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Sound power levels of trucks at low speeds

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ABSTRACT

For certain industrial companies the noise production of freight trucks, driving within the boundaries of their site, is a significant part of the total noise emission of all their activities. This is especially true for those companies with many truck movements such as haulage companies and distribution centres. Sound data available on trucks are derived from normalised procedures for use on public roads, in general obtained at higher speeds than trucks usually drive on site, and based on pass by measurements.

However, these data do not represent correctly the noise production at low speed. On behalf of different branch organisations our company determined the sound power levels of trucks at low speeds about ten years ago. This investigation has been repeated recently. The paper shows the results of this recent investigation, based on a large number of measurements in practice. It differentiates sound power levels related to type of truck and speed. Furthermore a comparison is made with the earlier investigation to see if an overall noise reduction has been achieved regarding these types of trucks under these circumstances.

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Figure 1: Industrial complex with high freight traffic.

1. INTRODUCTION

In The Netherlands noise of (industrial) companies is regulated in environmental permits or standard regulations. Important sources of noise are often heavy freight trucks driving at low speeds and manoeuvring within industrial sites or complexes; see for instance figure 1. In this study low speeds are considered to be between 10 km/h and 35 km/h. The noise emission is often a discussion topic for the granting of environmental permits. Truck manufacturers test the noise emission of their vehicles under certain circumstances that are only relevant for highway and road traffic (speeds higher than 50 km/h). Therefore sound measurements made by truck manufactures can not be easily applied to the situation at hand. In the year 1999 a survey was commissioned on the noise production of trucks cruising at low speeds by stakeholders in the Dutch freight traffic sector. Our survey of 1999 showed that two main factors affecting the noise production of a truck are the driving speed and behaviour of the driver.
A Danish report of 2004 presented sound emission data regarding trucks driving at low speed, however starting from 30 km/h [1].
Assuming an economic life time of 10 years for a heavy-duty truck, it can be expected that an almost new fleet is operating in The Netherlands. For this reason our study of 1999 was repeated.

2. METHODOLOGY

A. ISO method

The current method for the measurement of pass-by noise of vehicles is described in the international standard ISO 362:1998 [2]. According to ISO 362 a test site must be arranged as shown in figure 2. Two microphones are positioned between lines AA' and BB' at 7.5 m from the centre line of travel on each side. The driver must approach the line AA' at a constant speed while driving in second or third gear. When the line AA' has been reached the driver should open the throttle and accelerate until the line BB' is reached. The maximum overall sound pressure levels are measured by the microphones on either side of the track and averaged over a number of passes.

The ISO-norm is not entirely applicable in the present situation. The norm implies that the measurements should be staged at certain gears and speeds. This would not give a representative impression of the situation at industry sites and complexes. The ISO 362 norm requires a higher speed than those at industry sites and complexes and specific gears which are not the only ones used in the sites. To determine the real noise emission of the trucks in practical industrial situations a different approach has been used, which is described in the next paragraph.

