TECHNICAL NOTE

Nord2000 guide for alternating noise emission along railway tracks

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Performed for Banedanmark

Carsten Niebuhrs Gade 43

1577 København V

Att.: Lisette Mortensen

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Acoustics, Noise and Vibrations

Reviewed by

Erik Thysell

Erik Thysell

2023-06-30

Digitally signed by Erik Thysell
erth@forcetechnology.com
Senior Specialist

Reported by

Per Finne

Per Finne

2023-06-30

Digitally signed by Per Finne
pfi@force.dk
Senior Specialist

GTS ADVANCED TECHNOLOGY GROUP

FORCE Technology
Venlighedsvej 4
2970 Hørsholm
Tel.+45 43 25 14 00
Fax + 45 43 25 00 10

FORCE Technology Norway AS
Nye Vakås vei 32
1395 Hvalstad, Norway
+47 64 00 35 00
+47 64 00 35 01
info@forcetechnology.no

FORCE Technology
Park Allé 345
2605 Brøndby, Denmark
+45 43 25 00 00
+45 43 25 00 10
info@forcetechnology.dk
www.forcetechnology.com

1 Introduction and background

This guide contains instructions how to use the new and updated noise emission data for Danish trains running on Banedanmark's railway tracks. The new emission data (published 2023 [3]) are used for noise predictions using Nord2000 and are based on the most comprehensive measurement program in Denmark to date with more than 3,000 emission data sets corresponding to more than 1,500 train pass-bys.

The fact that Banedanmark has introduced condition-based maintenance on the tracks has led to an agreement with the Danish Environmental Protection Agency on Banedanmark being responsible for updating noise emission data for the tracks owned and maintained by Banedanmark. Banedanmark's responsibility is to ensure that the tracks are maintained in a way that the new emission data are representative.

In "condition-based maintenance" the track roughness is measured, and the tracks are being milled regularly, so the roughness is kept at a low level, hence minimizing noise emission.

The previous noise emission data were published by the Danish Environmental Protection Agency in 2005 [1]. Apart from entirely new measurements on the Metro and Øresund Trains, this consisted of a reanalysis of measurements made in the mid 1990'ies. This was done to get noise emission data in 1/3 octave bands for Nord2000.

Principally, both the previous and the new emission data assumes that wheels and rails are well-maintained, but in contradiction to the previous data it is now ensured that the track roughness is measured and documented at all train pass-bys. In the measurement program values for driving over switches and joints were also established from measurement of rail roughness in railway sections with switches and joints.

Noise from railways at train speeds between approx. 40 and 250 km/h are predominantly determined by rolling noise. The noise occurs because the contact between wheel and rail is not ideal; there is a certain roughness in the wheel and rail contact surface that generates rolling noise. Roughness is measured in µm and the roughness level L_r in dB re 1 µm.

In previous measurements, it was a precondition that wheels and rails were well maintained - however without adequate documentation of the roughness level. Nowadays, it's possible to measure both wheel and rail roughness and thus take the roughness into account when determining the noise emission. Banedanmark has since 2017 carried out yearly measurements of rail roughness along most tracks and from 2023 a limit value for rail roughness has been introduced, which in the future is intended to ensure a low level of rail roughness. The new emission data can be used for predicting railway noise using Nord2000 in cases where it has been determined that the rail roughness is documented low and is maintained in such a way that the noise indicator $L_{\lambda CA}$ [2] does not exceed 14 – apart from rail sections with switches and joints.

As there has been no similar and systematic monitoring of wheel roughness on trains so far, it is a precondition that the general condition of wheels is roughly the same as the measurements carried out in the years 2018-2020.

For other railway tracks, the previous (old) data for Danish trains must be used along with the existing (old) rules for calculating L_{Amax}.

Table 1 shows an overview of the previous and new emission data sets:

Previous data sets (2005)	Application	New data sets (2023)
Type A&D	Intercity trainsets	IC3/ER4/IC4
Type B, C, H & I	Freight trains, including locomotive.	Short Freight Train, ≤ 250 m* Long Freight Train, > 250 m*
Type E	Trainset for local and regional transport	Lint/Desiro
Type F	S-trains 4th generation	S-trains F4 (4th generation)
Øresundstog	Cross national trainset for Danish and Swedish tracks	ET (Øresundstog)
N/A	Double-decker train Vectron locomotive + double-decker wagons	DD (including Vectron locomotive)
*All freight trains on Banedanmark's tracks are assumed to have retrofitted or new brake blocks, i.e. without cast iron brake blocks.		

