Note

Project	Develop and implement harmonised noise assessment methods		
Concerns	Source Modules Rail – Architecture		
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1. Introduction

This report gives the architecture for the implementation of the source model for railway traffic noise as described in Chapter IV of the JRC Reference Report "Stylianos Kephalopoulos, Marco Paviotti, Fabienne Anfosso-Lédée (2012), Common Noise Assessment Methods in Europe (CNOSSOS-EU), EUR 25379 EN".
This chapter references to a CNOSSOS-EU database. However it is not stated what the structure of such a database is and which information can be derived from this database. For this another document (with a different source model) is used, namely "M. Dittrich, Work Package 6, IMAGINE railway noise source model, default source data and measurement protocol", dated September 12, 2005 (IMA6TR-050912-TNO01).

The source model calculates the source power of a railway segment for an hourly traffic flow and under given conditions. Typically calculations are performed for day, evening and night period. Values like ambient temperature could differ for these periods, but they might also differ on a seasonal basis. This however is outside the scope of the source model. The source model will only describe the calculation of the source power for a given hour under given conditions.

Chapter 2 gives the input and output for relevant formulas in the source model. Next to input and output all static data and look-up tables (data depending on input values, e.g. α and β values) are given.

Chapter 3 will combine all information from chapter 2 and will create an overview of:

- All input data needed in the source model before being able to perform a source power calculation.
- The final results (source power levels) and all possible intermediate results (to be used for testing purposes).
- All static data and all look-up tables.

Chapter 4 describes the individual lookup tables.

2. Break down of the formulas

2.1 Definitions

2.1.1 Definition of railway vehicles (*t*)

Railway vehicles will be defined by a coded name in which the first 4 digits describe:

1. Vehicle type
2. Number of axles per vehicle
3. Brake type
4. Wheel measure

Based on this coded name information and values for the calculations are derived from a look-up table.

2.1.2 Definition of track types (*j*)

Tracks and support structure will be defined by a coded name in which the first 6 digits describe:

1. Track base
2. Railhead roughness
3. Rail pad type
4. Additional measures
5. Rail joints
6. Curvature

Based on this coded name information and values for the calculations are derived from a look-up table.

2.1.3 Source definition

- *h* Source heights
  - *1* 0.5 m
  - *2* 4.0 m
- *p* Source types
  - *1* Rolling, impact, squeal and bridge → h=1
  - *2* Traction → h=1 and h=2
  - *3* Aerodynamic → h=1 and h=2
- *r* Running conditions
  - *1* Constant speed
  - *2* Accelerating
  - *3* Decelerating
  - 4 Idling

2.1.4 Static values

These static values are not mentioned in the following chapters anymore, as it is assumed that these values are globally accessible.

- T_{ref} Reference time period for which the average traffic is considered
- r_0 Reference value for roughness (= 1 µm)
- v_0 Speed at which aerodynamic noise is dominant (= 250 km/h)

2.1.5 Wavelength and frequency

Supported wavelengths [cm]:

100.000	80.000	63.000	50.000	40.000	31.500	25.000	20.000	16.000
12.500	10.000	8.000	6.300	5.000	4.000	3.150	2.500	2.000
1.600	1.250	1.000	0.800	0.630	0.500	0.400	0.315	0.250
0.200	0.160	0.125	0.100	0.080				

Supported 1/3 octave values [Hz]:

50	63	80	100	125	160	200	250	315
400	500	630	800	1000	1250	1600	2000	2500
3150	4000	5000	6300	8000	10000			

Supported 1/1 octave values [Hz]:

63	125	250	500	1000	2000	4000	8000

Relation wavelength and frequency:

$$\lambda = \frac{V}{0.036 \times f}$$

where

λ Wave length [cm]
V Speed [km/h]
f Frequency [Hz]

