

## COMPARISON OF NOISE EMISSION OF HCT AND CLASSIC VEHICLE COMBINATIONS FOR TIMBER TRANSPORTATION IN SWEDEN



Ulf SANDBERG  
Senior Research  
Scientist at the  
Swedish National  
Road and Transport  
Research Institute  
(VTI). PhD on  
tyre/road noise and  
measurement  
technology.



Sogol KHARRAZI  
Researcher at the  
Swedish National  
Road and Transport  
Research Institute  
(VTI). PhD on  
Machine and Vehicle  
Systems.



Piotr MIODUSZEWSKI  
Adjunct and researcher  
in the field of tyre/road  
noise and road traffic  
noise at the Gdansk  
University of Tech-  
nology in Poland.  
PhD on vehicle noise.

### Abstract

By means of a special simulation tool, the noise emission of a high-capacity heavy vehicle (11 axles) was compared to that of a classic heavy vehicle (a truck-dolly-semitrailer with 8 axles). The two cases are designated “Extended vehicle” versus “Classic vehicle” in this study, having total lengths of 34 and 25 m, respectively. The Classic vehicle represents the most common articulated heavy vehicle configuration for transport of timber and other goods in Sweden. Tyres were assumed to be typical of each axle and their noise emission values were taken from a recent study. Noise from the propulsion unit were assumed to just meet the present maximum legal levels. It was found that noise emission from the Extended vehicle is approx. 1.5 dB higher than for Classic vehicle, as max. A-weighted level per vehicle passage, but as the number of vehicles in traffic is lower for a certain transportation volume, the resulting road traffic noise exposure in terms of A-weighted equivalent level  $L_{Aeq}$  is similar. Consequently, noise emission is not a factor that gives either vehicle type a clear advantage over the other.

**Keywords:** Trucks, high-capacity, noise emission, simulation, timber trucks, high productivity vehicles, vehicle noise, tyres.

## **1. Introduction**

The large increase in the goods transport demands, the growing congestion problem and the environmental concerns over transportation emissions and fuel consumption, make High Capacity Transport (HCT) vehicles an attractive alternative to the conventional heavy vehicle combinations. HCT refers to heavy vehicle combinations with higher capacity (longer and/or heavier vehicles) than the existing vehicles on the roads. With such vehicles, the existing capacity in the road infrastructure might be utilized more efficiently without requiring too high investments, and the goods can be transported with fewer vehicles. It is expected that this will result in a reduction in transport cost, fuel consumption, air pollution and traffic congestion.

The existing legislation in Sweden, allows heavy vehicle combinations with maximum length of 25.25 m and maximum weight of 64 t. However, from April 2018, heavier vehicles up to 74 t has been allowed on a designated part of the road network. Furthermore, dispensations of longer and heavier HCT vehicles for trial periods have been granted in the recent years, which have shown considerable CO<sub>2</sub> reduction, fuel savings and improved transport economy [Cider & Ranäng, 2013].

To gain more knowledge about HCT vehicles and their effects on traffic safety, infrastructure and environment, the Swedish government is undertaking a large research program focused on HCT vehicles in Sweden. One of the projects in the HCT program is the “Performance based standards for high capacity transport in Sweden” [Kharrazi et al, 2014]. Performance Based Standards (PBS) is a way of regulating HCT vehicles and their access to the road network. Under a PBS approach, standards would specify the performance required from the vehicle operations rather than mandating prescriptive length and weight limits.

One part of this project was to study the effects on traffic noise emission of the longer vehicles compared to conventional vehicle combinations, which is the subject of this paper.

