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One's Personal Noise Footprint: what's your share in environmental noise production?

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Abstract
Environmental noise is generally considered a problem that should be tackled at governmental level. This is justified as long as citizens cannot really influence the amount of noise that is produced in their neighborhood. The consequence, however, is that people are not aware of their share in environmental noise, or worse, they are not interested at all in environmental noise and its (hidden) effects on health. Changing this attitude may be required for a sustainable quieter environment.
In many cases individuals can choose between different means of transportation. Citizens are willing to take environmental aspects like CO_2 emission and energy wastage into consideration, but up to now cannot decide on the noise impact. Will I take the bus or drive by car? Will I take the high speed train or an airplane? What is my share in noise impact, as a passenger, in these cases? To what extend do I have a share in industrial noise as well, being consumer and labourer?
In this article a method is given to calculate one's personal contribution in environmental noise. In order to visualise this contribution, we are borrowing the concept 'noise footprint' which is used in aircraft noise control and reform this into a 'personal noise footpring (PNF)'. The PNF has no directional information. It represents the area which is exposed to noise and it indicates which activity of individuals is dominant. Besides visualisation advantages, the noise footprint features simple maths instead of logarithms. Strenght and weaknesses of concept are discussed in this article.

Keywords: environmental noise, awareness, sustainable.

1 Introduction

Large parts of the world are covered by a blanket of noise. Noise levels are especially high along busy roads and railways, in the vicinity of airports and around industrial plants. The quality of life is being affected and in worst cases also our health is threatened. In general it is considered a task of the government to mitigate the effects of noise pollution. In most case the inhabitants of noisy areas meekly undergo this reduced quality of life. They do not feel any personal responsibilty for the noise annoyance – the authorities should care. At least, this is the common perception. But is this right?

As soon as their environment is changing or spatial plans are threatening their neighbourhood, residents start revolting. The initiator of the plans, in many cases the local authority, is regarded as the bad guy who is going to spoil the environmental quality a little further. But it's not as simple as that. All the noise produced by human activity is made by ourselves. Everyone contributes a personal part to the total noise annoyance.

For most environmental aspects, citizens fairly well realise that they are causing part of the problem themselves. As a result of this, people are willing to insulate their dwellings or to turn down the heating in order to reduce carbon dioxide emissions. All over the western world, household waste is separated more and more. While waste separation was mainly considered a task for the government until the 1980s, the average Dutch citizen has gradually re-organised his household in order to deal with over ten categories of waste. This transfer of responsibility from authority to citizen is an amazing achievement. Would this also be possible for noise pollution?

The problem with noise pollution is partly that it is not clear who causes the pollution. An individual person cannot determine his own contribution. As a consequence, a consumer is not able to make an independant choice in order to reduce this contribution. A novelty with respect to this is the Dutch 'silent tire' campaign which aimes at making car drivers aware of their influence on their own noise production. As such, the consumer can choose a silent tire to reduce his contribution.

1.1 Goals

The noise footprint will give citizens insight in the consequences of their own acting on noise emission. The following goals are strived for:

1. Citizens will be able to reduce their own noise production, by making better choices;
2. Citizens will note the inevitability of noise pollution, and will understand the role and projects of the authorities.

We can provide this insight by handing them a simple but powerful concept, the personal noise footprint (PNF), and by clarifying which of its components are most important.

1.2 What is meant by personal noise footprint?

The PNF is a square measure (unit [m^2] or [km^2]) which represents the area surrounded by a certain noise contour. While the noise footprints of roads, industrial parks or aircraft[1] have specific shapes, a personal noise footprint is just an imaginary concept without directional information, as we will see later. For popular or promotional reasons, we may visualize these imaginary areas as footprints (Figure 1). However, in acoustical practice, the area of a personal noise footprint will mostly be circular (point sources) or rectangular (line sources).

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[1] The term noise footprint is used in the field of aircraft noise to specify the shape and area of combined *SEL* contours for take-off and landing. Each type of aircraft has its own noise footprint. See also Appendix 1.