3. Calculation

3.1 Traffic flow

Main formula

$$L_{W',eq,T,dir} = 10 \times lg\left(\sum_{x=1}^{X} 10^{L_{W',eq,line,x}/10}\right)$$

where

T	reference time period for which the average traffic is considered
X	total number of existing combinations of i, t, s, r, p for the track section
t	index for vehicle types on the track section
s	index for train speed: there will be as many indexes as the number of different average train speeds on the track section
r	index for running conditions: 1 (for constant speed), 2 (accelerating), 3 (decelerating) and 4 (idling)
p	index for physical source types: 1 (for rolling, impact, squeal and bridge noise), 2 (traction noise), 3 (aerodynamic noise)
$L_{W',eq,line,x}$	x-th directional sound power per metre for a source line of one combination of t, s, r, p on the track section → §3.2

3.2 Traffic flow per source condition

3.2.1 Moving vehicles (*r=1, 2 and 3*)

$$L_{W',eq,line}(\omega,\varphi) = L_{W,0,dir}(\omega,\varphi) + 10 \times lg\left(\frac{Q}{1000 \cdot v}\right)$$

where

Q	the average number of vehicles per hour on the j-th track section for vehicle type t, average train speed s and running condition r (1/s)
V	their speed in (km/h) on the track section for vehicle type t and average train speed s;
$L_{W,0,dir}$	the directional sound power level of the specific noise (rolling, impact, squeal, braking, traction, aerodynamic, other effects) of a single vehicle in the directions ψ, φ defined with respect to the vehicle's direction of movement. → §3.3

3.2.2 Idling vehicles (*r=4*)

$$L_{W',eq,line}(\omega,\varphi) = L_{W,0,dir}(\omega,\varphi) + 10 \times lg\left(\frac{T}{T_{ref} \cdot L}\right)$$

where

T	Overall time for idling during T_{ref}
L	Section length for idling
$L_{W,0,dir}$	the directional sound power level of the specific noise. → §3.3

3.3 Directional sound power level

$$L_{W,0,dir}(\omega,\varphi) = L_{W,0} + \Delta L_{W,dir,vert} + \Delta L_{W,dir,hor}$$

where

$L_{w,0}$	Sound power → §3.4, §3.5 and §3.6
$L_{w,dir,vert}$	Vertical directivity correction → §3.3.1
$L_{w,dir,hor}$	Horizontal directivity correction → §3.3.2
ω	Vertical angle
φ	Horizontal angle

3.3.1 Vertical directivity correction

Source height = 0.5m

Vertical directivity at 0.5m applies to all sources.

$$L_{W,dir,vert,i} = \left(\left|\frac{40}{3} \times \left[\frac{2}{3} \times sin(2 \cdot \omega) - \sin(\omega)\right] \times lg\left[\frac{f_{c,i}+600}{200}\right]\right|\right)$$

where

$f_{c,i}$ Centre band frequency (1/3 octave)

$\Delta L_{w,dir,vert}$ Vertical directivity

Source height = 4.0m

Vertical directivity at 4.0m applies to aerodynamic noise.

$$L_{W,dir,vert,i} = 10 \times \lg(cos^2\omega) \quad for\ \omega < 0$$
$$L_{W,dir,vert,i} = 0 \quad elsewhere$$

3.3.2 Horizontal directivity correction

Horizontal directivity only applies to all sources.

$$L_{W,dir,hor,i} = 10 \times \lg(0.01 + 0.99 \times \sin^2\varphi)$$

3.4 Rolling noise (Hsrc = 0.5m)

3.4.1 Sound power

$$L_{W,0,i} = 10 \times \lg\left(10^{L_{W,TR,i}/10} + 10^{L_{W,VEH,i}/10} + 10^{L_{W,VEH,SUP,i}/10}\right) + \Delta L_{SQUEAL} + \Delta L_{BRIDGE}$$