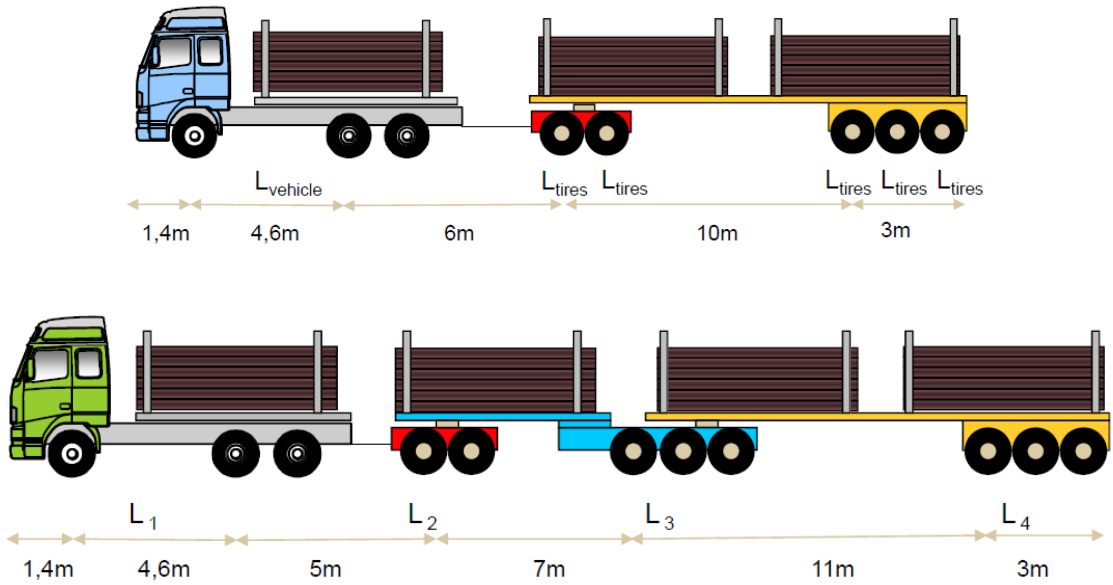
The authors have failed to find significant literature about the issue explored in this study. For example, in one report where the noise issue was at least mentioned, it was only discussed in one paragraph: saying that it has not been investigated, but there will probably be synergies with the impact on air pollution [Steer et al, 2013].

## **2. Research approach**

The objective of this part of the study was to determine whether the noise emission of HCT vehicles would be lower or higher than that of conventional vehicle combinations transporting the same load. Since representative vehicles of both main types were not available for actual measurements in this part of the study, simulations had to be made by means of a special tool.

By means of the simulation tool; first, the noise emission of an HCT vehicle versus a classic vehicle was calculated. The two cases compared are designated “Extended vehicle” versus “Classic vehicle” in this study. The Classic vehicle represents the most common articulated truck configuration for transport of timber and other goods in Sweden. The configurations are described in Figure 1. The configurations were taken from a presentation within the HCT project from Volvo Trucks [Sturk, 2017].

As the vehicles carry different loads, calculations were extended to represent a case where both types of vehicles were used to transport similar loads, by adjusting the number of these vehicles.



**Figure 1 - The Classic vehicle configuration above, with the Extended vehicle (HCT) shown below. Note that the Classic vehicle has a total length of 25 m, which is the maximum length normally allowed in Sweden.**

**3. The Vehicle Noise Simulation (VNS) tool**

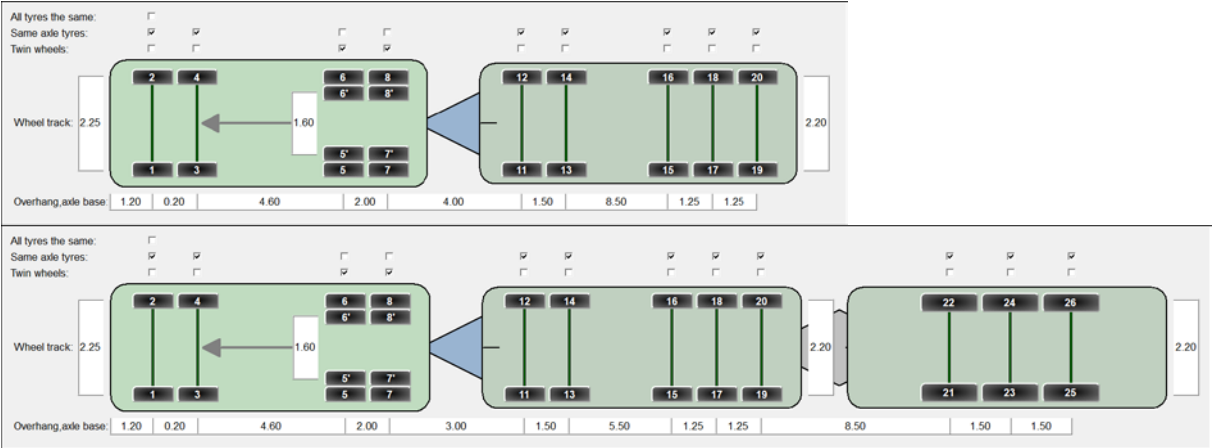
A special simulation tool was used to simulate the noise emission during a pass-by of each of the two vehicle configurations. Calculations of noise levels included the speeds 50 and 80 km/h and with the shortest distances from vehicle centre to the observer (microphone) of 7.5 and 30 m.