Figure 1 – The PNF logo

1.3 Which noise metric?

The next question that we asked ourselves in developing the concept, is which noise metric and which noise contour value we should take to define the noise footprint. In principal we can use any commonly accepted noise metric like *SEL*, L_{Aeq} or L_{den}. The size of the footprint can be calculated for different contour values, but we propose to use a fixed reference value. The Environmental Noise Directive (END) features L_{den} = 55 dB as lower limit for the noise-exposed areas that are reported. This value seems to be somewhat high, compared to target noise levels for dwellings: in the Netherlands L_{den} = 48 dB for road noise and L_{Aeq} = 50 dB(A) for daytime industrial noise. The WHO proposes a target of 50 dB(A) during daytime and 40 dB(A) during night time [1]. In line of these values we propose L_{den} = 50 dB as our reference value for noise footprints.

2 National noise footprint

The total noise load within a country can be seen as the sum of all PNFs of its inhabitants. A first estimation of the area of the average PNF can thus be obtained using available noise maps which show in fact the national noise footprint. The current data from the END are not sufficient, however, as they only report areas with a noise load above 55 dB. In addition the European data only comprise major infrastructure and major agglomerations. In the Netherlands alternative noise maps are published regularly by RIVM [2]. An integrated GIS map is available for all major noise sources combined: roads and railways, industrial parks and wind turbines, airports and low altitude flight routes, for L_{den} > 45 dB.
The surface within the 50 dB L_{den} contour within the Netherlands equals to 10145 km^2 (see figure 2). The national noise footprint of this country represents 30% of the total land area. The main source is road noise, claiming one third of the national noise footprint (10% of the land area).
If it is assumed that all noise sources are shared by the 16.5 million inhabitants, the average Dutch citizen has a personal noise footprint of 614 m^2. This means that they all pollute an area of about 20 x 30 m with noise. This area is bigger than a typical Dutch home with a garden.

But not everyone feels responsible for the noise of cars, especially those who are mainly using public transport. So, the PNF of some people may be small, while other people are responsible for a larger footprint. This also means that we can actively influence the size of our personal noise footprint. But first we will discuss the acoustics behind the footprint. After that we will answer a more basic question: what is the acoustical sense of adding or dividing noise-exposed areas – is this allowed at all?

Figure 2 – Dutch noise footprint (50 dB L_{den} contour).
This map includes wind turbine noise at sea. After [2].

3 Noise-exposed area and source strength

We use textbook acoustics of stationary and moving point sources to demonstrate the relationship between source strength and footprint area. Industrial noise sources can generally be treated as stationary point sources. Moving sources like cars and trains are line sources. Aircraft noise is slightly more complicated. As the directional source characteristics of airplanes are important during take off and landing a different approach is necessary. In addition, aircraft are not audible above a certain altitude. Aircraft are treated in Appendix 1.

The free field noise contours of an acoustical point source are circles. The radius R of the circles depends on the source strength L_W (the sound power level of the point source). The noise level L_{Aeq} at distance R is then given by:

$$L_{Aeq} = L_W - 10 \log(2\pi R^2) - D \quad (1a)$$

In this equation D stands for the effects of ground impedance, meteorology and air absorption. Shielding by buildings and barriers is not considered in our calculations. Similarly, moving sources like cars traveling along a distance L can seen as line sources and have cylindrical geometry (figure 3):

$$L_{Aeq} = L_W - 10 \log(\pi RL) - D \quad (1b)$$

For simplicity we assume that D is the same as for the point sources. If we now set L_{Aeq} = 50 dB we can calculate the noise-exposed area A for a point sources as follows:

$$A_{\text{point}} = \pi R^2 = 10^{(Lw - D - 10\log(2) - 50)/10} = 10^{Lw/10} \cdot 10^{-(D + 10\log(2) + 50)/10} \quad (2a)$$

For a line source the area amounts to:

$$A_{\text{line}} = RL = 10^{(Lw - D - 10\log(\pi) - 50)/10} = 10^{Lw/10} \cdot 10^{-(D + 10\log(\pi) + 50)/10} \quad (2b)$$

These formulas directly demonstrate the most important feature of footprints: doubling the source strength, i.e. increasing L_W with 3 dB, leads to doubling the area within the contour. So, twice as much traffic means twice as much area polluted by noise. By reciprocity, we can also say that if two people are using one source, for instance a car, we can divide the footprint of this source by a factor of 2 to obtain the footprints of each individual. This linear dependency makes the PNF an excellent noise metric for popular use, as we do not need to bother about logarithms any more.