Table 1 *Overview of new and previous data sets for railway noise.*

2 Preconditions for the new noise emission data

As of March 2023, Banedanmark's tracks are divided into two noise categories: Well-maintained tracks, and Poorly maintained tracks.

2.1 Well-maintained tracks

Well-maintained tracks are tracks which are underlying condition-based maintenance and with noise indicator less than $L_{\lambda CA} \leq 14$. The new emission data of 2023 should be used for these well-maintained tracks and for sections with switches and joints with Nord2000.

2.2 Poorly maintained tracks

Poorly maintained tracks are tracks, which are **not** underlying condition-based maintenance, and tracks with noise indicator $L_{\lambda CA} > 14$, i.e. all other tracks than well-maintained tracks. The previous emission data of 2005 should be used for these tracks with Nord2000 including the "old" rules for calculating L_{Amax}.

2.3 Switches and joints

For trains running on track sections with switches and joints there are new increased emission data. The data corresponds to completely different emission data with separate a- og b-values for the 1/3-octave bands (50 Hz – 10000 Hz).

Currently, the maintenance program for these sections are not incorporated in the ordinary maintenance program for condition-based maintenance due to technical reasons, hence the noise emission is higher on the sections with switches and joints.

Since the roughness of the individual switches vary a lot, it has been decided that several trains advantageously can be merged. The emission data for track sections with switches and joints are limited into three vehicle categories:

- Passenger trains, covering IC3/ER4/IC4, ET (Øresund), Lint/Desiro and Double-decker Trains
- Freight trains, covering all retrofitted freight trains (diesel and electrical) – see Table 1.
- S-trains

The emission data for these are shown in Appendix 1.

It should be noted that the new emission data for S-trains is not linked to the rail roughness, since the roughness measurement campaign was not available. However, the same procedure for normal tracks and sections with switches and joint is used.

3 Effects on the noise model

The new emission data influences predictions of both L_{den} and L_{Amax}.

3.1 L_{den}

Around sections with switches and joints, L_{den} will increase compared to a well-maintained track. The increase in noise depends on the types of trains on the line, in the extent of the section with switches and joints and on the distance from the track. Typically, the influence will be greater at the lowest frequencies (below 800 Hz – 1000 Hz).

3.2 L_{Amax}

The corrections used so far for switches and joints (frequency independent +6 dB) is used exclusively in connection with predictions using the "old" emission data (type A&D, type E, etc.,) – see Table 1.

The following is only valid for tracks with condition-based maintenance.

3.2.1 Predicting L_{Amax} for well-maintained tracks

The rules for predicting L_{Amax} when running on well-maintained tracks are briefly summarized below. Please note that this is also included as a part of the **approximate method** in Appendix 2 for trains running on sections with switches and joints. The prediction rule depends on whether diesel-powered freight trains occur on the track:

1. The maximum value L_{Amax} is determined by the noisiest train type considering the maximum train lengths and the maximum speed for the different train types that occur on the line. This applies to ordinary passenger trains and electric freight trains.

2. For diesel-powered freight trains with retrofitted wagons, the method depends on the distance of the calculation point from the nearest track centre, *d*:

   If ***d*** **≤ 50 m:** the freight train's maximum value is estimated using a solo train pass-by with a diesel locomotive on a well-maintained track. The length of the diesel locomotive is 21 m.

   If ***d*** **> 50 m:** the freight train's maximum value is calculated for the greatest possible train length and speed on a well-maintained track.

Diesel-powered freight trains will most likely be phased out over time in line with the electrification of the tracks. The procedure with diesel locomotives is included for the sake of completeness due to a given transition phase which is not known precisely.

For the time being it is estimated that solo diesel locomotives have identical noise emission on well-maintained tracks on sections with switches and joints – see Appendix 1.

3.2.2 Predicting L_{Amax} for sections with switches and joints

For prediction tools having a perfect implementation of how to alter emission values for the parts with well-maintained tracks and the sections with switches and joints, the procedure is identical to the above described (section 3.2.1).