This tool was developed by the third author of this paper, by request from VTI. The idea came from a much older and now obsolete but similar tool developed 25-30 years ago by the same person, which had been used in studies at VTI during the 1990’s. For this and future purposes, a new and more adapted tool was developed for use in Windows, designated the VNS program, where VNS stands for Vehicle Noise Simulation.

In the VNS tool, the configurations illustrated above were created as shown in Figure 2. They do not exactly represent the trailers shown in Figure 1, but the important thing is that the noise emitting sources, the tyres, are located where the corresponding axles are located.

At the front, there are – surprisingly - two axles. This is because the leftmost (first) “axle” represents the source of the power unit (engine, fans, exhaust, etc), and not tyres, since there was no other provision in VNS to add a power unit source. The second axle is the real steering axle. The locations of the axles are exactly as the location of axles in Figure 1 (with the unimportant exception that in Figure 1 the distance between the multiple axles are not shown).

Essentially, the VNS is based on a number of tyre sources located at positions corresponding to the axles in Figure 2, allowing both single and double tyres, where each tyre is assigned a certain noise emission level (maximum A-weighted noise level at pass-by). The tyres are supplemented by a source representing the power unit of the vehicle. One may assign a certain directional radiation of sound around the tyre or choose (default) omnidirectional radiation. The tool then calculates the noise emission for each metre of vehicle movement from a point A before the microphone to a point B after passage of the microphone. Point A (the vehicle front) is 20 m before the position at the roadside which is closest to the microphone, and calculation continues until the front of the vehicle is 50 m after the closest position; i.e. for a total of 70 m of vehicle travel. This distance was chosen, but it could have been longer, if desired.



**Figure 2 - The two vehicle configurations, as used in the noise simulations, with the Classic vehicle above and the Extended vehicle (HCT) below.**

The input data consisted of noise levels for modern truck tyres measured in an earlier project [van Blokland et al, 2015], separate for tyres for the steering, drive and trailer axles. Further, it was assumed that the power unit source emits 77 dB(A) for the driving of the Classic vehicle, at both 50 and 80 km/h, and 79 dB(A) for the driving of the Extended vehicle, at both 50 and 80 km/h [Kharrazi et al, 2017]. The value 77 is often the target when the maximum legal level for type approval is 80 dB. Both vehicles have the same engine but the Extended one needs to use a little more power, which justifies the extra 2 dB.

The curve of noise level (SPL – sound pressure level) versus distance travelled is called the “time history of the noise”, since the distance is proportional to time. One may print out the time history of this vehicle passage and/or the maximum or integrated ( $L_{eq}$ ) overall levels during the pass-by. In addition, some overall noise levels are calculated. These are:

- $L_{max}$ : The maximum noise level during the pass-by (measured with time constant F), in dB (A-weighted)
- $L_{eq}$ : The equivalent noise level during the 70 m travelled distance, in dB (A-weighted)
- SEL: Sound Exposure Level, normalized to one second period, in dB (A-weighted)

weighted)

The latter two are “averages” based on the accumulated acoustic power during the pass-by. There is also a fourth measure -- SENEL which is the Single Event Noise Exposure Level -- but this is nominally equal to the  $L_{eq}$ , and thus not presented separately in this study.

#### **4. Selected tyres**

For the simulation, due to the existence of recently measured noise levels for them [van Blokland et al, 2015], and since they are very popular tyres, three types of truck tyres were selected as follows:

For the steering axle: Michelin Xline Energy Z, 315/70 R 22.5

For the drive axles (twin mounting): Michelin Xline Energy D, 315/70 R 22.5

For the trailer axles: Michelin Xline Energy T, 385/55 R 22.5

Note that the trailer tyres are much wider and may carry about 1000 kg more load per tyre, than the others. The drive axle tyres were the same type both for the outer pairs and for the inner pairs. However, to take into account the fact that the outer tyres partly screen the inner pairs, it was chosen to distinguish between the outer and inner pairs in this way:

Michelin Xline Energy D (out), the outer pairs

Michelin Xline Energy D (inn), the inner pairs

The only difference was that the inner tyres were assigned 1 dB(A) lower noise level than the outer tyres. This is an expert judgement based on earlier experience, which is that the outer tyres screen some of the noise emission of the inner tyres.