We must be aware, however, that the attenuation term D is not a constant, but a function of R, which will cause deviations at larger distances from the source. In practice sometimes a 5 dB raise of source power is required, instead of 3 dB, to obtain a double footprint area. But, as these deviations will be more or less equal for different sources, we should not be too concerned about this when comparing footprints of various forms of transport for a large audience of non-acousticians.

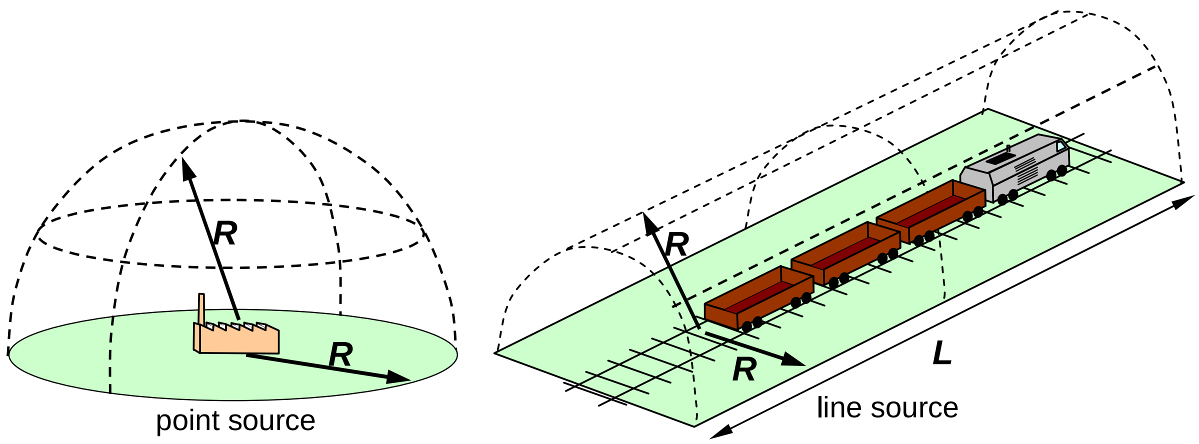

Figure 3 – Hemisphere and semi cylinder for acoustic point and line sources

4 Comparing footprints of different means of transport

Now we know how noise-exposed area is related to the source strength, we can make some comparisons. In this section we will calculate the personal noise footprint of a single trip, which requires a different approach than calculating the average yearly PNF.

We will solve the following problem: which type of transport has the smallest footprint for a journey of 500 km. This distance represents a journey from Madrid to Sevilla, or from

Amsterdam to Paris, where travellers have a choice to take a passenger car, a touring-car, a conventional train, a high speed train or an aeroplane. Table 1 summarizes the input data as well as the results of the calculation.

Table 1 – Comparing footprints of modes of transport for a journey of 500 km.

means of transport	speed [km/h]	number of seats	seat occu-pancy rate*	source characteristics		Noise footprint per mode of transport	PNF of one passenger
				traffic flow	SEL =80 dB(A)		
passenger car**	120	4	25-50%	15.3 veh/h	at R = 50 m	3.3 km2 per car	1.63 km2
touring-car**	100	60	50-70%	9.40 veh/h	at R = 50 m	5.3 km2 per car	0.13 km2
IC double-decker train** (8x26 m)	160	780	35-55%	0.151 trains/h	at R = 50 m	331 km2 per train	0.77 km2
High speed train*** (200 m)	300	377	50-70%	0.093 trains/h	at R = 50 m	538 km2 per train	2.04 km2
Airplane**** (narrow-body)	850	165	70-85%	1 take-off and 1 landing	$A_{footprint}$ = 8.6 km^2	9.0 km2 per A/C	0.064 km2

* seat occupancy rate from [3], except touring-car (equal to IC train)
** source characteristics from [4], listed traffic flow used as input in this calculation model.
*** based on Thalys PBA (10 coaches) and ICE 3M (8 coaches), source characteristics taken from [5]
**** based on Boeing 737-700 and Airbus 320, source characteristics taken from [6]

The PNFs in Table 1 are calculated based on a *SEL* value of 80 dB(A). The reason for using *SEL* is that this noise indicator is more appropriate for comparison of single events. Note that the L_{Aeq} or L_{den} refer to a certain time span during which a noise level is present, which is arbitrary: one could consider the duration of the pass-by but also the journey time. The *SEL* avoids this question and integrates the total acoustical energy of the journey into one second[2]. The drawback of using *SEL* may be that it is a rather abstract concept, quite remote from one's listening experience. However, the *SEL* value of 80 dB(A) can be expressed easily in a constant L_{Aeq} of 44.4 dB(A) during one hour, for example. Besides that, for aircraft footprints the *SEL* is used as standard indicator.

