Clarifications And Refinements To Squeal Noise In CNOSSOS

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ABSTRACT

The common European method for environmental noise computations [1], to which we refer here as CNOSSOS, incorporates a description of curve squeal noise that needs clarification and refinement on a few aspects. Firstly, there is a (possibly) ambiguous formulation, as it features both an "appropriate description" and a "simple approach" for curve squeal. The text needs to clarify which of these formulations is to be used in which case. Secondly, the curve radius that is generally associated with squeal noise of tram systems is much smaller than the two curvature classes declared in CNOSSOS. Trams do not tend to squeal in curves with radii over 200 metres. Thirdly, the track length restriction, stating that squeal in sections shorter than 50 m can be ignored, implies that short turnouts (of switches) as well as tight tramway curves, both of which are likely to cause severe squeal, would be excluded. Finally, the expression 'branch-outs of points' needs to become more descriptive. This paper discusses the issues with the current model description and substantiates the modifications that are needed in the formal method description. In the course of 2019 it will be become clear if the proposed modifications to CNOSSOS will be accepted.

Keywords: Noise, Curve Squeal, Source Model
I-INCE Classification of Subject Number: 76

1. INTRODUCTION

The paragraph on curve squeal in the CNOSSOS method [1] is short. The text consists of three paragraphs, which are copied here for convenience:

Curve squeal is a special source that is only relevant for curves and is therefore localised. As it can be significant, an appropriate description is required. Curve squeal is generally dependent on curvature, friction conditions, train speed and track-wheel geometry and dynamics. The emission level to be used is determined for curves with radius below or equal to 500 m and for sharper curves and branch-outs of points with radii below 300 m. The noise emission should be specific to each type of rolling stock, as certain wheel and bogie types may be significantly less prone to squeal than others.

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The applicability of these sound power spectra shall normally be verified on-site, especially for trams. Taking a simple approach, squeal noise shall be considered by adding 8 dB for R < 300 m and 5 dB for 300 m < R < 500 m to the rolling noise sound power spectra for all frequencies. Squeal contribution shall be applied on railway track sections where the radius is within the ranges mentioned above for at least a 50 m length of track.

In this section we will address three issues with this text. Then we will propose and substantiate solutions, and give an impression of the consequences for modelling railway noise sources (Section 2). We conclude with offering a new text for the CNOSSOS method (Section 3).

These modifications for squeal noise are part of larger set of corrections and improvements, that are proposed for different parts of CNOSSOS, about which the European Commission will most likely decide in the course of 2019 [2].

1.1 Ambiguity

The first paragraph of the CNOSSOS text on squeal noise describes the most important characteristics of squeal and declares that 'an appropriate description' is required. In that paragraph two classes of curvature are introduced, apparently as starting point for such an appropriate description. The second paragraph is just one sentence. The term 'sound power spectra' in this sentence implies that the 'appropriate description' allows for the use of spectral excess values. The third paragraph is a very practical one, the 'simple approach', which describes which penalty values (flat spectrum) are to be used.

What is the relationship between the first and third paragraph? Is it allowed to choose between the appropriate description and the simple approach, or is the third paragraph intended to be the final decision of how to model squeal noise? The text leaves open the possibility to choose between appropriate and simple, but it is not clear if this is intended. The original intention cannot be derived from previous drafts of CNOSSOS (2010 and 2012).

This ambiguity needs to be elucidated, otherwise different authorities will interpret the Directive in a different way, at the risk of not giving proper attention to squeal in noise mapping and action planning.

