, as presented in table I. The vehicle type distinguishes macroscopically between locomotives, self-propelled and hauled vehicles, and amongst freight or passenger, high or non-high speed. The number of axles per vehicle is a fundamental parameter due to railway noise emission (rolling noise specifically) being dependent on the wheel-rail contact. The other fundamental parameter for noise is the roughness, but for simplicity, knowing that the brake type has the largest influence on overall roughness, the latter is used to distinguish between vehicles. Also, this can easily be derived from the technical data available for the rail vehicle. Finally, if a vehicle adopts some innovative noise reduction measures, this may be accounted for by the fourth descriptor.

Table I. Descriptors of railway vehicles

Descriptors of railway vehicles
Vehicle Type
Number of axles per vehicle
Brake type
Wheel measures

3.2 Wheel roughness

Wheel roughness is known to have a significant effect, from the vehicle side, on railway noise emission. Wheel roughness can be obtained following similar principles to those described for track roughness in the EN15610:2009. Wheel roughness spectra are measured on a set of wheels from different wagons of the same type, and statistics are used to derive an average value for roughness. These spectra represent the effective wheel roughness, or else the roughness that can indeed be felt by a wheel-rail contact patch, that excludes pitches and dips. The method also uses a contact filter while adding the roughness of the wheel to the roughness of the rail (the “combined effective roughness”), to consider the effect of the contact patch. The method presents a set of contact filters as a function of wheel diameter and wheel load. Before being used in the formulae, the method explains that the roughness, typically expressed in the wavelength domain, has to be converted to frequency domain by knowing the speed of the vehicle(s) on a specific track section.

3.3 Tracks

Tracks are classified following a set of descriptors, as presented in table II. The track base is distinguished macroscopically between slab tracks and ballast tracks, plus some special cases such as bridges or embedded track.

Railhead roughness is defined, and if necessary collected, according to EN15610:2009, meaning that pits and spikes are excluded. Needless to say, railhead roughness is a lead element in a railway noise calculation, classified macroscopically into four groups, from "well maintained and very smooth" to "not maintained and bad condition". It is expected that this may be the most difficult parameter to acquire, as in many cases this is not collected. Railpad type is the third descriptor that needs to be defined for the most common tracks. Additional measures, rail joints and curvature are then descriptors that differentiate only special cases, such as damped tracks, old jointed tracks and small-radius curves as in depots.

Table II. Descriptors of railway tracks

Descriptors of railway tracks
Track base
Railhead roughness
Railpad type
Additional measures
Rail joints
Curvature

4. Migrating from existing national methods to CNOSSOS-EU

4.1 General approach

In order to enable data, and knowledge relevant to existing national methods, to be applied to the CNOSSOS-EU approach, it is necessary to identify how national method categories of vehicles and infrastructure may be represented in CNOSSOS-EU. Preferably the MS would establish, either from records or new measurements, relevant data in the CNOSSOS-EU database format. However, as an interim approach, the closest match between a selection of national method data categories and the default data examples within 'CNOSSOS-EU_Rail_Input_Database_Tables_Final - 01April2014' ("the database") have been established as follows. In several instances the national methods include generic groupings which can comprise vehicles with disparate acoustic characteristics (e.g. different brake types) and, as CNOSSOS-EU is vehicle-based rather than train-based, the national method rolling stock categories have been subdivided where necessary to maintain acoustic homogeneity within category.

4.2 Vehicle information

4.2.2 Vehicle rolling noise transfer function

The database includes transfer functions between "combined effective roughness" and sound power per axle for wheels with diameters ranging from 680mm to 1200mm. These transfer functions are a function of wheel vibration response and radiation and can be derived from theory (e.g. TWINS modelling) or by the use of pass-by source separation techniques combined with direct or indirect measurement of combined effective roughness. New wheel diameters for national method rolling stock, either actual or assumed from experience, have been used to identify the closest relevant database categories. The database does not currently contain information on vehicle transfer functions where wheel dampers have been fitted. Vehicles that are known to have these devices installed have therefore not had a transfer function allocated to them at this stage, but a worst-case assumption could be made for modelling purposes by applying the transfer function for the relevant wheel diameter without a damper fitted.

4.2.3 Contact filter

The contact filter at the wheel-rail interface modifies the combined wheel and rail roughness due to the ellipsoid contact zone and is largely a function of wheel diameter and wheel load. This filter is normally derived from analytical approaches, with examples provided in the database against a range of wheel loads and wheel diameters. The highest wheel load catered for in the database is 100 kN. As this would be typical for main line stock, and as the contact filter value is not highly sensitive to load, the values for 100 kN have been used throughout in the equivalence process.

4.2.4 Wheel roughness

The database holds three default sets of wheel roughness data, for cast-iron tread brakes, composite tread brakes and disc brakes. Brake types are not often readily available from industry and public-domain sources, and therefore, where definitive information has not been available, an assumption has been made for stock categories in national methods that is based on the types of vehicle, their vintage, and by examination of public-domain photographs where, for example, brake discs may be visible. Where a vehicle has a combination of disc brakes and cast-iron tread brakes, the allocated brake category is always the latter.