For the footprint of narrow-body aircraft, typically operated on short distances, we refer to Appendix I. For the other modes of transport we used the Dutch standard computation model RMR [4]. Using thise method we have modelled a certain hourly traffic flow that produces an L_{Aeq} of 44.4 dB(A) at 50 m distance from the road or track (on both sides). The total area of this stretch of land along the road or track is 50 km^2. We divide this area by the traffic flow rate to retrieve the footprint of a single car or train. Finally, the right column of Table 1 gives the personal noise footprint per passenger of this tripe, while taking the maximum seat occupancy rate for that transport mode is taken into account.

It may be surprising that a trip by aircraft results in a substantially lower personal noise footprint than other means of transport. Second best is the long-distance coach (touring-car). The differences between both types of train and the passenger car are not so big. They are of the same order of magnitude as the variance between specific types or brands within their mode of transport (a few decibels).

The calculations are based on typical reference conditions for each mode of transport: non-porous asphalt concrete as road pavement, ballasted track for railroads, footprints for

[2] $SEL = L_{Aeq} + 10 \log(T)$, where T is the measurement time during which L_{Aeq} is evaluated.

standard take-off and landing procedures. The ratios between the PNFs may change somewhat if noise controlling measures are taken on the source. However, typical source measures like porous asphalt (road), rail dampers (track), and continuous descent approach (aircraft, [7]) have similar effects in terms of noise reduction (2-4 dB). Therefore applying these measures for the respective modes of transport will not lead to a different rating.

Perhaps interesting is that a passenger who chooses to travel 2nd or economy class, will realize a reduction of his personal footprint area because these seats occupy less space than first class or business class seats (up to about 40% in trains). Consequently, the 1st class passengers are responsible for a larger personal footprint per trip.

Note that single-event PNFs cannot be compared directly with the PNFs calculated in Section 2. This is due to the different time basis, one second versus one year, and the different reference value (80 dB versus 50 dB).

5 Industrial sources

Unlike passenger transport, where the noise event can be directly assigned to those who are transported, the footprint of industrial noise can only be indirectly assigned to an individual. Table 2 lists examples of actions and events that can be directly or indirectly linked.

Table 2 – Assigning of noise pollution

direct linkable to individuals	**Indirectly linkable to individuals**
Passenger transport	Freight transport
Outdoor events (festivals, leisure)	Industry
Scooters	Load/unload near shops in towns

The noise production of industry in a broad sense, including freight transport, is caused by economic activity of all citizens. To relate this to the PNF we might divide the total industrial noise footprint by the total population. It can be expected that our share of industrial noise forms a considerable part of our total personal footprint. For example, freight transport represents about one fifth of the road traffic. In the Netherlands, harbour activity is quite space consuming and noise polluting in Amsterdam and Rotterdam.

This method of equal sharing of the industrial noise footprint implies that nobody needs to feel responsible for these kinds of noise. Although citizens cannot directly influence this type of noise pollution, it must be remarked that some types of industrial noise can fairly well be linked to our individual choices. For example, since the energy market it is liberated in Europe, we can choose between renewable and conventional energy offered by different energy suppliers. Unfortunately, despite its ‘green’ character, the production of some types of renewable energy is still rather noisy (wind turbines).

Even if citizens are not free to buy goods on a free and acoustically transparent market, it makes sense to compare the footprints of some industrial activities. For example, it has been shown by Thompson [8] that freight trains are many decibels less noisy than road trucks that carry the same load. It will be interesting to explore the noise footprints for other freight transportation modes as well, like freight boats and airplanes.

In addition, the noise footprint of a single product might be calculated as well. This could be used for noise labeling purposes. Even a product that is silent by itself, like an orange, has an associated noise footprint.