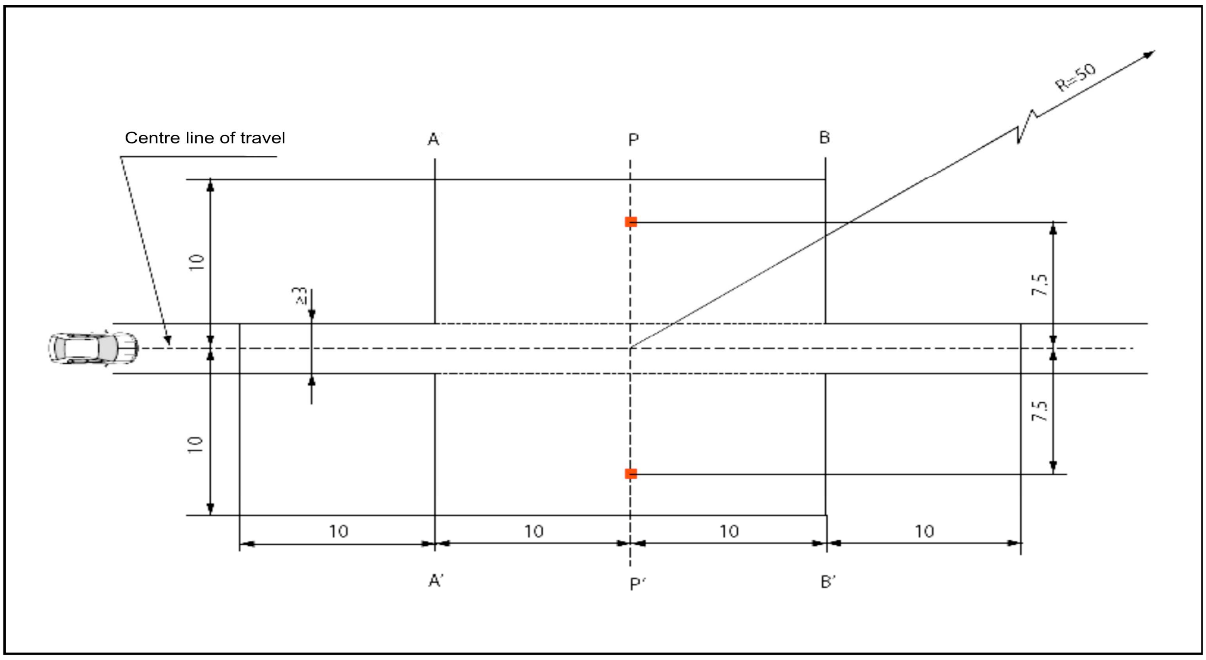

Figure 2: Measurement set-up for pass-by noise testing according to ISO:362

B. Dutch guideline

The Dutch "Guideline for measuring an calculating industrial noise" of the Dutch Ministry of Environmental Affairs describes different methods to determine the sound power levels of sources [3]. One of these methods is the so-called concentrated source method. The purpose of concentrated source method is to determine the sound power level of the source in a certain direction from a source or an array of sources during a well-defined situation. This method is suitable for sources which dimension can be regarded as small in comparison to the distance between the source and the sound level meter. The condition is that the measuring distance is at least 1.5 times larger than the biggest dimension of the source.

The following equation is used to calculate the sound power level (L_{WR}) of a ground-based source on a reflecting surface, within a distance of less than 20 m, according to method II.2.

$$L_{WR} = L_{eq,T} + 10\log(4\pi R^2) - 2 \quad (1)$$

with:

R distance between the source and the microphone

$L_{eq,T}$ Equivalent sound level measured within a time duration T

C. Statistics

According to the CBS (Dutch Central Bureau for Statistics, August 2008) the truck population in The Netherlands is about 200.000 vehicles, including buses. This population is divided into a number of manufactures, engines, power and cabin layouts among other parameters. To make the survey representative all acoustical relevant characteristics should be represented sufficiently. The accuracy and reliability of a survey can be calculated by using table 1 and equations 2 and 3.

$$\alpha = \frac{(1-\beta)}{2} \qquad (2)$$

with:

α right exceedance probability

β probability confidence chance

Table 1: Relation between *β*, *α* and *μ(α)*

reliability %	99	98	95	90	80
α	0.005	0.01	0.025	0.05	0.10
μ(α)	2.57	2.33	1.96	1.645	1.28

$$\left[x-\left(\mu(\alpha)\cdot\frac{\sigma}{\sqrt{n}}\right), x+\left(\mu(\alpha)\cdot\frac{\sigma}{\sqrt{n}}\right)\right] = [x \pm \varepsilon] \qquad (3)$$

with

x calculated averaged from a random survey

n number of samples

σ standard deviation of the population

ε length of the reliability interval

$\mu(\alpha)$ positive number that in a normal distribution a right exceedance probability of α contains

It is also necessary to determine how many samples are needed to make a representative survey. There is a correlation between the number of samples and the accuracy of the statements that can be done about the population. The more samples, the more accurate the judgements. Taking equation 3 into account the following formula 4 can be derived.

$$n = \frac{\mu^2(\alpha)\cdot\sigma^2}{\varepsilon^2} \qquad (4)$$

The value of the standard deviation of the population is not known. To make a rough estimate of the required number of samples the value of the standard deviation from a previous survey has been used. In this case and average standard deviation of 4 was used with a 95% reliability interval of ± 1.5 dB. This gives a minimal of about 30 samples per speed class.