The drive axle tyres are classified also as M+S tyres, so they are likely to be used in Sweden all the year.

#### **5. Selected speeds and driving conditions for the simulation**

Two speeds and driving conditions were chosen:

- Cruising at constant speed at 80 km/h
- Moderate acceleration at an average speed of 50 km/h

The latter is assumed to be typical of driving in other traffic through a village, when it is difficult to keep a constant speed.

#### **6. Input data (noise levels)**

The noise levels representing these three tyres were taken from a report of a study made in a so-called NordTyre research programme [van Blokland et al, 2015], where the A-weighted noise levels ( $L_{max}$ ) of 32 truck tyres from the market (about 5 years ago) were measured on four road surfaces, including one ISO 10844 surface. The noise levels from Table III in [van Blokland et al, 2015] on the four surfaces at a coast-by speed of 70 km/h were averaged arithmetically to give a noise level as input to this study. Using a speed exponent of 33 (typical of the data in [van Blokland et al, 2015]), the noise levels at 70 km/h were extrapolated to 50 and 80 km/h, which were the test speeds in the simulation.

The noise levels were increased in the cases where it was considered that the drive axle tyres were subject to significant torque, as a noise level correction for torque on the tyres, in relation to free-rolling tyres:

- 50 km/h, Classic vehicle: + 3 dB for the drive axle tyres
- 50 km/h, Extended vehicle: + 4 dB for drive axle tyres (higher load to pull requires more torque)
- 80 km/h, Classic vehicle: + 1 dB for the drive axle tyres
- 80 km/h, Extended vehicle: + 2 dB for drive axle tyres (higher load to pull requires more torque)

The noise levels were further adjusted for directionality as follows:

- Steering axle tyres Michelin Xline Energy Z: No adjustment, they were supposed to be omnidirectional
- Drive axle tyres (twin mounting) Michelin Xline Energy D: +2 dB at front and rear directions, + 1 dB at 45, 135, 225 and 315 degrees relative to the rolling direction
- Trailer axle tyres Michelin Xline Energy T: Same as for the drive axles. This is motivated by the tyres being extra wide.

These adjustments are judged to be very conservative. It is known that tyres emit noise differently in different directions; almost always with higher levels in the forward and rearward directions than to the sides. As there is too little data published about this, the author chose very conservative additions to the directions that are not towards the sides of the tyres.

## 7. Power unit noise

Both vehicles are assumed to have the same engine power. However, the Extended vehicle will need a higher degree of utilized power as it has something like 25 % more mass to pull. This is accounted for here by assuming that the power unit emits 2 dB(A) more noise due to the higher load of the Extended vehicle (authors' estimation), at both the 50 and 80 km/h driving conditions. Thus, it has been assumed that the power unit source emits:

- 77 dB(A) for the driving of the Classic vehicle, at both 50 and 80 km/h
- 79 dB(A) for the driving of the Extended vehicle, at both 50 and 80 km/h

Since there is no option in VNS for a power unit source, it was decided to let two sources (one axle) indicated as "tyres" emit this noise. Thus, the overall 77 dB(A) for the Classic vehicle power unit is shared as 74 dB(A) on the left "tyre" source and 74 dB(A) for the right "tyre" source, and similar for the Extended vehicle.

The power unit noise appears to have little or no influence on the overall noise of the vehicles. Even if it has been underestimated by a couple of dB here, it would not affect the results at 80 km/h, and just marginally affect the results at 50 km/h. In the latter case, it would not influence the comparison of the vehicles significantly.

## 8. Acoustic properties related to the sound propagation from tyres and vehicle to microphone

In practice, the noise emitted from the side of the vehicle that is furthest from the microphone is partly screened by the vehicle body and by tyres on the nearest side. This effect may be substantial on cars (having relatively low ground clearance), and for microphone positions high above ground, but for these trucks with relatively open structures and high ground clearance, any such screening should be minor and was neglected here.

The VNS tool assumes that there is no ground absorption of sound when it propagates from the sources to the microphone. The ground is assumed to be acoustically hard, such as asphalt or well packed gravel or soil. This is no problem at 7.5 m distance, unless the road surface is porous, but at 30 m there is often loose soil, grass and bushes, or even a ditch, that may provide some absorption. Such absorption will essentially have the same effect for the two vehicles studied here; thus, it does not affect the comparison.