However, it is well-known that in most implementations this is not possible now and then the approximate method of using precalculated correction values (in total dBA) should be followed.

The approximate method is described in Appendix 2.

In future software implementations with the new emission data, see Appendix 1, each train should have two sets of emission data: one set for well-maintained tracks and one set for sections with switches and joints. This is important, because L_{Amax} calculations take the sound power dispersed along a line source, stretched along the train on the tracks, see [4] for further specification of the source model. For calculation of L_{Amax} for a specific situation, when the train is in a certain position along the track with a receiver at a given point, each part of the train contributes to the L_{Amax} – see Figure 1. If a part of the track has a different roughness, its contribution has to be taken into account to the total L_{Amax}.

It is proposed that the user of noise modelling software can for any given part of the track specify whether this part is considered as either normal/well-maintained tracks or "switches and joints", and the software will take care of selecting the corresponding emission data for each train and each part of the track.

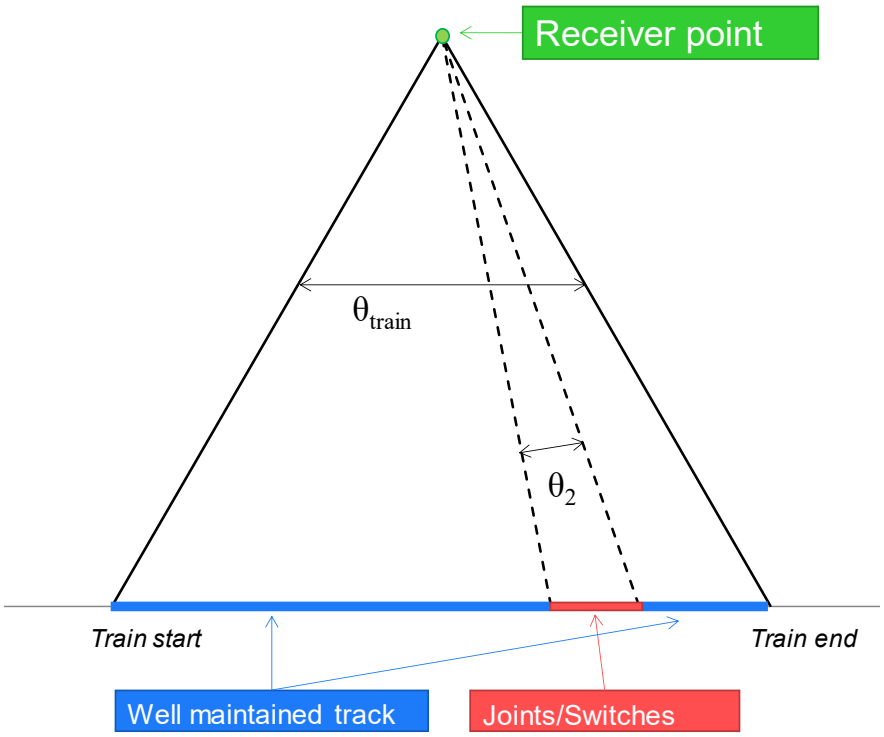

Figure 1 *Illustration of different roughness along track.*

4 References

[1] Danish Environmental Protection Agency: "Kildestyrkedata for togstøj til Nord2000. Miljøprojekt Nr. 1014", 2005 (in Danish).

[2] Helmut Venghaus, ACCON GmbH: "Study on rail roughness embedding the noise indicator $L_{\lambda CA''}$, AIA-DAGA 2013 Merano.

[3] Guidance from the Danish EPA Reference Laboratory no. 54/2023: "Kildestyrker til Nord2000 for tog på vel vedligeholdte spor" (in Danish).

[4] Technical Note RL 14/16: "Revision af kildemodel ved anvendelse af Nord2000 til beregning af maksimalværdi fra jernbaner", Danish EPA Reference Laboratory, 2016 (in Danish).