3. MEASUREMENTS AND ANALYSIS

A. Parameters

The following parameters are considered in the current survey:

- Manufacturer
- Type truck and category (in this case: heavy and middle-sized trucks)
- Load (loaded or not loaded)
- Driving speed
- Pavement type
- Driving conditions
- Cooling unit
- Truck docking at a docking shelter
- Truck stationary while engine still running (idle, speed 0)

B. Used method

A measuring method and protocol are devised taking in account both the ISO method and the Concentrated Source method II.2. It is assumed that the noise production from the trailer is relatively low and irrelevant in comparison with the tractor. Taking this into account the largest dimension of the source (tractor) would correspond with 10 m. The whole pass-by is recorded to be analysed. This serves two purposes: recording the sound for later analysis as well as to determine the average speed of the passing-by truck by signalling when it reaches a mark at the beginning of the track and a mark at the end.

A track is selected depending on the conditions of the measuring site. Two microphones are used to measure each pass-by position: one at 7.5 m and the other at 15 m from the middle of the road as shown in figure 3. The reasons to use two microphones are:

- to be able to verify each measurement, especially when the sound transfer is influenced by differences in pavement;
- to trace the moment at which the vehicle is at closest distance to the microphones, which appears to be most optimal from the measurements at 7.5 m distance; see also figure 4.

To measure docking and stationary vehicles only one sound level meter is used. The measurement of docking vehicles is achieved by keeping the sound level meter in a constant position relative to the truck at one side of the cabin at a distance of at least 15 m.

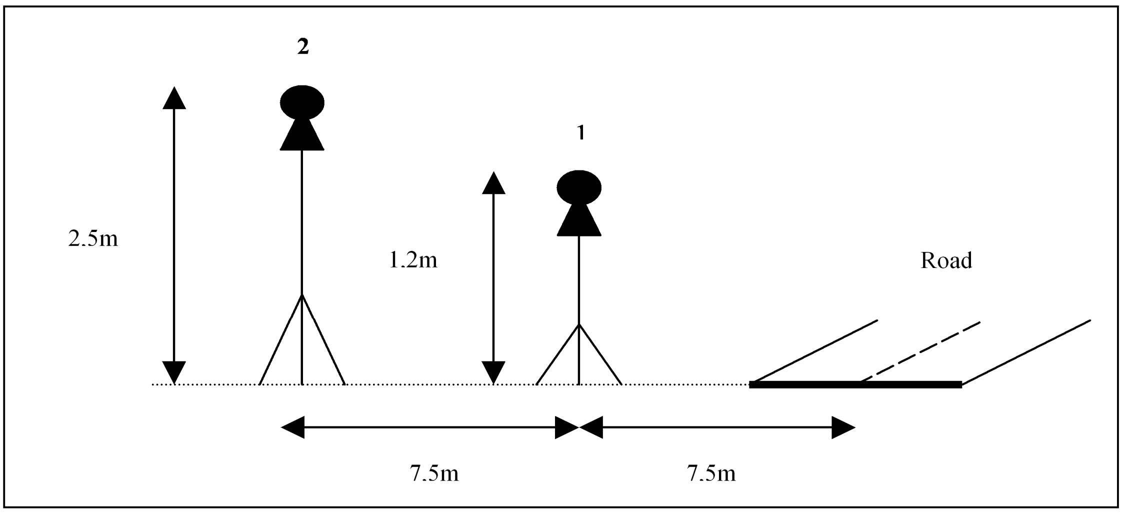

Figure 3: Measuring positions.

C. Analysis

The recorded pass-by noises are analysed with the software package Spectralyzer, developed by Peutz. The analysis time is narrowed down to one second. The average sound pressure level over one second ($L_{eq,1}$) is determined around the moment at which the loudest sound pressure level occurs during the pass-by (see figure 4). In that way the measured sound pressure level would not be determined by sudden loud noise events but rather by the average noise during that second. It also takes into account that a truck has different noise sources (air inlet, exhaust pipe) at a certain mutual distance of each other. It is required that the sound pressure level during one second is constant enough to be able to derive the sound power level in an accurate way. This appears to be the case with the measurements at 15 m but not quite for the measurements at 7.5 m.