## 9. Results

The results of the simulations are shown in Table 1 as overall values expressed in A-weighted decibels. The calculations were made for three types of measures, as indicated in Section 3:

- $L_{\max}$ : The maximum noise level during the pass-by (measured with time constant F), in dB (A-weighted)
- $L_{\text{eq}}$ : The equivalent noise level during the 70 m travelled distance, in dB (A-weighted)
- SEL: Sound Exposure Level, normalized to one second period, in dB (A-weighted)

However, it appears that the results in terms of noise level differences between the Extended and the Classic vehicles are very similar for the three cases.

The time histories, i.e. the variation of noise level during a vehicle passage, are shown in Figures 3 (for 50 km/h) and 4 (for 80 km/h). On the horizontal axis, time has then been converted to location in metres for the speed (50 km/h). The circle indicates the location in noise level and time of the maximum. There are two diagrams side-by-side, with the left one for the case when the microphone is located 7.5 m from the centre of the vehicle path, and the other one at four times that distance; i.e. at 30 m microphone distance.

Figure 4 shows the same as Figure 3, but for the vehicle speed 80 km/h.

Unfortunately, the vertical scales are determined automatically by the software (VNS and Excel). Therefore, when comparing results, one must be aware of the sometimes incompatible vertical scales.

**Table 1 - Results of the vehicle noise simulations, expressed in A-weighted dB.**

**Based on the maximum pass-by noise level (Lmax):**

<i>Vehicle combination</i>	<i>Micr distance m</i>	<i>Speed km/h</i>	<i>Driving type</i>	<i>Noise level dB</i>	<i>Noise level diff: Extended - Classic</i>
Classic	7.5	50	Moderate accel.	84,4	
	7.5	80	Constant speed	88,9	
	30	50	Moderate accel.	73,3	
	30	80	Constant speed	78,0	
Extended	7.5	50	Moderate accel.	85,5	1,1
	7.5	80	Constant speed	90,3	1,4
	30	50	Moderate accel.	74,6	1,3
	30	80	Constant speed	79,5	1,5

**Based on the equivalent pass-by noise level (Leq):**

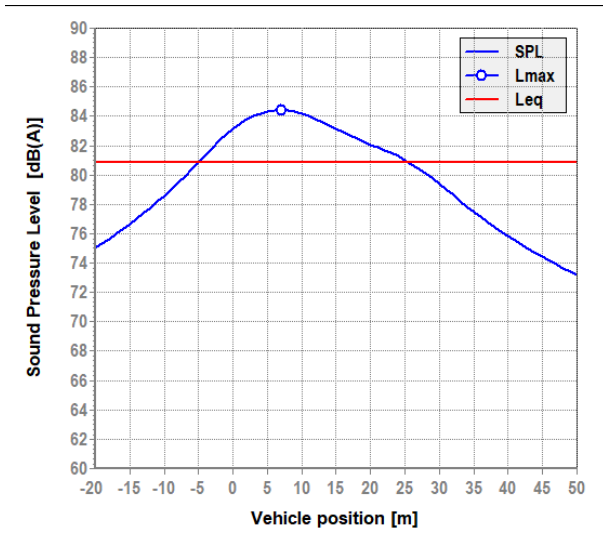
<i>Vehicle combination</i>	<i>Micr distance m</i>	<i>Speed km/h</i>	<i>Driving type</i>	<i>Noise level dB</i>	<i>Noise level diff: Extended - Classic</i>
Classic	7.5	50	Moderate accel.	80,9	
	7.5	80	Constant speed	85,5	
	30	50	Moderate accel.	72,4	
	30	80	Constant speed	77,1	
Extended	7.5	50	Moderate accel.	82,2	1,3
	7.5	80	Constant speed	87,2	1,7
	30	50	Moderate accel.	73,7	1,3
	30	80	Constant speed	78,7	1,6