Furthermore, it is noted that the expression 'branch-outs of points' in the first paragraph has caused many translation problems. As the CNOSSOS method has to be translated to all official languages of the European Union, a more descriptive wording is required for this term. The common UK English term would be turnouts of railroad switches or, in short, switch turnouts. Figure 1 clarifies the terminology.
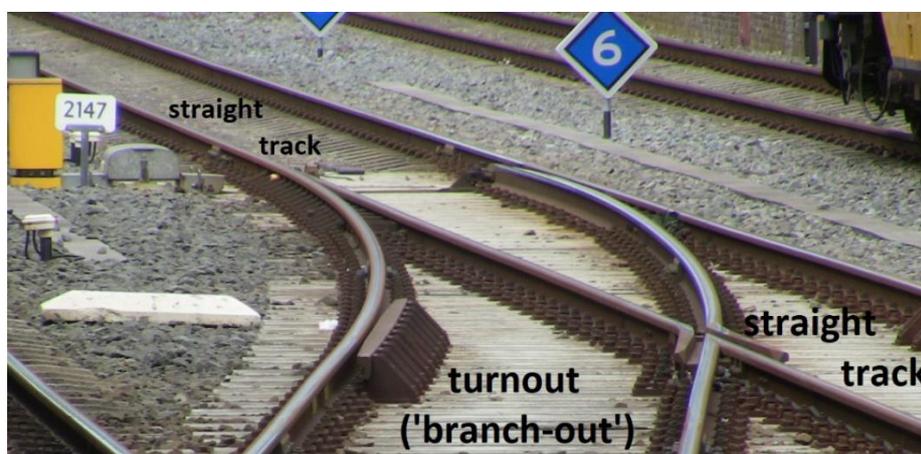

Figure 1 Railroad switch ('set of points') and turnout ('branch-out').

1.2 Tram squeal noise

Trams tend to squeal in curves with radii that are much less than those given as 'simple approach' in the CNOSSOS text. As rule of thumb, see for example reference [3], is that generally no squeal occurs in curves with radius over $100b$ where b is the wheelbase (i.e. the distance between the two axles in a bogie, see Figure 2). As the wheelbase of trams is much smaller than the wheelbase of trains, the simple approach needs to handle trams differently from trains.
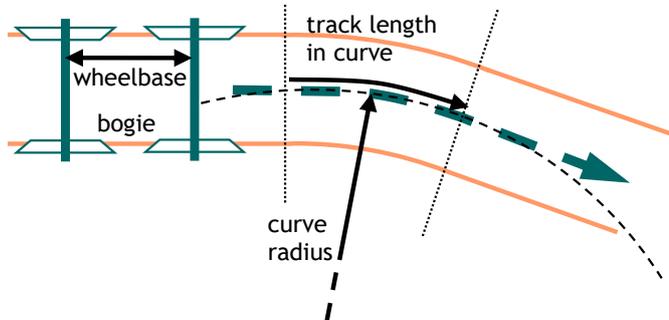

Figure 1 Relevant aspects of the vehicle in a curve

The wheelbase of trams is usually around 1,8 m (for example FLEXX Urban 2000 by Bombardier and Combino by Siemens), from which it can be estimated that squeal does not occurs in curves with radii over 180 m. Krüger found an empirical relationship between the excess value and the curve radius for tramway systems [4]. The function is plotted in Figure 3. Above 200 m radius the excess value becomes small, hence no correction value would be needed.

Because the two default curvature classes in CNOSSOS are not suited for trams, a more adequate description for trams is needed.
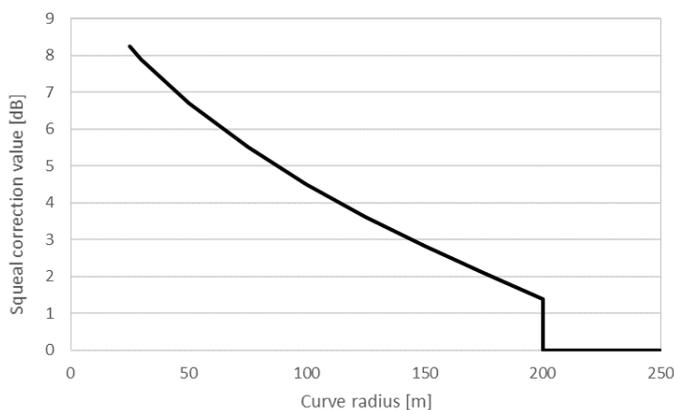

*Figure 3 Relationship for the correction value (*Korrekturpegel*) for tram squeal [4].*

1.3 Track length restriction not suitable for switches and tramway curves

Presumably the track length restriction of 50 m, in the last sentence of the CNOSSOS text, has a practical reason. It is probably only meant to be applicable to curves in (heavy) railway systems. To avoid confusion, it should be made clear in the text that the rule is not applicable to turnouts of switches, nor to short tramway curves.