Appendix 1 Emission data, a- and b-values

	IC3/ER4/IC4 (well-maintained track)		IC3/ER4/IC4 (switches and joints)	
f [Hz]	**a**	**b**	**a**	**b**
25				
31,5				
40				
50	31.8	84.9	30.2	91.1
63	35.2	84.5	11.3	93.0
80	38.9	84.1	26.0	91.9
100	26.0	84.7	15.3	92.2
125	23.2	83.9	15.2	90.2
160	25.1	83.4	15.3	89.6
200	22.1	80.4	20.3	86.0
250	22.7	82.2	21.5	87.1
315	18.7	83.6	19.5	88.6
400	12.5	85.9	15.1	90.6
500	7.9	86.4	12.6	91.3
630	14.7	86.6	21.2	91.2
800	20.0	86.7	24.8	90.4
1000	29.2	87.2	33.5	90.3
1250	35.9	85.6	36.5	88.2
1600	43.3	83.2	39.1	85.9
2000	45.0	83.4	43.8	85.8
2500	45.9	81.2	37.6	84.8
3150	38.3	80.1	28.9	84.0
4000	25.3	79.4	30.3	82.3
5000	22.5	77.2	30.0	80.0
6300	23.6	75.4	27.4	77.7
8000	23.0	72.7	23.4	74.6
10000	26.5	71.2	19.3	73.8

	Lint/Desiro (well-maintained tracks)		Lint/Desiro (switches and joints)	
f [Hz]	**a**	**b**	**a**	**b**
25				
31,5				
40				
50	32.0	88.2	30.2	91.1
63	5.3	89.4	11.3	93.0
80	23.0	89.7	26.0	91.9
100	19.9	89.5	15.3	92.2
125	7.5	85.6	15.2	90.2
160	6.9	85.2	15.3	89.6
200	25.1	82.1	20.3	86.0
250	10.7	81.9	21.5	87.1
315	4.7	82.8	19.5	88.6
400	3.5	84.2	15.1	90.6
500	4.2	87.0	12.6	91.3
630	13.1	86.3	21.2	91.2
800	21.4	86.7	24.8	90.4
1000	37.9	88.9	33.5	90.3
1250	31.1	86.7	36.5	88.2
1600	29.2	83.8	39.1	85.9
2000	34.4	83.9	43.8	85.8
2500	22.8	83.3	37.6	84.8
3150	13.6	82.5	28.9	84.0
4000	21.5	81.6	30.3	82.3
5000	25.2	79.6	30.0	80.0
6300	20.7	78.2	27.4	77.7
8000	16.6	75.9	23.4	74.6
10000	13.2	76.8	19.3	73.8

	ET (well-maintained tracks)		ET (switches and joints)	
f [Hz]	**a**	**b**	**a**	**b**
25				
31,5				
40				
50	86.7	81.1	30.2	91.1
63	37.5	80.5	11.3	93.0
80	21.1	81.0	26.0	91.9
100	1.0	83.4	15.3	92.2
125	28.3	83.2	15.2	90.2
160	16.3	82.7	15.3	89.6
200	10.0	79.2	20.3	86.0
250	24.8	79.4	21.5	87.1
315	24.9	81.8	19.5	88.6
400	12.0	84.2	15.1	90.6
500	8.2	86.1	12.6	91.3
630	34.7	84.7	21.2	91.2
800	26.6	84.2	24.8	90.4
1000	29.9	84.8	33.5	90.3
1250	39.3	84.8	36.5	88.2
1600	39.6	83.6	39.1	85.9
2000	45.9	82.5	43.8	85.8
2500	49.5	80.8	37.6	84.8
3150	25.0	79.7	28.9	84.0
4000	35.1	78.5	30.3	82.3
5000	48.2	76.4	30.0	80.0
6300	45.3	74.6	27.4	77.7
8000	44.6	71.8	23.4	74.6
10000	48.8	70.3	19.3	73.8

	F4 (well-maintained tracks)		F4 (switches and joints)	
f [Hz]	**a**	**b**	**a**	**b**
25				
31,5				
40				
50	38.2	83.5	31.7	87.1
63	44.2	81.3	37.1	85.0
80	27.8	83.9	20.7	87.9
100	15.1	87.4	8.1	91.7
125	18.9	87.9	12.2	92.7
160	44.7	85.6	38.0	91.2
200	44.4	81.4	39.2	87.8
250	47.2	82.4	44.4	90.0
315	42.8	83.2	44.6	92.2
400	20.2	85.3	26.1	95.4
500	11.0	85.3	20.6	95.9
630	32.8	86.6	45.3	97.3
800	22.6	85.3	35.7	95.2
1000	40.2	87.5	52.2	95.7
1250	54.0	86.1	62.6	92.3
1600	44.8	83.8	50.2	88.1
2000	60.8	82.1	64.5	85.4
2500	48.2	80.3	51.6	83.2
3150	44.7	79.8	49.2	82.7
4000	54.6	79.0	59.6	81.7
5000	44.1	78.0	48.5	80.1
6300	38.3	76.8	40.7	77.9
8000	34.3	75.5	35.4	76.0
10000	43.0	73.7	43.0	73.7