**Based on the single-event pass-by noise level (SEL):**

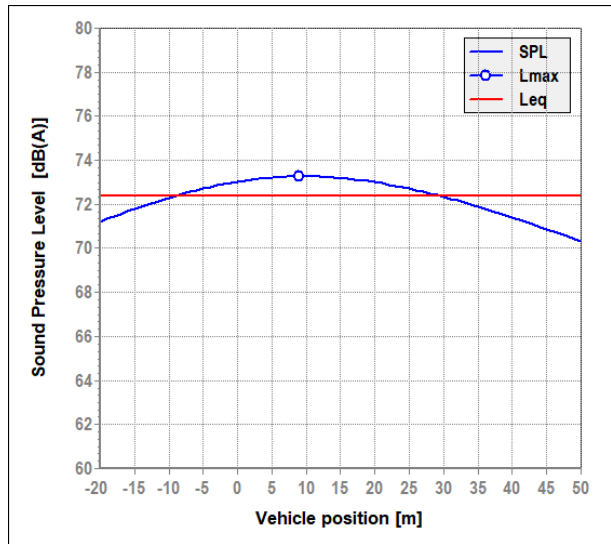
<i>Vehicle combination</i>	<i>Micr distance m</i>	<i>Speed km/h</i>	<i>Driving type</i>	<i>Noise level dB</i>	<i>Noise level diff: Extended - Classic</i>
Classic	7.5	50	Moderate accel.	87,9	
	7.5	80	Constant speed	90,5	
	30	50	Moderate accel.	79,4	
	30	80	Constant speed	82,1	
Extended	7.5	50	Moderate accel.	89,2	1,3
	7.5	80	Constant speed	92,2	1,7
	30	50	Moderate accel.	80,8	1,3
	30	80	Constant speed	83,7	1,6



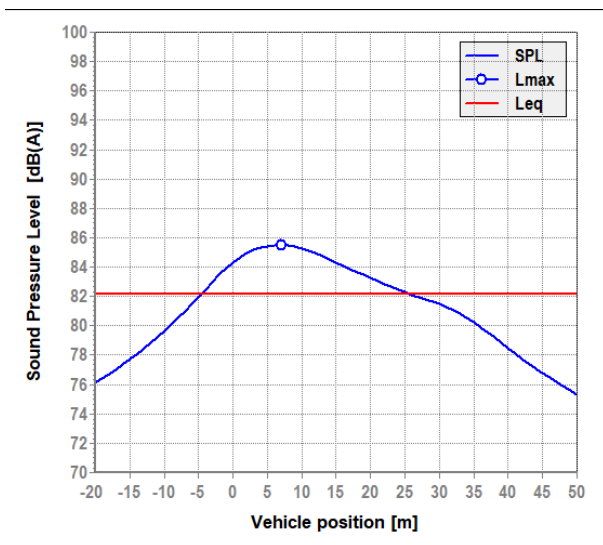
Classic vehicle, 50 km/h, 7.5 m



Classic vehicle, 50 km/h, 30 m



Extended vehicle, 50 km/h, 7.5 m



Extended vehicle, 50 km/h, 30 m

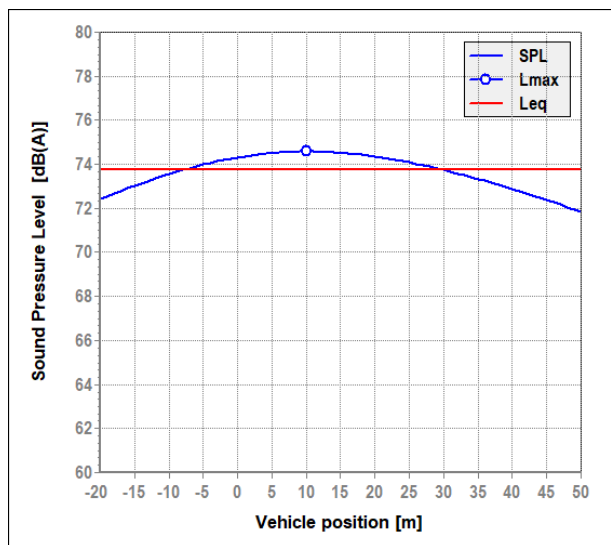
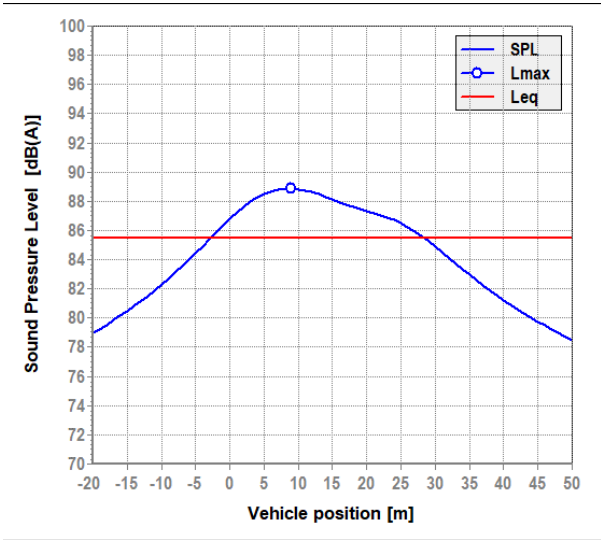
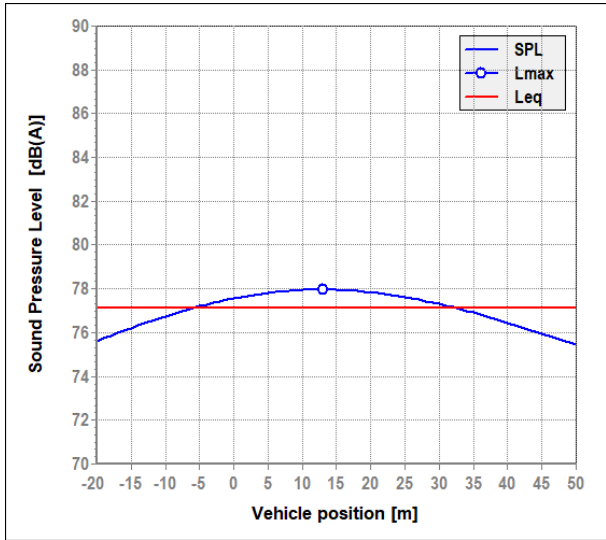