where

$L_{W,TR,i}$ Source power of rail sleeper and ballast/slab emission → §3.4.2

$L_{W,VEH,i}$ Source power of wheel and bogie emission → §3.4.2

$L_{W,VEH,SUP,i}$ Source power of superstructure emission → §3.4.2

ΔL_{SQUEAL} Frequency independent correction for curve squeal → §3.4.4

ΔL_{BRIDGE} Frequency independent correction for curve squeal → §3.4.5

3.4.2 Vehicle and track transfer function

$$L_{W,TR,i} = L_{R,TOT,i} + L_{H,TR,i} + 10 \times lg(N_a)$$
$$L_{W,VEH,i} = L_{R,TOT,i} + L_{H,VEH,i} + 10 \times lg(N_a)$$
$$L_{W,VEH,SUP,i} = L_{R,TOT,i} + L_{H,VEH,SUP,i} + 10 \times lg(N_a)$$

where

$L_{H,TR,i}$ Speed independent transfer function for track emission (SWL/axle)

$L_{H,VEH,i}$ Speed independent transfer function for vehicle emission (SWL/axle)

$L_{H,VEH,SUP,i}$ Speed independent transfer function for superstructure emission (SWL/axle)

$L_{R,TOT,i}$ Speed dependent transfer function for rail and wheel roughness → §3.4.3

N_a Number of axles

Lookup tables "Transfer track" (§4.1), "Transfer vehicle" (§4.2) and "Transfer super" (§4.3), definition:

- ID (string)
- Value [dB] per 1/3 octave

Input:

- References to records in lookup tables

Output:

- $L_{H,TR,i}$ [dB]
- $L_{H,VEH,i}$ [dB]
- $L_{H,VEH,SUP,i}$ [dB]

3.4.3 Roughness and impact

According to the CNOSSOS method:

$$L_{R,TOT,i} = 10 \times lg\left(10^{L_{R,ROUGH,i}/10} + 10^{L_{R,IMPACT,i}/10}\right)$$

$$L_{R,ROUGH,i} = 10 \times lg\left(10^{L_{R,TR,i}/10} + 10^{L_{R,VEH,i}/10}\right) + A_{3,i}$$

$$L_{R,IMPACT,i} = L_{R,IMPACT\_SINGLE,i} + 10 \times lg\left(n_i/_{0.01}\right)$$

where

$L_{R,ROUGH,i}$	Combined roughness level of the rail and wheel
$L_{R,IMPACT,i}$	Additional roughness level due to impacts (switches, joints and crossings)
$L_{R,TR,i}$	Roughness level of the rail
$L_{R,VEH,i}$	Roughness level of the wheel
$A_{3,i}$	Contact filter depending on wheel diameter and load
n_i	"1m joint Density" [joints/m]
$L_{R,IMPACT\_SINGLE,i}$	Additional roughness level due to a single impact/100m, i.e. where n_i=0.01

Lookup tables "Rail Roughness" (§4.5), "Wheel Roughness" (§4.6), "Contact filter" (§4.7) and "Impact noise" (§4.8), definition:
- ID (string)
- Value [dB] per wavelength [cm]

Input:
- References to records in lookup tables
- Speed [km/h]

Output:
- $L_{r,TR,i}$ [dB]
- $L_{r,VEH,i}$ [dB]
- $A_{3,i}$ [dB]
- $L_{r,IMPACT\_SINGLE,i}$ [dB]

3.4.4 Squeal

As a default the squeal noise is determined as a single dB value based on the curvature:

ΔL_{SQUEAL} = 8 dB	for R < 300m
ΔL_{SQUEAL} = 5 dB	for 300m <= R < 500m
ΔL_{SQUEAL} = 0 dB	for R >= 500m

where

R Radius of the curve [m]

3.4.5 Bridge

Lookup table "Bridge constant" (§4.9), definition:
- ID (string)
- Value [dB]

Input:
- References to record in lookup table (bridge type)

Output:
- ΔL_{BRIDGE} [dB]