	DD (well-maintained tracks)		DD (switches and joints)	
f [Hz]	**a**	**b**	**a**	**b**
25				
31,5				
40				
50	36.9	84.6	30.2	91.1
63	77.4	80.2	11.3	93.0
80	96.3	77.4	26.0	91.9
100	65.2	79.8	15.3	92.2
125	55.5	80.8	15.2	90.2
160	34.7	83.2	15.3	89.6
200	62.5	73.8	20.3	86.0
250	61.4	76.5	21.5	87.1
315	68.4	75.1	19.5	88.6
400	33.7	78.8	15.1	90.6
500	24.9	79.6	12.6	91.3
630	26.3	81.5	21.2	91.2
800	21.1	85.4	24.8	90.4
1000	50.2	80.2	33.5	90.3
1250	29.0	80.8	36.5	88.2
1600	18.8	83.0	39.1	85.9
2000	40.7	80.1	43.8	85.8
2500	42.1	78.8	37.6	84.8
3150	34.7	78.8	28.9	84.0
4000	26.2	77.8	30.3	82.3
5000	34.3	73.8	30.0	80.0
6300	38.0	71.3	27.4	77.7
8000	39.7	68.9	23.4	74.6
10000	46.0	66.9	19.3	73.8

	Freight train, electric (well-maintained tracks)		Freight train, electric (switches and joints)	
f [Hz]	**a**	**b**	**a**	**b**
25				
31,5				
40				
50	31.7	89.0	32.0	97.5
63	13.1	85.7	13.3	94.2
80	2.1	86.9	2.3	95.5
100	4.2	86.4	5.6	95.1
125	0.7	84.4	2.0	93.0
160	0.6	84.6	2.2	93.1
200	0.3	82.0	3.2	90.4
250	0.1	83.5	4.5	92.1
315	0.0	85.6	5.9	94.3
400	0.0	87.5	6.4	96.1
500	0.6	88.5	8.0	96.2
630	12.6	89.8	20.1	97.0
800	22.1	90.9	28.1	97.1
1000	26.6	91.6	31.7	96.8
1250	29.3	90.7	33.0	95.1
1600	26.7	88.4	29.0	91.8
2000	18.8	86.4	21.2	89.6
2500	14.4	84.8	17.2	87.9
3150	14.9	84.1	19.4	87.4
4000	15.7	81.7	20.6	84.7
5000	16.5	79.4	20.7	81.6
6300	16.5	78.2	19.5	79.7
8000	17.9	75.3	19.0	75.8
10000	17.7	73.2	17.0	72.9

	Short freight train, diesel (< 250m) (well-maintained tracks)		Short freight train, diesel (< 250m) (switches and joints)	
f [Hz]	**a**	**b**	**a**	**b**
25				
31,5				
40				
50	13.8	91.4	32.0	97.5
63	13.2	91.9	13.3	94.2
80	0.1	97.6	2.3	95.5
100	5.6	93.9	5.6	95.1
125	4.5	92.4	2.0	93.0
160	6.8	90.6	2.2	93.1
200	5.2	87.2	3.2	90.4
250	0.4	88.9	4.5	92.1
315	0.4	89.5	5.9	94.3
400	0.0	91.0	6.4	96.1
500	1.1	91.9	8.0	96.2
630	2.1	94.6	20.1	97.0
800	20.0	96.5	28.1	97.1
1000	34.9	95.5	31.7	96.8
1250	30.7	92.6	33.0	95.1
1600	28.2	91.2	29.0	91.8
2000	26.0	90.3	21.2	89.6
2500	16.2	89.4	17.2	87.9
3150	20.9	88.5	19.4	87.4
4000	21.9	85.5	20.6	84.7
5000	21.8	83.3	20.7	81.6
6300	20.8	80.3	19.5	79.7
8000	21.9	77.3	19.0	75.8
10000	22.1	74.9	17.0	72.9