As shown in Figure 1, a 'branch-out of points' (switch turnout) connects a railway track to a diverging track. Figure 4 gives an overview of a railway switch. A switch turnout is designed with a curve radius that depends on maximum train speed for which it is allowed. The likelihood and strength of squeal noise in a turnout depends on this

radius (and on many other aspects). For example, the maximum speed in 190-1:9 type switches, that are often found near railway stations in several European countries, is 40 km/h. The curve radius of its turnout equals 190 m and the tangent of the crossing angle is 1:9 (hence the annotation 190-1:9). This type of switch turnout, which is likely to cause wheel squeal and flanging noise under dry conditions, has a total length of about 27 m. Only part of it is curved. Literally following the 50 m rule would mean that this potentially noisy switch turnout, and many similar ones, would be excluded from the penalty system.
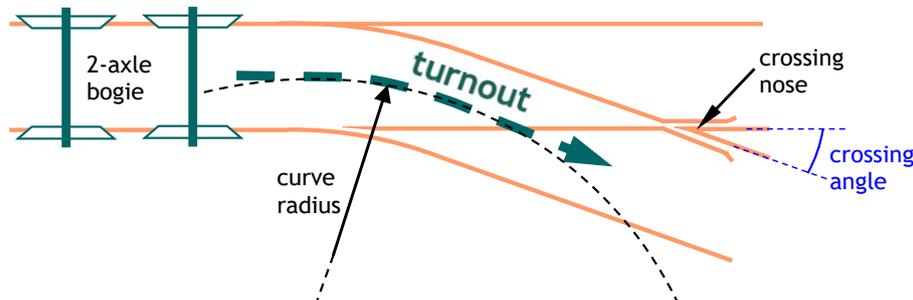

Figure 4 Terminology of the railroad switch.

Sharp tramway curves in city centres may have radii as small as 15 or 20 m. The track length in such curves is 24 to 31 m if the track is around a 90° street corner. Unless measures against squeal are taken, curves of this radius are likely to cause severe wheel squeal. However, literally following the 50 m rule would imply that the most annoying tramway curves would be excluded.

2. SOLUTIONS
2.1 Appropriate description
Given the wide range of relevant parameters that are associated with squeal and the stochastic nature of this type of noise, it is impossible to develop an analytical formula and/or to provide a set of excess power spectra valid for all tram, metro and train systems and climate conditions throughout Europe. Therefore, authorities should be given the opportunity to explore their own approach instead of relying on default excess values. This approach should be based on measurements and it should take account of the stochastic nature.

Authorities that wish to develop an appropriate method would perhaps need some guidance or basic conditions. The CNOSSOS document is not suited for this: measurement and assessment methods are outside of the scope of the document but is considered elsewhere [5].

One basic question, however, needs to be addressed in the Directive. Is it allowed to apply an excess power *spectrum*, or should authorities be restricted to apply an excess *value* (i.e. flat spectrum)? For software programmers and authorities that want to use power spectra it is necessary to make an explicit statement about this. Before we answer this question here, we discuss some relevant data.

In this respect it should be noted that the excess noise in tight curves is not always a tonal sound (high pitch). Sometimes a juddering sound can be heard (midrange frequencies), and sometimes flanging occurs ('hissing', high frequencies, non-tonal). Example noise spectra are given in Figure 5. The noise spectrum of the passenger train in a dry switch, clearly shows the characteristics of flanging noise (wide peak above 2 kHz). The noise level is reduced by 16 dB(A) after spraying water on the switch. The noise spectrum of the tram in a curve is about 9 dB(A) higher under dry condition than than

after application of a friction modifier (lubrication). Observers said the peak around 500 Hz was not audible as squeal. Only the peaks above 1000 Hz were tonal [6].