Figure 3 - Results of the vehicle noise simulations for 50 km/h, expressed as “time histories”. The vertical axis shows sound pressure levels (SPL) in A-weighted dB, while the horizontal axis shows the position of the vehicle compared to the microphone location, with time re-calculated into position in metres.

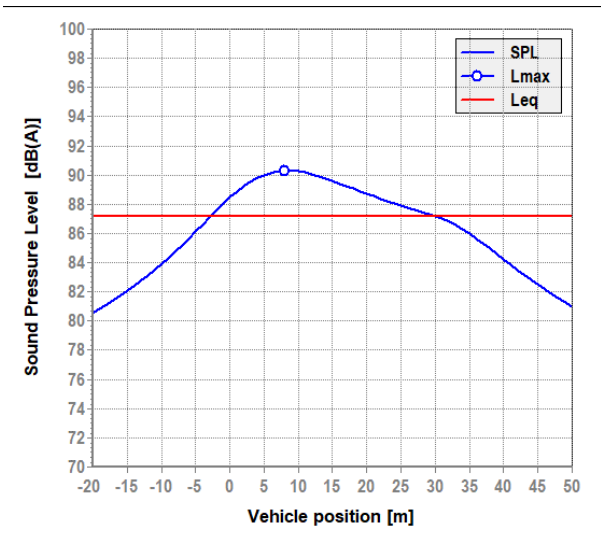
Classic vehicle, 80 km/h, 7.5 m



Classic vehicle, 80 km/h, 30 m



Extended vehicle, 80 km/h, 7.5 m



Extended vehicle, 80 km/h, 30 m

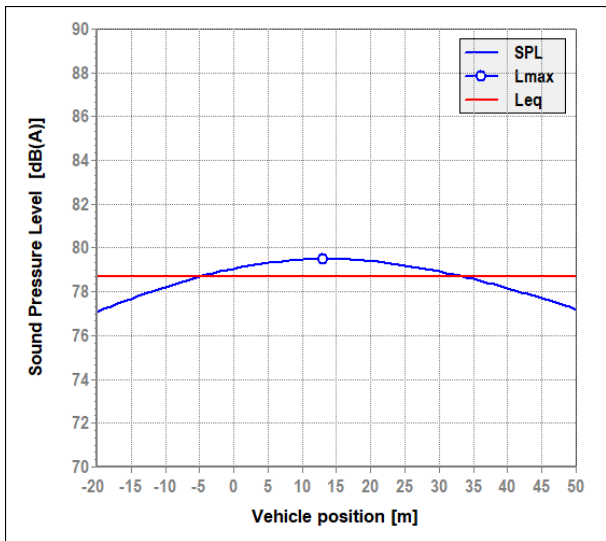


Figure 4 - Results of the vehicle noise simulations for 80 km/h, expressed as “time histories”. The vertical axis shows sound pressure levels (SPL) in A-weighted dB, while the horizontal axis shows the position of the vehicle compared to the microphone location, with time re-calculated into position in metres.