To be able to determine the differences with the sound power levels, based on maximal sound pressure levels during pass-by as prescribed by the ISO-standard, also maximal sound pressure levels (L_{max}) are analysed. Both values ($L_{eq,1}$ and L_{max}) are represented in the results in the next paragraph. The distance between the sound level meter and the centre line of travel of the vehicle is used for the determination of the sound power levels.

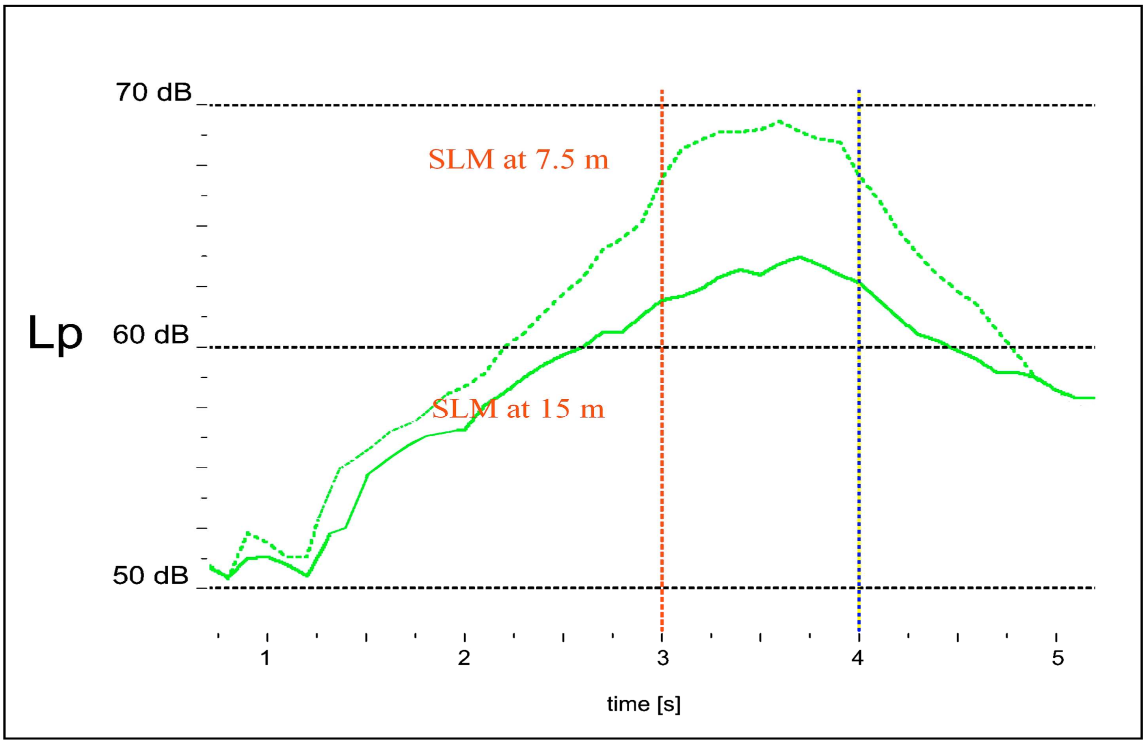

Figure 4: Sound levels (L_p) during a pass-by as a function of time

For the $L_{eq,1}$ the greatest random position error occurs at the highest driving speed of 35 km/h with a maximum distance error of 0.8 m at the sound level meter 15 m from the source and 1.4 m at the sound level meter 7.5 m from the source. Taking this into account it is clear that the measurement taken by the sound level meter the farthest from the road are the most reliable. The measurements from both meters are calculated. The difference between the calculated sound power levels from one meter in comparison to the other averages 1.1 dB. The maximum sound level over the analysis time is calculated as well. All sound power levels as presented in this paper are based on the measurements at 15 m. For the docking trucks the average sound level over the whole measurement is calculated. The same analysis is made to calculate the average sound level of a stationary truck.