The shape of a squeal spectrum is also dependent on the vehicle. For example, the present tram series in the city of Rotterdam squeal at 720 Hz, while the previous series had a peak between 1,2 and 1,7 kHz [7]. Hence, an excess power spectrum based on one vehicle type is outdated as soon as a new type is introduced.
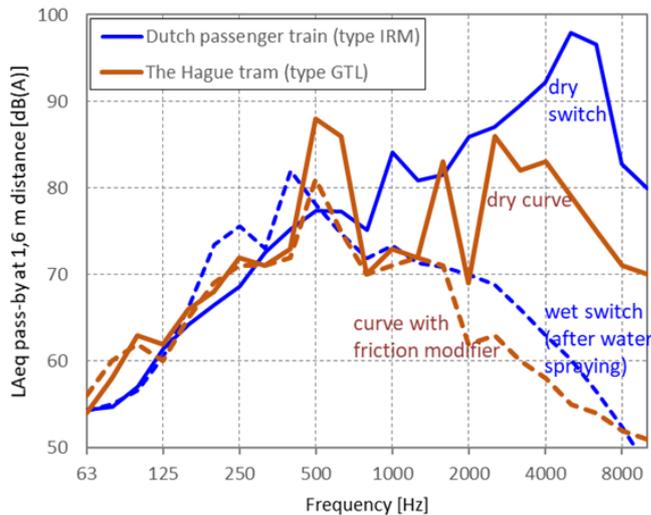

Figure 5 Squeal noise in railway switch (1:10, radius unknown) and tramway curve (R = 43 m) [6]

Given the variety of possible spectral shapes associated with different vehicles, and the variety associated with different causes of squeal (juddering, hissing and squealing), it is recommended to used one broad or flat spectrum for squeal. This will in general be more robust over time. On the other hand, there is no need to exclude the possibility to use a spectrum determined by measurements.

Apart from this, the present text already implies in the second paragraph that spectra are allowed. It is therefore recommended to explicitly confirm that spectral excess power spectra, statistically appropriate for the description of squeal noise, are acceptable.

The excess noise radiated by steel and concrete bridges may take many spectral shapes, but a flat spectrum is very unlikely. Of course, this was known during the development process of CNOSSOS. Considering a whole railway network, bridges make up less than 1 percent of the track length in most countries and because of that, it may have seemed fair to regard bridges as a particularly noisy stretch of track, as it is now in CNOSSOS. Unfortunately, declaring that C_{bridge} is a constant deprives EU Member States of taking advantage of their potentially available spectral measurement data or noise classification systems for bridges. It will not be a large step to replace this constant by a frequency dependent term $C_{bridge,i}$ which, of course, can still be set to a constant if no spectral information is considered necessary. Besides this, the maximum value of 9 dB listed in table G-7 of CNOSSOS will unfortunately not be sufficient for some noisy bridges. Excess noise up to 20 dB would be no exaggeration.

With respect to the term 'branch-outs of points', we recommend replacing it by 'switch turnouts'. Translators can use Figure 1 and the (English) wikipedia lemma "Railroad switch" to find proper descriptions. In German *Gleisabzweigung* can be used, in Dutch *afbuiging van een wissel*. The RailLexic of UIC (subscription required) may also contain good translations for a switch turnout.

2.2 Tram squeal noise

A simple approach for tram squeal noise in CNOSSOS could be to take the German 'correction value' for tramway curves of radii less than 200 m. That value is 4 dB (flat spectrum). In the German computation method it is remarked that this value should be considered to be added to the rolling noise of 50 km/h, even if the actual speed of a tram in tight curves is much less than 50 km/h.