3.5 Traction noise (Hsrc = 0.5m + 4.0m)

$L_{W,0,i} = L_{TRACTION,i}$

Lookup table "<u>Traction</u>" (§4.10), definition:
- ID (string)
- Source type A or B
- Operating condition (r): Constant speed, Accelerating or Decelerating or Idling;
- Value [dB] per 1/3 octave band (SWL/vehicle)

Input:
- Reference to record in lookup table
- Source type
- Operating condition

Output:
- $L_{TRACTION,i}$ [dB]

3.6 Aerodynamic noise (Hsrc = 0.5m + 4.0m)

<u>Source height = 0.5m</u>

$L_{W,0} = 0$ *for* $v_{ts} <= 200$ *km/h*

$L_{W,0} = L_{W,0}(v_0) + \alpha_1 \times lg\left(\frac{v_{ts}}{v_0}\right)$ *for* $v_{ts} > 200$ *km/h*

<u>Source height = 4.0m</u>

$L_{W,0} = 0$ *for* $v_{ts} <= 200$ *km/h*

$L_{W,0} = L_{W,0}(v_0) + \alpha_2 \times lg\left(\frac{v_{ts}}{v_0}\right)$ *for* $v_{ts} > 200$ *km/h*

Where

$L_{w,0}(v_0)$	Source power for aerodynamic noise at speed v_0 km/h
v_{ts}	Vehicle speed
v_0	Speed at which aerodynamic noise is dominant
α_1 and α_2	Coefficients for aerodynamic noise (default = 50)

Lookup table "<u>Aerodynamic</u>" (§4.11), definition:
- ID (string)
- Values for $L_{w,0}(v_0)$ and v_0
- Values for α_1 and α_2

Input:
- Reference to record in lookup table

Output:
- $L_{w,0}(v_0)$, v_0, α_1 and α_2

4. Lookup table structure

4.1 Vehicle definition

- ID → Unique ID, referenced by input data
- Code → Short description vehicle (informative)
- Description → Description vehicle (informative)
- P_Mech → Power in kW (informative)
- V_Max → Max speed in kmh (informative)
- Weight → Weight in tonnes (informative)
- Length → Length in m
- Axles → no of axles
- WheelDiameter → in mm (informative)
- WheelDiameterCode → diameter in mm (informative)
  `large, >800mm`
  `medium, 500 to 800mm`
  `small, <500mm`
- WheelMeasure →Wheel measures (informative)
  none
  WheelDampers
  Screens
  Others
- BrakeCode →Brake type (informative)
  CastIronBlock
  CompositeBlock-k-block
  Disk-Non-Tread
- Load → load in kN (informative)
- RefTransfer → Reference to "Vehicle transfer" record
- RefContact → Reference to "Contact filter" record
- RefRoughness → Reference to "Wheel roughness" record
- RefTraction → Reference to "Traction noise" record
- RefAerodynamic → Reference to "Aerodynamic noise" record

4.2 Track transfer

- Track Transfer Function ID → Unique ID, referenced by input data
- Default → `true` or `false` (informative)
- Reference → text (informative)
  `IMAGINE project`
  `European Commission`
  `Member State`
  `Local User`
  `CNOSSOS`
- Description → text (informative)
- Sleeper Type Code → text (informative)
  `concrete bi-block`

concrete mono-block
steel
wood
steel zigzag

- Railpad Type Code → text (informative)
  stiff
  medium
  soft
- 50 Hz .. 10000 Hz → float value (dB per 1/3 octave)

4.3 Vehicle transfer

- Vehicle Transfer Function ID → Unique ID, referenced by vehicle definition
- Default → `true` or `false` (informative)
- Reference → text (informative)
  IMAGINE project
  European Commission
  Member State
  Local User
  CNOSSOS
- Description → text (informative)
- Wheel Diameter → diameter in mm (informative)
- Wheel Diameter Code → text (informative)
  large, >800mm
  medium, 500 to 800mm
  small, <500mm
- 50 Hz .. 10000 Hz → float value (dB per 1/3 octave)