4. RESULTS

Around 950 measurements have been taken into account regarding freight trucks with driving speeds ranging from 10 km/h until 35 km/h. The driving speeds are divided into speed classes of 5 km/h. Furthermore docking manoeuvring and stationary (speed 0) are presented. The following tables summarise the results of the pass-by measurements at the observed speeds, dock and stationary, with the respective standard deviation (stdev) and the 95% reliability interval.
In table 2 the equivalent ($L_{WR\ eq,ave}$ based on $L_{eq,1}$–values) and maximal A-weighted ($L_{WR\ max\ ,ave}$ based on L_{max}–values) sound power levels are presented of all passages (“total”), so without classification of type of truck.

Table 2: A-weighted equivalent and maximal sound power levels (total)

Speed	Number of samples	$L_{WR\ eq,ave}$	stdev	Reliability Interval 95%	$L_{WR\ max\ ,ave}$	stdev	Reliability Interval 95%
0	25	95.0	4.3	2.1	97.1	5.0	1.8
10	75	102.2	2.1	0.5	102.8	2.2	0.5
15	69	102.3	3.2	0.8	103.0	3.3	0.8
20	223	102.5	2.5	0.3	103.3	2.5	0.3
25	310	102.5	4.5	0.5	103.4	4.6	0.5
30	101	103.9	2.6	0.5	104.8	2.7	0.5
35	21	105.4	2.6	1.1	106.2	2.6	1.1
dock	109	106.7	2.9	0.6	107.7	3.0	0.5

Differences between $L_{eq,1}$ and L_{max} appear to be about 1.0 dB on average . However, because of the different noise sources in the truck (such as air inlet, exhaust pipe) the sound power levels based on $L_{eq,1}$ are considered as the most accurate and representative values for the trucks.

Table 3 shows the equivalent and maximal A-weighted sound power levels of the passages of middle size trucks.

Table 3: A-weighted equivalent and maximal sound power levels of middle-sized trucks

Speed km/h	Number of samples	$L_{WR\ eq,ave}$	stdev	Reliability Interval 95%	$L_{WR\ max,ave}$	stdev	Reliability Interval 95%
15	3	102.6	18.5	18.5	103.3	18.5	18.5
20	52	101.7	4.0	4.0	102.6	4.0	4.0
25	114	99.0	3.9	3.9	102.8	3.9	3.9
30	31	103.6	4.2	4.2	104.8	4.2	4.2
dock	6	98.0	6.6	6.6	102.5	6.6	6.6

In table 4 the relevant equivalent and maximal A-weighted sound power levels are presented of the passages of heavy trucks

Table 4: A-weighted equivalent and maximal sound power levels of heavy trucks

Speed	Number of samples	$L_{WR\ eq,ave}$	stdev	Reliability Interval 95%	$L_{WR\ max,ave}$	stdev	Reliability Interval 95%
0	25	95.0	4.3	1.8	97.1	5.0	2.1
10	4	100.4	3.0	4.8	101.0	3.0	4.8
15	66	102.2	3.3	0.8	103.0	3.3	0.8
20	171	102.7	2.4	0.4	103.6	2.4	0.4
25	267	102.8	5.3	0.6	104.0	4.9	0.6
30	71	104.0	2.7	0.6	104.8	2.8	0.7
35	20	105.4	2.6	1.2	106.2	2.6	1.2
dock	103	97.2	4.9	0.9	102.4	5.6	1.1

Also sound power levels due to differences in driving behaviour are shown. In table 5 the equivalent and maximal A-weighted sound power levels are presented of the passages during calm driving.

Table 5: A-weighted equivalent and maximal sound power levels during calm driving

Speed km/h	Number of samples	$L_{WR\ eq,ave}$	stdev	Reliability Interval 95%	$L_{WR\ max,ave}$	stdev	Reliability Interval 95%
0	24	94.4	4.3	3.1	96.5	3.9	1.6
10	65	101.8	2.1	1.8	102.4	1.9	0.5
15	53	101.6	3.2	2.9	102.3	2.9	0.8
20	194	102.2	2.5	2.4	103.1	2.4	0.3
25	287	102.3	4.5	4.6	103.2	4.7	0.5
30	81	103.3	2.6	2.3	104.2	2.4	0.5
35	20	105.4	2.6	2.6	106.2	2.6	1.2
dock	103	97.0	2.9	4.8	102.2	5.5	1.1

Sound powers levels during calm driving are slightly lower, than those during normal driving behaviour.