4.2.5 Traction noise

The database currently only holds data, in terms of sound power level per vehicle, for one example each of Diesel Multiple Unit, Electric Multiple Unit and Electric Locomotive, and therefore stock within the national methods that fall into these categories are identified accordingly. In the case of Diesel Locomotives however, a range of types and available power is provided. Details of the type and power of each diesel locomotive included within the national method has therefore been used to inform the choice of the appropriate database equivalent. This choice can be considered to apply for all modes of operation included within the database, i.e. idling, accelerating, constant speed and braking.

4.2.6 Aerodynamic noise

Where aerodynamic noise is included in a national method for higher speed stock, or if the MS wishes to add this capability to the national method, the database provides a single reference spectrum in terms of sound power per vehicle at 300 km/h with associated speed exponents for the two source heights.

4.3 Track information

4.3.1 Track transfer function

The transfer function between combined effective roughness and track sound power level per axle is a function of vibration response and radiation due to its structure type and pad stiffness. These transfer functions can be derived as for vehicle rolling noise transfer functions. Where track types are described in national methods it has been possible to choose an appropriate equivalent CNOSSOS type in a selection of cases. Medium pad stiffness is assumed, to reflect the fact that harder pads, despite their acoustic benefits in increasing track vibration decay rate, are not attractive to infrastructure engineers who wish to protect the sleepers from high track forces. For track with wooden sleepers, the database holds only one transfer function dataset.

4.3.2 Rail roughness

The database holds rail roughness spectra for ISO3095:2013 conditions and for the Netherlands average network. The former is track of low roughness designed for type testing (Technical Specification of Interoperability [TSI]) purposes, while the latter can be taken to represent an average figure for a typical European network that is maintained to a generally high level. However, for equivalence purposes some additional considerations have been taken into account. For RMR, being a Netherlands method, the Netherlands average network figure is considered appropriate. For the UK method “CRN”, it has been found from previous research studies that total pass-by noise for disc-braked stock on “CRN track” is typically 1.7 dB greater than total pass-by noise of the same stock on ISO3095:2013 track. The ISO3095 rail roughness has therefore been adjusted to provide this increase when combined with a typical disc-braked wheel roughness at the TSI testing speed of 80 km/h, leading to the new rail roughness spectrum provided in the CRN equivalence table. For the German “Besonders Überwachtes Gleis” (BÜG) specially monitored acoustically-ground track, Schall03 provides a sound level reduction at certain frequencies. For the purpose of CNOSSOS equivalence it has been assumed that these reductions apply directly to the rail roughness (which is a reasonable first approximation in the presence of smooth wheels) and the relevant frequencies have therefore been converted to roughness wavelength for the Schall03 reference speed of 100 km/h. Schall03 also refers to TSI track and ISO3095:2005 track and, for the purposes of equivalence, the use of the database rail roughness for ISO3095:2013 roughness is recommended here.

4.3.3 Impact noise

Where a method includes the noise increase due to impacts from joints, switches and crossings, CNOSSOS provides an additional rail roughness element that is based on joint density. Therefore, where a national method takes this into account, it is necessary for n, the number of discontinuities per 100m, to be established for the track section in question and the database default spectrum “single switch /joint /crossing /100m” adjusted by the addition of 10log(n) at all wavelengths.

4.3.4 Bridge noise

There are many variants of railway elevated structures, constructed typically from steel, concrete, masonry and various combinations of all these, and other, materials. Therefore in the database there are only two key examples of bridge type with an associated enhancement to overall sound level, i.e. “Predominantly concrete or masonry bridges with any trackform” +1 dB(A) and “Predominantly steel bridges with ballasted track" +4 dB(A). There is, however, also the "max" value of +9 dB(A) which can be applied as an approximation for known very high noise structures. This information has informed the choice of bridge enhancement applied to the Schall03, RMR and CRN equivalence tables.

5. Example migrating RMR'96 to CNOSSOS-EU

A reasonable step by step approach, most likely in line with the requirement of having an influence of less than +/- 2dB on the overall accuracy of the sound source definition, may look like the following.

Catalogue the trains on the network; identify the type of vehicles that form them, separating the locomotives, self-propelled and hauled vehicles that are dominant on the network (e.g.: those that form more than 80% of the pass-by); divide them by: number of axles per vehicle, brake type, wheel measure and wheel size. Further exclude those that are quite unique (e.g.: less than 5% of the fleet) unless the entire fleet is very much heterogeneous. For those remaining selected, find the appropriate input data based on real data at least for the number of axles per vehicle, wheel roughness and wheel transfer function, or plan to collect new data if real data is not available.