4.4 Superstructure transfer

- Structure Transfer Function ID → Unique ID, referenced by input data
- Default → `true` or `false` (informative)
- Reference → text (informative)
  IMAGINE project
  European Commission
  Member State
  Local User
  CNOSSOS
- Description → text (informative)
- 50 Hz .. 10000 Hz → float value (dB per 1/3 octave)

4.5 Rail roughness

- Rail Roughness ID → Unique ID, referenced by input data
- Default → `true` or `false` (informative)

- Reference → text (informative)
  `IMAGINE project`
  `European Commission`
  `Member State`
  `Local User`
  `CNOSSOS`
- Description → text (informative)
- Rail Roughness Condition code → text (informative)
  `not maintained and bad condition`
  `well maintained and very smooth`
  `normally maintained smooth`
  `not well maintained`
- 100 cm .. 0.08 cm → float value (per wave length)

4.6 Wheel roughness

- Wheel Roughness ID → Unique ID, referenced by vehicle definition
- Default → `true` or `false` (informative)
- Reference → text (informative)
  `IMAGINE project`
  `European Commission`
  `Member State`
  `Local User`
  `CNOSSOS`
- Description → text (informative)
- 100 cm .. 0.08 cm → float value (per wave length)

4.7 Contact filter

- Contact filter ID → Unique ID, referenced by vehicle definition
- Default → `true` or `false` (informative)
- Reference → text (informative)
  `IMAGINE project`
  `European Commission`
  `Member State`
  `Local User`
  `CNOSSOS`
- Description → text (informative)
- Load → integer value (Load in kN) (informative)
- Wheel diameter → integer value (diameter in mm) (informative)
- Wheel diameter code → text (informative)
  `large, >800mm`
  `medium, 500 to 800mm`
  `small, <500mm`
- 100 cm .. 0.08 cm → float value (per wave length)

4.8 Impact noise

- Impact noise ID → Unique ID, referenced by input data
- Default → `true` or `false` (informative)
- Reference → text (informative)
  - `IMAGINE project`
  - `European Commission`
  - `Member State`
  - `Local User`
  - `CNOSSOS`
- Description → text (informative)
- Rail Roughness Condition code → text (informative)
  - `not maintained and bad condition`
  - `well maintained and very smooth`
  - `normally maintained smooth`
  - `not well maintained`
- 100m Joint Density → joints/100m
  - `2`
  - `3`
  - `0`
  - `1`
- Decription100m Joint Density → text (informative)
  - `2 switches/joints/crossings / 100m`
  - `>2 switches/joints/crossings / 100m`
  - `none`
  - `single switch/joint/crossing / 100m`
- 100 cm .. 0.08 cm → float value (per wave length)

4.9 Bridge constant

- Bridge constant ID → Unique ID, referenced by input data
- Default → `true` or `false` (informative)
- Reference → text (informative)
  - `IMAGINE project`
  - `European Commission`
  - `Member State`
  - `Local User`
  - `CNOSSOS`
- Description → text (informative)
- Cbridge → float value (Cbridge constant in dB)

4.10 Traction Noise

- Traction noise ID → Unique ID, referenced by vehicle definition
- Default → `true` or `false` (informative)
- Reference → text (informative)
  - `IMAGINE project`

```
European Commission
Member State
Local User
CNOSSOS
```

- Description → text (informative)
- Source type → "A", "B"
  - Running condition → Constant, Accelerating, Decelerating, Idling
    - 50 Hz .. 10000 Hz → float value (dB per 1/3 octave)

4.11 Aerodynamic Noise

- Aerodynamic noise ID → Unique ID, referenced by vehicle definition
- Default → `true` or `false` (informative)
- Reference → text (informative)

```
IMAGINE project
European Commission
Member State
Local User
CNOSSOS
```

- Description → text (informative)
- Source type → "A", "B"
  - V0 → Reference speed [km/h]
  - 50 Hz .. 10000 Hz → float value (dB per 1/3 octave)
  - Alpha → float value