6. Discussion

In comparing footprints of different noise sources, we have not accounted yet for the difference in annoyance, related to the source characteristics. For example, aircraft noise is more annoying than road traffic noise, and road traffic on it's turn is more annoying than railway noise, at the same noise level [9]. In principle, it is possible to extend the footprint calculations with a correction factor for differences in annoyance. One way to do this is indicated in figure 4. The correction factor can be derived directly from the difference in noise level ΔL between sources at a certain percentage of equal annoyance (for example centred around L_{den} = 50 dB).
However, some dose-effect relationships appear not to be constant over time or are dependent on local conditions [10]. Therefore, some caution is required when applying corrections factors.
Another issue may be that noise footprints are blind for population density in the area of concern. What sense would it make to show that one source has a larger footprint than another source, while the first source is typically found in rural areas and the second on in urban areas? Though we believe that it is possible to compensate footprints for such situations, we stress that noise pollution is not only a problem in built-up areas or other densely populated areas. Noise is also annoyingly present in leisure and nature areas, where people want to recover. Besides this, too many corrections may affect the transparency and simplicity of the footprint.

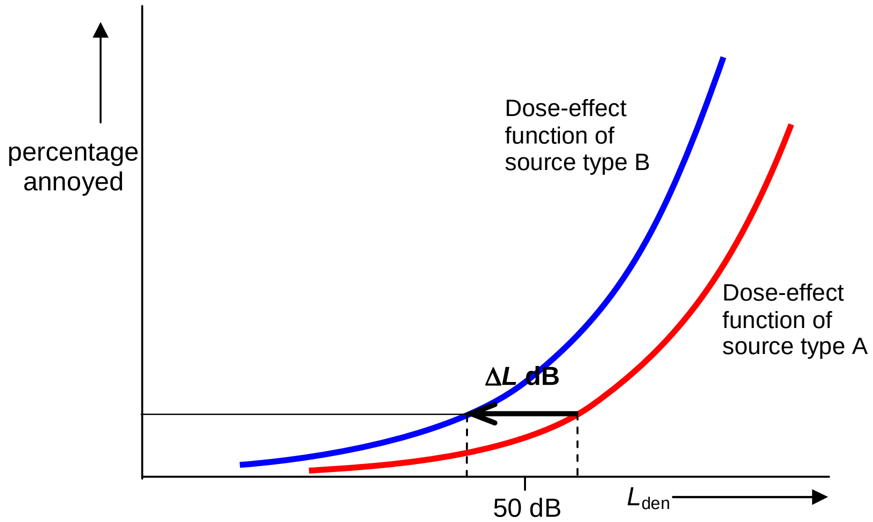

Figure 4 – Compensating for annoyance by using dose-response relationships

7. Conclusions

The personal noise footprint can be used as an environmental label that enables consumers to visualize the effect of their decisions, especially in situations where the acoustic effect is hard to notice within an environment that is already quite noisy. The examples described in this article focus mainly on transportation, being a major source of noise annoyance in western society. But also other activities can be labeled: football matches, open-air concerts and festivals.

Other opportunities are to evaluate the footprint of a product's life-cycle: how noisy is the production and distribution of a TV set, food, cloths et cetera? It would be interesting to develop a web application that allows visitors to build up their own footprint, and to compare this with the average citizen's footprint.
It is obvious that the noise footprint can be combined with other environmental components. Given the public arousal about the climate change, a combination with CO_2 emission or energy consumption could be considered. This would certainly temper the results of our exercise on transport noise.

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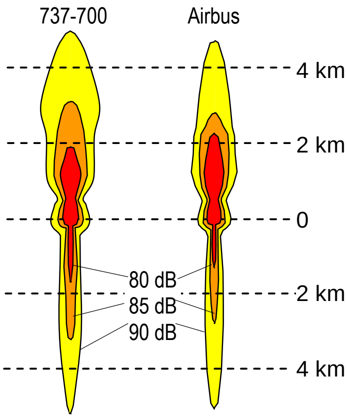
Appendix I

Treating an aircraft as a point source during take-off and landing would not be a valid approximation because of the directional characteristics of its noise sources. Luckily, noise footprints are available for many types of aircraft. Such footprints represent the exposed area (*SEL*) during one take-off and one landing under prescribed conditions. Figure A shows the footprint contours of a Boeing 737-700 and an Airbus 320. These were derived from the drawings produced for Sea-Tac Airport [6].



Type	Number of seats	SEL		
		80 dB(A)	85 dB(A)	90 dB(A)
Boeing 737-700	150	8.6 km^2	2.9 km^2	1.1 km^2
Airbus A320	180	6.6 km^2	2.4 km^2	1.1 km^2

Figure A – Noise footprints an areas of two narrow-body aircraft.