In the case of the railway track, each single section of track, regardless of the fact that its configuration is quite unique or common within the railway network, is essential for that specific track section, therefore it is not possible to exclude a track configuration from the list of input data to be accurately collected. It is important to recall, however, that only a few track parameters have a major influence, and it is therefore necessary to focus at first on collecting those. They are usually track base and railhead roughness.

Set out below in Figures 1 to 3 is an example of the process of developing look-up tables between parameters within an existing national method and the CNOSSOS method. This example uses the RMR '96 method, which forms the basis of the EC recommended Interim Method. When migrating from one method to another, there are certain known limitations in addition to the variation in detailed aspects which are inherent in the new method.

RMR Train Cat		CNOSSOS ID Veh TF	Contact filter	Wheel roughness	Traction noise*	Default length m	Axles/ vehicle
Cat 1	All	3	6	3	10	26	4
Cat 2	ICM-III, ICR trailer vehicles, DDM-1 trailer vehicles, SNCF passenger coaches and TEE	3	6	3	10	26	4
	ICR 1700 locomotive, DDM-1 1800 locomotive and Belgian locomotives	6	6	3	9	18	4
Cat 3	All	3	6	5	10	26	4
Cat 4	Freight wagons	3	6	3	-	Variable	Variable
Cat 5	DE1, DE2, DE3	3	6	3	8	25	4
	2200 and 2300 locomotive	3	6	3	3	14	4
	2400 and 2500 locomotive	3	6	3	3	13	4
Cat 6	All	3	6	5	8	26	4
Cat 7	All	3	6	5	10	15	3
Cat 8	ICM IV and IRM	3	6	5	10	26	4
	DDM 2/3	3	6	3	10	26	4
Cat 9	TGV PBA type, power car	3	6	3	9	20	4
	TGV PBA type, trailer car adjacent to power car	3	6	5	-	20	3
	TGV PBA type other trailer cars	3	6	5	-	20	2
Cat 10	ICE-3 type assuming no wheel dampers	3	6	5	10	25	4
					*Where appropriate		

Figure 1. CNOSSOS vehicle ID lookup table for RMR Train Category

RMR Joints "m"		Impact noise ID
1	Jointless rails (fully welded tracks) with or without jointless switches or crossings	1
2	Rails with joints (= tracks with joints) or an isolated switch	3
3	Switches and crossings with joints, 2 per 100m	3
4	More than 2 switches per 100m	2

RMR Structure		Bridge constant ID
	TT & U-type bridge - predominantly concrete or masonry	3
	TT & U-type bridge - predominantly steel	4
	Plate & girder bridge	4
	Steel deck bridge	4

Figure 2. Impact noise ID lookup table for RMR Joint "m", and Bridge constant ID lookup table for RMR Structure

RMR Track Cat "b"		Track Transfer ID
1	Monoblock	4
	Bi-block	7
2	Wooden	9
3	See impact correction table below for jointed track	
4	"Blocks" - not catered for in CNOSSOS - would require additional source data acquisition	
5	"Blocks" - not catered for in CNOSSOS - would require additional source data acquisition	
6	"Adjustable rail fixation" - not catered for in CNOSSOS - would require additional source data acquisition	
7	"Adjustable rail fixation" - not catered for in CNOSSOS - would require additional source data acquisition	
8	"Poured in" not catered for in CNOSSOS - would require additional source data acquisition	
9	"Level crossings" not catered for in CNOSSOS - would require additional source data acquisition	

Figure 3. CNOSSOS Track transfer ID lookup table for RMR Track

In the case of the RMR '96 example, the following should be noted during the conversion:

1. CNOSSOS-EU is single vehicle-based in general, and therefore it is assumed that each vehicle in an RMR category will be considered separately;
2. Aerodynamic noise is not included in RMR'96;
3. The referred identities (IDs) for the different descriptors (parameters) are those in 'Rail_Input_Database_Tables_Final-01April2014';
4. Rail roughness is assumed to be that of CNOSSOS-EU "ID 4" corresponding to 'NL average network with extrapolation'.

In the present example, data is readily available for all trains, and provided that the type of vehicles is quite homogeneous it can be assumed that data available is sufficient to meet the quality standards required. But still it might be necessary to verify, for instance by means of a dedicated measurement campaign, that the values found in the CNOSSOS-EU database for wheel roughness and wheel transfer function meet the desired quality criteria.

6. Conclusion

The new Common Noise Assessment Method for Europe (CNOSSOS-EU) has been adopted within a revision of Annex II of Directive 2002/49/EC. To support the migration from existing national methods to the new method, as an interim solution, look-up tables have been established which help to translate existing national railway methods to CNOSSOS-EU. It is envisaged that as experience with the new method increases, and the CNOSSOS-EU databases are extended, the use of these look-up tables will reduce over time as the specific rail vehicles, track types, impact sources and bridges within each country are captured in line with the CNOSSOS methodology and used to extend the CNOSSOS databases.

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