Footprint of a vehicle – The Swiss Contribution for noise of heavy road traffic

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Introduction

Footprint is a European collaborative research project within the pan-European EUREKA framework for development and exploitation of technologies crucial to global competitiveness and better life quality. The aim of the project is to relate the environmental "footprint" of a heavy road or rail vehicle to the lifetime cost of maintaining the infrastructure and environment. This may provide the information needed to develop strategies to minimise the footprint, e.g. to raise individual road charges for heavy vehicles relating to their footprint. The footprint is characterised by dynamic load, noise, ground borne vibration and gaseous emissions induced by the vehicle.

As a project partner Switzerland installed in 2005 the first footprint monitoring station (FMS) in Europe for road traffic on the East-West-transit motorway A1. Objectives included the development of techniques to measure and characterise impacts and to determine e.g. the acoustical footprint of a heavy road vehicle. FMS for road and rail exist in various European countries like Austria, the Netherlands (Rail) and U.K. (Road).

The equipment of the Swiss FMS allows also to relate the environmental impacts to parameters like vehicle type, axle load and vehicle speed.

Footprint Monitoring Site in Switzerland

In June 2005 the first road FMS in Europe was built on the A1 motorway in Switzerland near Lenzburg. The motorway has two lanes in each direction, the maximum allowed speed is 120 km/h for passenger cars and light vehicles and 80 km/h for heavy vehicles and trucks. About 6000 heavy vehicles pass this site on weekdays and 2000 on weekends. The FMS monitors amongst noise and various other data like e.g. temperature and dynamic loads using weigh in motion sensors (as to Fig 1).

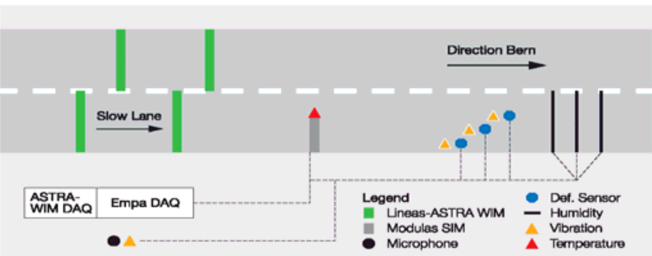

Figure 1: Schema of the Footprint Monitoring Site in Switzerland

The microphone was installed on the east side of the road with a geometry based on the ISO 11819-1 standard [1]. The distance and the height of the microphone had to be slightly adjusted (6.5 m and 3.0 m) to avoid significant shielding of the guard rail. The A,Fast-weighted sound pressure level was recorded with a time resolution of 100 ms. Furthermore traffic was counted by two induction loops, delivering e.g. event time of the pass-by of a vehicle.

Single event measurements of heavy road vehicles in freely flowing traffic [2]

Problem

The determination of a vehicle's sound power is usually based on a measurement of the maximum pass-by sound pressure level, recorded at a distance of 7.5 m. In dense traffic a measurement of the wanted vehicle is often disturbed by neighbour vehicles. Following ISO 11819-1 a measured maximum value can be approved valid if the level drops down for at least 6dB before and after the maximum is reached.

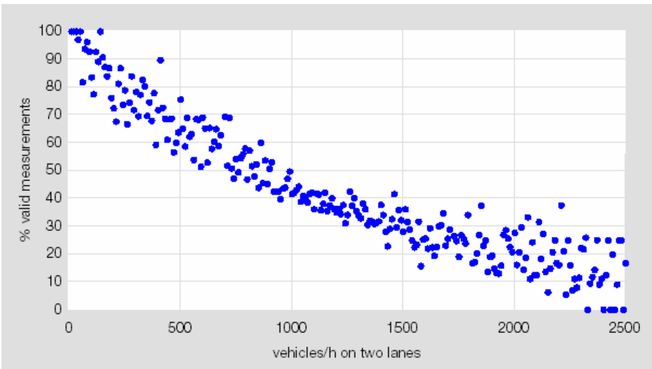

Figure 2: Percentage of valid (6dB down criterion) single truck measurements as a function of number of total vehicles / hour on two lanes heading in one direction.