	Long freight train, diesel (≥ 250m) (well-maintained tracks)		Long freight train, diesel (≥ 250m) (switches and joints)	
f [Hz]	**a**	**b**	**a**	**b**
25				
31,5				
40				
50	22.3	89.4	32.0	97.5
63	13.1	87.5	13.3	94.2
80	0.5	91.5	2.3	95.5
100	4.9	88.9	5.6	95.1
125	2.4	87.2	2.0	93.0
160	2.8	86.2	2.2	93.1
200	2.0	83.2	3.2	90.4
250	0.2	84.9	4.5	92.1
315	0.1	86.5	5.9	94.3
400	0.0	88.3	6.4	96.1
500	0.3	89.1	8.0	96.2
630	6.9	91.1	20.1	97.0
800	20.9	92.4	28.1	97.1
1000	28.8	92.6	31.7	96.8
1250	29.7	91.0	33.0	95.1
1600	26.5	88.8	29.0	91.8
2000	20.5	87.3	21.2	89.6
2500	14.4	85.9	17.2	87.9
3150	16.2	85.1	19.4	87.4
4000	16.8	82.5	20.6	84.7
5000	17.5	80.2	20.7	81.6
6300	16.9	78.5	19.5	79.7
8000	18.2	75.5	19.0	75.8
10000	18.2	73.4	17.0	72.9

	Diesel locomotive (21 m) (well-maintained tracks)		Diesel locomotive (21 m) (switches and joints)*	
f [Hz]	**a**	**a**	**a**	**b**
25				
31,5				
40				
50	7.9	95.2	7.9	95.2
63	13.3	97.8	13.3	97.8
80	0.0	104.1	0.0	104.1
100	5.8	100.0	5.8	100.0
125	5.3	98.6	5.3	98.6
160	9.4	96.5	9.4	96.5
200	7.4	92.9	7.4	92.9
250	0.5	94.6	0.5	94.6
315	0.6	94.7	0.6	94.7
400	0.0	95.9	0.0	95.9
500	1.6	96.9	1.6	96.9
630	0.0	100.0	0.0	100.0
800	19.5	102.3	19.5	102.3
1000	46.4	100.3	46.4	100.3
1250	32.3	96.3	32.3	96.3
1600	30.0	95.9	30.0	95.9
2000	33.9	95.4	33.9	95.4
2500	17.3	95.0	17.3	95.0
3150	26.0	93.9	26.0	93.9
4000	28.7	90.6	28.7	90.6
5000	26.7	88.4	26.7	88.4
6300	29.8	84.2	29.8	84.2
8000	30.3	81.1	30.3	81.1
10000	33.5	78.4	33.5	78.4

*Estimated values

Appendix 2 Approximate method for L_{Amax}

With the approximate method the difference in L_{Amax} is calculated for a train running on an infinitely long section with switches and joints compared to an infinitely long well-maintained track. L_{Amax} is predicted in a cross-section perpendicular to the track at up to 400 m. Flat porous terrain without noise barriers, reflections or terrain variations is assumed.

The calculations are performed in 1/3-octave bands, but the results are given as a correction to the total value ΔL_{Amax}. The ΔL_{Amax} are most correctly used as a correction added to the track section. This will also include correction for the length of the section with switches and joints.

Note that the correction values in Table 2 differ for each train type.

Train type	**Correction ΔL_{Amax} [dB]**
IC3/ER4/IC4	+3 dB
Lint/Desiro	+2 dB
ET, Øresundstog	+4.5 dB
DD, Double-decker Train	+6 dB
S-train (F4)	+7 dB
Freight Train, electrical locomotive.	+5 dB
Freight Train, diesel locomotive. (length > 250 m)	+5 dB
Freight Train, diesel locomotive. (<250m)	+2 dB

Table 2 *Correction values ΔL_{Amax} for the different train types used for approximate prediction of L_{Amax} for sections with switches and joints. The correction values are added to the emission data for a well-maintained track.*

Calculating the maximum value for driving on sections with switches and joints is done by calculating the maximum value on a well-maintained track with an addition, cf. Table 2, to the noise emission $L_{W,1m}$ for the current train type.