Table 6: A-weighted equivalent and maximal sound power levels of accelerating trucks

Speed km/h	Number of samples	$L_{WR\ eq,ave}$	stdev	Reliability Interval 95%	$L_{WR\ max,ave}$	stdev	Reliability Interval 95%
10	11	107.8	3.6	2.4	109.1	3.8	2.5
15	44	107.0	3.1	0.9	108.0	3.4	1.0
20	24	108.1	4.5	1.9	109.1	4.6	2.0
25	7	107.0	2.9	2.7	108.3	2.9	2.7

30	2	114.9	7.1	63.8	116.1	7.1	63.8

From comparing the values in table 5 and 6 it appears that driving behaviour is of great importance on sound power levels.

Table 7 summarises the spectral linear sound power levels of the measured pass-by at the observed speeds.

Table 7: Spectral average sound power levels and

speed km/h	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
0	97.6	96.5	93.5	91.4	90.1	90.8	88.3	82.0	71.5
10	100.2	103.0	101.0	98.6	98.4	99.0	96.4	89.5	79.0
15	96.3	102.6	101.4	98.8	98.1	98.5	95.6	89.0	77.8
20	95.8	102.6	101.6	98.5	97.8	98.0	95.8	89.1	78.9
25	96.8	103.1	101.4	98.7	97.9	97.9	95.6	89.6	80.1
30	96.9	102.9	101.9	100.0	99.9	99.2	96.5	91.1	82.2
35	96.2	101.0	101.8	101.9	101.4	100.4	97.3	93.4	84.8
dock	100.1	97.9	96.9	93.8	91.5	91.8	90.8	83.9	75.9

Table 8 shows the differences between the average calculated A-weighted sound power level and the linear sound power level of each frequency band.

Table 8: Differences between the average calculated A-weighted sound power level and the linear sound power level of each frequency band

speed km/h	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz
0	-2.5	-1.5	1.6	3.7	5.0	4.2	6.8	13.0	23.6
10	2.0	-0.8	1.3	3.6	3.8	3.2	5.8	12.7	23.2
15	6.0	-0.4	0.8	3.4	4.2	3.8	6.6	13.2	24.4
20	6.6	-0.1	0.9	4.0	4.7	4.5	6.7	13.4	23.6
25	5.7	-0.6	1.1	3.8	4.6	4.6	6.9	12.9	22.4
30	7.1	1.0	2.0	3.9	4.0	4.7	7.4	12.8	21.8
35	9.1	4.3	3.6	3.5	4.0	5.0	8.0	12.0	20.6
dock	-2.9	-0.7	0.3	3.4	5.7	5.5	6.5	13.4	21.4

From the average equivalent A-weighted spectrum of freight trucks (total) shown in figure 5, it appears that the main sources of noise are within the frequency bands of 500 Hz until 4 kHz. It can also be concluded that there is a correlation between the noise production of a truck and its speed. The sound power level increases as function of the speed of the truck.