Our proposal for CNOSSOS is to use 5 dB for all tramway curves with radii less than 200 m and no excess value for curve radii above 200 m. This proposal is based on the following considerations:

- This value is slightly higher than in the German method. This because in CNOSSOS the minimum tram speed is 30 km/h, rather than 50 km/h in the German method. In order to calculate the same total noise in a squealing curve as in the German model, a squeal excess value slightly higher than 4 dB is required in CNOSSOS.
- Instead of taking one penalty of 5 dB for all tramway curves, it is possible to define classes, for example 10-100 m, and 100-200 m, and use values based on Krüger's inventory (cited in Figure 3). This would yield excess values around 6 dB and 3 dB respectively for these classes. This classification approach is not proposed here, for simplicity. An authority that make a classification is free to do so under the option 'appropriate description'.

For curves or rolling stock that are treated with measures against squeal, one is allowed to omit any excess values based on the rule in the second paragraph of the text.

In Section 1.3 it has been clarified that there is no *a priori* reason to exclude tight tramway curves that are shorter than 50 m. Hence, the 50 m track length restriction should not be applicable to tramway curves.

2.3 Turnouts

If squeal noise occurs in a turnout, it is a result of the curvature of the diverging track in the switch. A train in straight direction will generally not produce (tonal) squeal noise. Because of this, the CNOSSOS method should explicitly mention switch turnouts as potential sources of squeal, not just switches. It will be a practical problem for the noise mapping agency to determine how often the turnout of a switch is taken (possibly squealing), relative to the straight direction (no squeal). Some turnouts are run only occasionally, for example a so-called crossover (a pair of switches) that is used only if a (delayed) train is blocking the route.

As we have seen, the curve radius is specific to the design of the switch and it is based on the maximum speed that is allowed in the diverging direction. There are many switch designs. Their range of standard dimensions differs only slightly between countries, but there are deviations from standard designs depending on the local track lay-out (e.g. space available, curvature of main track). The common radius series is as follows: 190 m (40 km/h), 300 m (40-60 km/h), 500 m (60 km/h), 760 m (80 km/h), 1200 m (100 km/h).

If an authority wants to apply a classification to turnouts based on their curvature, it can be done under the option 'appropriate description'. For the simple approach it is recommended that only turnouts with radii of 300 m or below are given a penalty, in this case 8 dB. Turnouts with radii above 300 m do not receive a penalty. This seems to be implied by the present text of the Directive and besides that, it also corresponds to the experience of the Dutch rail infrastructure management organisation ProRail. Turnouts of switches until type 300-1:12 are known to cause squeal [7], while turnouts with higher

radii do not. The squeal sound power in switches can be very high in practice. For example, the Dutch computation method for railway depots and shunting yards (industrial noise) applies a penalty of 10 dB for such switches. If friction modifier is applied, the penalty can be omitted [8]. The practical aspects of the acoustics of curves and switches and measures against squeal are described in more detail in the Railway Noise Technical Measures Catalogue of the UIC [9].

In Section 1.3 it has been clarified that there is no *a priori* reason to exclude railroad switch turnouts that are shorter than 50 m. Hence, the 50 m track length restriction should not be applicable to turnouts.

2.4. Modelling curves and turnouts in practice

Once the new method is programmed into a software application, modelling of turnouts and curves will not be difficult. Note that the level of automation and user-friendliness is not part of the method. For example, for users that want to use default excess values, the software could automatically select the track segments that are in one of the default curvature classes and assign default excess values to them.

The most basic software implementation would be that a freely selectable squeal excess spectrum can be attributed by the user to specific parts (curves and turnouts) of the source line at 0,5 m height.