Fig. 2 shows results of a measurement campaign where the data for more than 40'000 heavy vehicles were gathered. As can be seen for a traffic density of 500 heavy vehicles per hour about 85% are valid. On an increased traffic density to 2500 per hour the percentage of valid events drops to about 45%. An elementary difficulty is that a noisy vehicle is more likely to fulfill the 6dB down criterion whereas a silent vehicle with a low maximum level will violate the criterion and will be excluded from further analysis (for details see [2]). The average pass-by level is thus dependent on traffic density and is overestimated systematically when using the methodology described in ISO 11819-1. To classify heavy vehicles regarding their acoustical footprint on a motorway with dense traffic a new strategy had to be developed within the footprint project which allows valid events of statistical pass-by measurements for almost all the heavy vehicles without systematic overestimation.

Compensation strategy for the effect of disturbing vehicles

The strategy is based on acoustical level time information and event time information for the wanted vehicle.

The level time curve Ls denotes the sound pressure stemming from the wanted vehicle, Ln is the contribution of a disturbing vehicle. At the microphone only the total sound pressure level Lt can be observed (see Fig 3). Starting point is the maximum level Lt0 which is identified as belonging to the vehicle under consideration. The analysis of the 6 dB down criterion yields that the minimum level L_{t1} at time t_1 is less than 6 dB below L_{t0}.

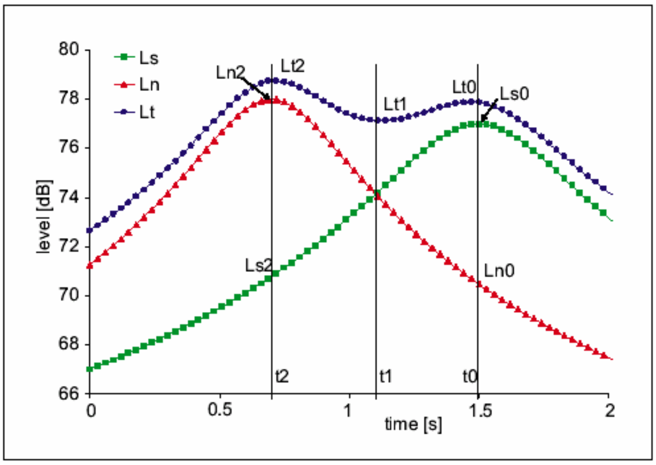

Figure 3: Modelled level time curves at a microphone in a distance of 7.5 m for two vehicles (Ls: wanted vehicle, Ln: disturbing vehicle) resulting in a total sound pressure level Lt.

L_{t0} significantly overestimates the true maximum value for the wanted vehicle (L_{s0}) and must be corrected for by the following procedure (compare Fig. 3):

1) Estimate the slope parameter s_s for the wanted vehicle pass-by. With good accuracy it can be assumed at time t_1 the level of the wanted vehicle and the level of the disturbing vehicle are equal. From that follows:

$$s_s = \frac{A_s (t_0 - t_1)^2}{1 - A_s}, \quad (1)$$

where $A_s = 10^{\frac{L_{t0} - L_{t1} - 3}{7.6^*}}$

* Compared to an omnidirectional point source the pass-by level time curve of a real vehicle with a horizontal directivity shows less steep slopes. This broadening can be approximated by using 7.6 instead of 10

2) Identify time t_2 and level L_{t2} for the pass-by of the disturbing vehicle.