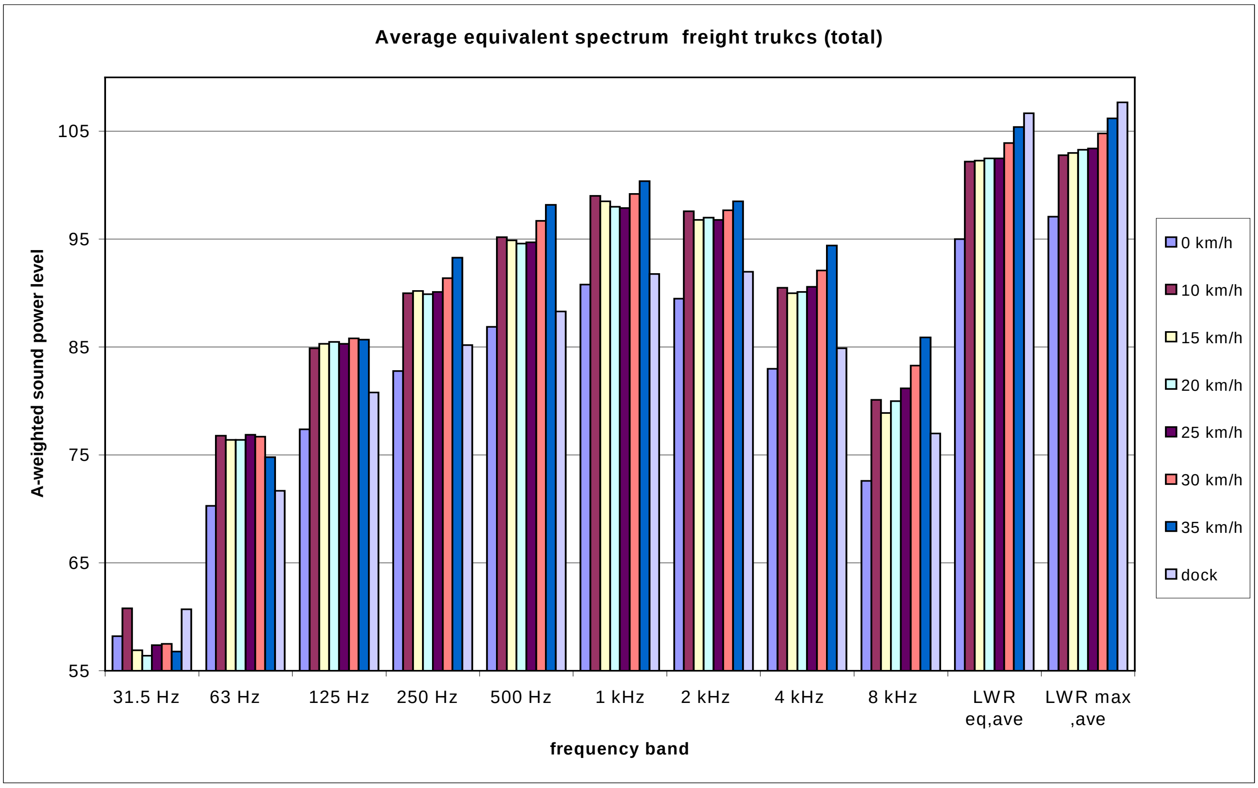

Figure 5: Average equivalent spectrum freight trucks (total) A-weighted.

5. COMPARISON WITH EARLIER MEASUREMENTS

Results of the current study and the study of 1999 are compared in table 9. In the previous of 1999 also the average sound level over one second was used, as well as in the current survey.

Table 9: Comparison between current and previous surveys (middle-sized trucks)

Speed	$L_{WR\ eq,ave}$ current (2009)	stdev	$L_{WR\ max,ave}$ previous (1999)	stdev
10	-	-	102	5
15	103	19	-	-
20	102	4	102	3
25	99	4	-	-
30	104	4	104	3
35	-	-	103	3
dock	98	7	-	-

Table 10: Comparison between current and previous surveys (heavy trucks)

Speed	$L_{WR\ eq,ave}$ current (2009)	stdev	$L_{WR\ eq,ave}$ previous (1999)	stdev
0	95	4	95	4
10	100	3	99	5
15	102	3	102	4
20	103	2	102	5
25	103	5	103	3
30	104	3	106	3
35	105	3	106	3
dock	97	5	-	-

6. CONCLUSION

There is a difference between $L_{eq,1}$ and L_{max} of about 1.0 dB on averaged. This is expected to be caused by the presence of multiple noise sources in the truck (tractor).
The most significant contributions to the total sound power level come from the frequency bands at 500 Hz, 1 kHz and 2 kHz.

From the results presented in table 9 and 10 can be concluded that the noise emission of freight trucks has not significantly changed in comparison with the survey of 1999.
As far as possible regarding the considered driving speeds, this study shows comparable sound power levels as the Danish report [1].
Speed plays an important roll in the noise production of freight trucks. The most common driving speeds at industry sites and complexes are 20 km/h and 25 km/h. The sound power levels at this speeds could be taken into account when estimating the noise production of a truck in an industry site or complex where the average driving speed is not known.

The driving behaviour is an even more important factor on the noise production of trucks. Accelerating trucks produce significantly more noise than a truck driving at constant speed. This points out that there might be a even more important relation between the engine speed and the noise production of these trucks.

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