In the simple approach, using the railroad map of Amsterdam of Figure 6, the marked curves and turnouts could be given penalty values. If the most frequently applied position of a switch is unknown (straight or diverging), the penalty should be based on the worst-case position (diverging). This means that all railway traffic that passes through switches up to 300-1:12 will receive an emission penalty of 8 dB.
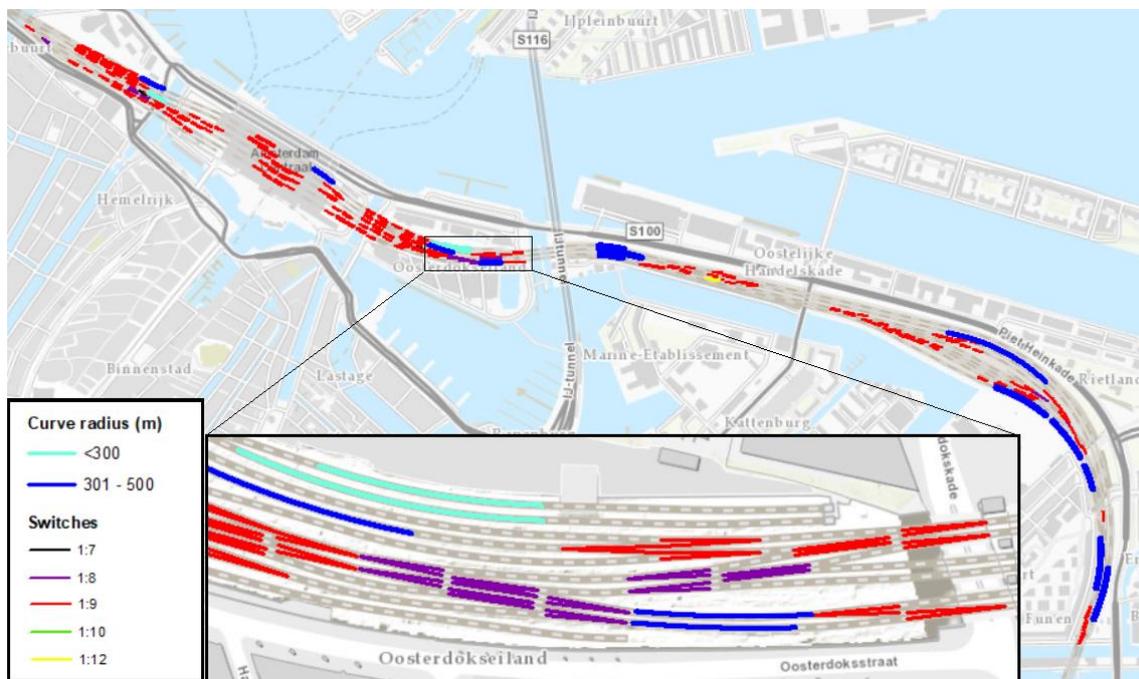

Figure 6 Curves and switches near Amsterdam Central Station (information of ProRail).

3. CONCLUSION: A PROPOSAL FOR THE NEW CNOSSOS TEXT

Curve squeal is a special source that is only relevant for curves and is therefore localised. Curve squeal is generally dependent on curvature, friction conditions, train speed and track-wheel geometry and dynamics. As it can be significant, an appropriate description is required. At locations where curve squeal occurs, generally in curves and

turnouts of railroad switches, suitable excess noise power spectra need to be added to the source power. The excess noise may be specific to each type of rolling stock, as certain wheel and bogie types may be significantly less prone to squeal than others. If local measurements of the excess noise are available that take account sufficiently of the stochastic nature of squeal, these may be used.

If no appropriate measurements are available, a simple approach can be taken. In this approach, squeal noise shall be considered by adding the following excess values to the rolling noise sound power spectra for all frequencies.

Train	5 dB for curves with 300 m $< R \leq$ 500 m and $l_{track} \geq$ 50 m;
	8 dB for curves with $R \leq$ 300 m and $l_{track} \geq$ 50 m;
	8 dB for switch turnouts with $R \leq$ 300 m
Tram	5 dB for curves and switch turnouts with $R \leq$ 200 m

where l_{track} is the length of track along the curve and R is the curve radius.

The applicability of these sound power spectra or excess values shall normally be verified on-site, especially for trams and for locations where curves or turnouts are treated with measures against squeal.

4. ACKNOWLEDGEMENTS

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