### 10. Discussion

The differences between the Classic and Extended vehicles are small (1.1 – 1.7 dB) but systematic and consistent for all studied cases. As expected, the Extended vehicle means more noise emission. However, as discussed later, three Extended vehicles may carry the same load as four Classic vehicles, and this may balance the higher noise level per vehicle.

The noise difference is marginally higher, the higher the speed is.

At hindsight, for the 30 m source-microphone distance, it would have been better to extend the studied distance of travel from the chosen -20 m until +50 m, to from -50 m until +80 m. Any future analyses should use these limits. However, it is unlikely that the comparison of the vehicles would change significantly then.

### **11. The case for both vehicles transporting the same amount of load**

As mentioned already, three Extended vehicles may carry the same load as four Classic vehicles. It means that for the same transportation need, vehicle passes along a certain road will become 25 % fewer if Classic vehicles are exchanged for Extended ones. For calculation of noise exposure in terms of daily  $L_{eq}$ , the lower vehicle numbers would mean a noise reduction of 1.25 dB(A) (according to common calculations in traffic noise prediction models  $10 \times \log(3/4)$ ). This almost exactly balances out the increase in per-vehicle-noise emission according to the results presented above.

Consequently, for noise exposure for people living or staying along the road, expressed by  $L_{eq}$  values, the choice of vehicle has no significant effect ( $< 0.5$  dB).

### **12. Considering $L_{eq}$ or $L_{max}$ levels**

Then one should note that these vehicles do not frequently travel in urban areas, where noise exposure from road traffic due to high volumes of traffic reach harmful levels. Therefore, what the  $L_{eq}$  level is for these vehicles, is of limited interest as it would hardly contribute to too high  $L_{eq}$  levels.

Instead, it is the maximum level  $L_{max}$  which is the most relevant to consider in this case. The EU regulations or recommendations deal only with  $L_{den}$  vales, where “den” stands for Day-Evening-Night, and levels during nighttime are subject to 10 dB penalty and evening levels are subject to 5 dB penalty on top of the  $L_{eq}$  during daytime. In Sweden, however,  $L_{eq}$  during 24 h are used in noise standards. In addition, and this is unique for Sweden,  $L_{max}$  values are considered in the standards (guidelines) for existing homes near roads. In the “Target values” (“Riktvärden”) practiced in Sweden,  $L_{max}$  above 70 dB in a garden or patio location (“uteplats”) at a home is considered as undesirable. Such levels are “allowed” to be exceeded no more than 5 times per “average maximum-hour” during the day-evening time period 06-22. See further [3].

There are complicated standards also for maximum levels during nighttime [3], in order to avoid awakening effects. These are expressed as for the case above, but where it is assumed that 70 dB at the façade outside the bedroom corresponds to 45 dB indoors in the bedroom.

Since the standards consider both the maximum level and the number of times when that level is exceeded, it is very complicated to say what the effect of the Extended versus the Classic vehicles is. It is more likely that the 70 dB level is exceeded by the Extended vehicles (see for example the diagrams above for 30 m distance), but on the other hand, if also the Classic vehicles emit maximum levels above 70 dB, the number of such events is lower for the Extended vehicles.

### **13. Conclusion**

The noise emission related to extending heavy vehicles seems to be an under-researched issue since the authors have failed to find significant literature on the subject.

Based on this study, the noise emission from the Extended vehicles is somewhat higher than for Classic vehicles, per vehicle passage, but as the number of vehicles in traffic is lower for a certain transportation volume, the resulting road traffic noise exposure in terms of  $L_{eq}$  is very similar (maximum 0.5 dB higher for the Extended vehicles).

The maximum pass-by levels are potentially affecting the possibility for wake-up from sleeping due to a vehicle passage. In terms of noise exposure expressed by  $L_{max}$  values, it is arguable whether Extended or Classic vehicles are better, since the former, having approx. 1.5 dB higher levels, gives a higher chance of exceeding the limit at a certain home garden or patio; but in locations and events when both vehicles exceed the limit, the Extended vehicle results in fewer exceedance events.

Consequently, noise emission is not a factor that gives either vehicle type a clear advantage over the other.

#### **14. Acknowledgement**

This work would not have been possible without the VNS program produced by Dr Piotr Mioduszewski, Technical University of Gdansk, Poland.

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