3) Estimate L_{n2} by subtracting the contribution of the wanted vehicle

$$L_{n2} = 10\log\left(10^{0.1L_{t2}} - 10^{0.1L_{s2}}\right), \quad \text{[dB]} \quad (2)$$

where $L_{s2} = L_{t0} + 7.6\log\left(\frac{s_s}{s_s + (t_0 - t_2)^2}\right)$

4) Estimate the slope parameter s_n for the disturbing vehicle pass-by:

$$s_n = \frac{A_n (t_1 - t_2)^2}{1 - A_n}, \quad (3)$$

where $A_n = 10^{\frac{L_{n2} - L_{t1} - 3}{7.6}}$

5) Estimate L_{s0} by subtracting the contribution of the disturbing vehicle:

$$L_{s0} = 10\log\left(10^{0.1L_{t0}} - 10^{0.1L_{n0}}\right), \quad \text{[dB]} \quad (4)$$

where $L_{n0} = L_{n2} + 7.6\log\left(\frac{s_n}{s_n + (t_0 - t_2)^2}\right)$

In step 1) the level time curve for the wanted vehicle is based - as a first guess - on the maximum level of the total sound pressure. At the end of step 5) a better estimate is available thus the procedure could be repeated iteratively. However numerical experiments have shown that the final result for L_{s0} after a second and a third run alters only by 0.1 to 0.3 dB.

Using the described compensation strategy the percentage of pass-by events in dense traffic that could be evaluated successfully increases up to 95%.

Factors that influence noise emission of heavy road vehicles

The measured emission of a heavy road vehicle for speeds above 60 km/h is influenced by several factors. General facts and evaluating data from the Swiss FMS identifies the following factors [3]:

Site specific factors

Type, age and condition of pavement: Taking standard dense asphalt as a reference porous asphalt can reduce emissions up to 5 dB(A) in the beginning, losing much of its noise reduction potential during time. Rough concrete pavement can increase emissions up to 3 dB(A) compared to standard dense asphalt as a reference. Defects of the surface of the pavement can create a considerable increase of noise emissions.

Additionally it was also found that soft ground in the vicinity of the receiver position may have considerable influence on ground effect due to alterations in the interference pattern between direct and ground reflected sound [3].

Vehicle

Speed: For a given site and vehicle category the most important parameter influencing noise emission is vehicle speed. The speed dependency on noise can be calculated with high accuracy. To use footprint data in order to develop road charges with regard to the impacts to the infrastructure and the environment it seems necessary to normalize measured sound levels for a reference speed, e.g. 80 km/h.

Mass: Evaluating the measurements after normalisation shows that the influence of weight on sound emission for the measured vehicle classes is relatively small:

Vehicle class		**Noise increase per tonne [dB(A)]**
COST 323 class	**Swiss 10 category**	
3	8 (Lastwagen)	0.12
4 or 5	10 (Sattelzug)	0.06
6	9 (Lastenzug)	0.03

Table 1: Effect of mass on noise emission for different vehicle classes

Comparisons between FMS in Switzerland and the U.K. show differences in the vehicle fleet: At the Swiss Site class 6 vehicles are the noisiest ones while in the U.K. class 6 vehicles are the quietest ones compared to class 4 and 5 vehicles [3].

Suspension: Noise can be transmitted via the suspension to the vehicle body which amplifies the noise. Good sound absorption characteristics were found from air suspension and glass fibre plastic leaf springs [4]

Conclusions and further steps

With the above described compensation strategy for the effect of disturbing vehicles a method has been developed to fullfill the needs of a noise pass-by measurement of a single heavy road vehicle within footprint. To compare data, the measurements have to be normalized for a certain speed, e.g. 80 km/h. When comparing data from different countries a uniform vehicle classification system should be used. In addition, site specific factors have to be taken into account.

Comparison of different parameters show that it is not always possible to find a direct correlation between vehicles considered as environmentally friendly in one respect (e.g. gaseous emissions) and its environmental friendliness in another respect (e.g. noise). All parameters need therefore to be monitored separately to determine a vehicles total footprint [5].

Further steps will be a development of a rating for each measured parameter as well as a method to sum up the individual ratings to a total footprint index of the vehicle. Once a total footprint can be determined, this information can be used for implementing individual infrastructure access charges for vehicles.

The EU-package for greening transport from July 2008 aims to make all transport users pay for the negative impacts they cause [6]. By providing a footprints index for different transport vehicles the project may help to continue to reduce the environmental impact of transport.

Also continuous monitoring of footprints would allow to measure the effectiveness of noise reduction strategies.

References

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