Noise charges for Swedish railways based on marginal cost calculations*

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Abstract

This paper describes an effort to calculate marginal costs for railway traffic in Sweden using 1) standardised and already well established methods for calculating noise and 2) valuations of noise based on hedonic regression. The main point is that the marginal costs are calculated using well established methods used for other purposes (urban planning for the noise method and cost benefit analysis for the noise values), the combination of these methods requires knowledge in both transport economics and acoustics but apart from that no new methods need to be developed. The results show large variations over the network explained mainly by the large variations in population density. It is necessary to include similar variations in a charging system in order to gain the full benefits of internalizing the noise cost.

Keywords: Railway noise; Infrastructure charging; Marginal costs; Noise charges

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1 Introduction

Transport related noise is a major environmental and health problem as many people, mostly in urban areas, is suffering from such noise. The problem is also increasingly important since urbanization and increasing traffic cause more people to be exposed to high noise levels (Nijland et al., 2003). In economic terms transport noise is an external cost, and if this external cost is not taken into account, the market solution will be inefficient.

The efficient way to internalize the external cost is to charge the infrastructure users based on the marginal cost of the external effect. The user should pay for its external cost which will provide an adjustment towards the efficient quantity and also provide an incentive to reduce the sources of the external cost.

Considering the railway noise, the train operators should pay for its marginal external cost of noise. This article describes an effort to calculate the marginal cost of noise for railway traffic in Sweden. The marginal cost will differ depend on a number of aspects, among others, the valuation in monetary terms of noise exposure, number of individuals exposed, traffic volume, noise exposure level, and the characteristics of the train type under study.

2 Method

2.1 Marginal costs of railway noise

The calculations in this subsection is based on the methodology of Andersson and Ögren (2007), which is extended to cover the whole country of Sweden and also to be based on the estimated demand relationship in this study. For each railway line section to be investigated three steps need to be taken to calculate the marginal cost of noise for a specific rail vehicle:

1. Calculate the noise level at all exposed dwellings
2. Sum up the monetary contributions from each exposed individual using a valuation function
3. Calculate how much a specific train contributes to the total level and assign a proportional cost to each train type

For the first step there are standardized noise calculation methods that can be used, in this case the Nordic method (Ringheim, 1996) is employed. It calculates the equivalent sound pressure level (noise level) at the façade of a dwelling. The method takes the total traffic and speed of different train types into account, and by correcting for distance, screening by terrain, buildings or noise barriers and the overall terrain profile estimates the noise level. Most Swedish train types are included in the method, and new train types can be added using standardized field measurement procedure. Unfortunately the method is too complex and requires too much input data for a calculations covering the whole railway network of Sweden, so a simplified procedure was developed as described in Sec. 2.3.

The second step is basically where the noise level is translated into a monetary effect, essentially the willingness to pay (WTP) for reducing the noise level. Several options exist in the Swedish context. The most widely used Swedish valuation is known as ASEK (SIKA, 2008), which is based on a hedonic regression on properties exposed to road traffic noise, adjusted to railway noise and with an added percentage due to health effects which is assumed not to be included in the WTP. Here a more recent study based on a larger sample of properties exposed to railway traffic noise is used known as JÄSMAGE, but the results are still at *working paper* status (Swärdh et al., 2010).

In the third step the contribution to the total noise level of a single passage of the various train types in traffic is calculated. The contribution is expressed as the increase in total noise level a single extra passage will cause. For railway lines with very low traffic this might be as high as an increase of around 1 dB on the total level, but it is typically much lower. On lines where the traffic is very intense the contribution can be as low as an increase of 0.001 dB. This rather small increase is due to the logarithmic nature of the sound pressure level expressed in dB's, but since the number of exposed can reach thousands per km of railway it does still cause a noticeable marginal cost for the train operator.

The marginal cost calculation for a specific train over a 1 km long rail section can be calculated as

$$\sum c(L)\,\Delta L, \tag{1}$$

where L is the A-weighted equivalent sound pressure level on the exposed façade (often denoted $L_{AEq,24h}$ but simplified to L in this paper), $c(L)$ the marginal cost function and ΔL the increase in noise level one extra passage will cause. The summation is over all exposed inhabitants, in our case all inhabitants with a noise level higher than 49.1 dB, below which the marginal cost function is zero. To a close approximation the contribution ΔL is constant where the traffic is constant and can be taken out of the summation, see Andersson et al. (2009). This greatly simplifies the calculations for large areas, and follows from the linearity of the Nordic method and the logarithmic nature of noise levels.

The marginal cost function $c(L)$ (SEK price level 2011) is the WTP for a 1 dB reduction, and the WTP increases with increasing noise level. Our function determined using Hedonic regression in (Swärdh et al., 2010) is

$$c(L) = 57.94L - 2844.50 \qquad L > 49.1 \tag{2}$$

$$c(L) = 0 \qquad L \leq 49.1\,. \tag{3}$$

This function is undefined above 75 dB, since no higher equivalent levels where included in the sample used to estimate the function.

2.2 Population and railway data

The basic properties of the data sets used for the calculation procedure is outlined in Tab. 1. The population data has a resolution of one total population value for each square with 250 m side, and was obtained from SCB (Statistics Sweden). The traffic data is the number of freight and passenger train passages for 1407 control points (denoted "trafikplats" in Swedish) on the network. For freight trains the length distribution is also included.

Table 1: Input data sets for the marginal cost calculations.

Data	Overview
Population	Total population 2009-12-31, 250 m squares
Railway lines	Trafikverket GIS, approximately 25 m resolution
Traffic	Trafikverket, data for freight and passenger trains at 1407 points in the network

All data sets needed some form of pre-processing before being suitable for the final calculation. The population data was reduced so that only squares with one corner within 1 km distance or less of any railway line were included. The major tunnels were removed from the network to avoid assigning high noise levels to inhabitants living above tunnels. Lines with no traffic were also removed since in theory the marginal cost of adding a train to an empty line would be infinite. A large amount of work was also needed in cleaning the data and assigning traffic to the right lines, but the details are omitted here. An example of the final data with railway lines and population squares can be seen in Fig. 1.

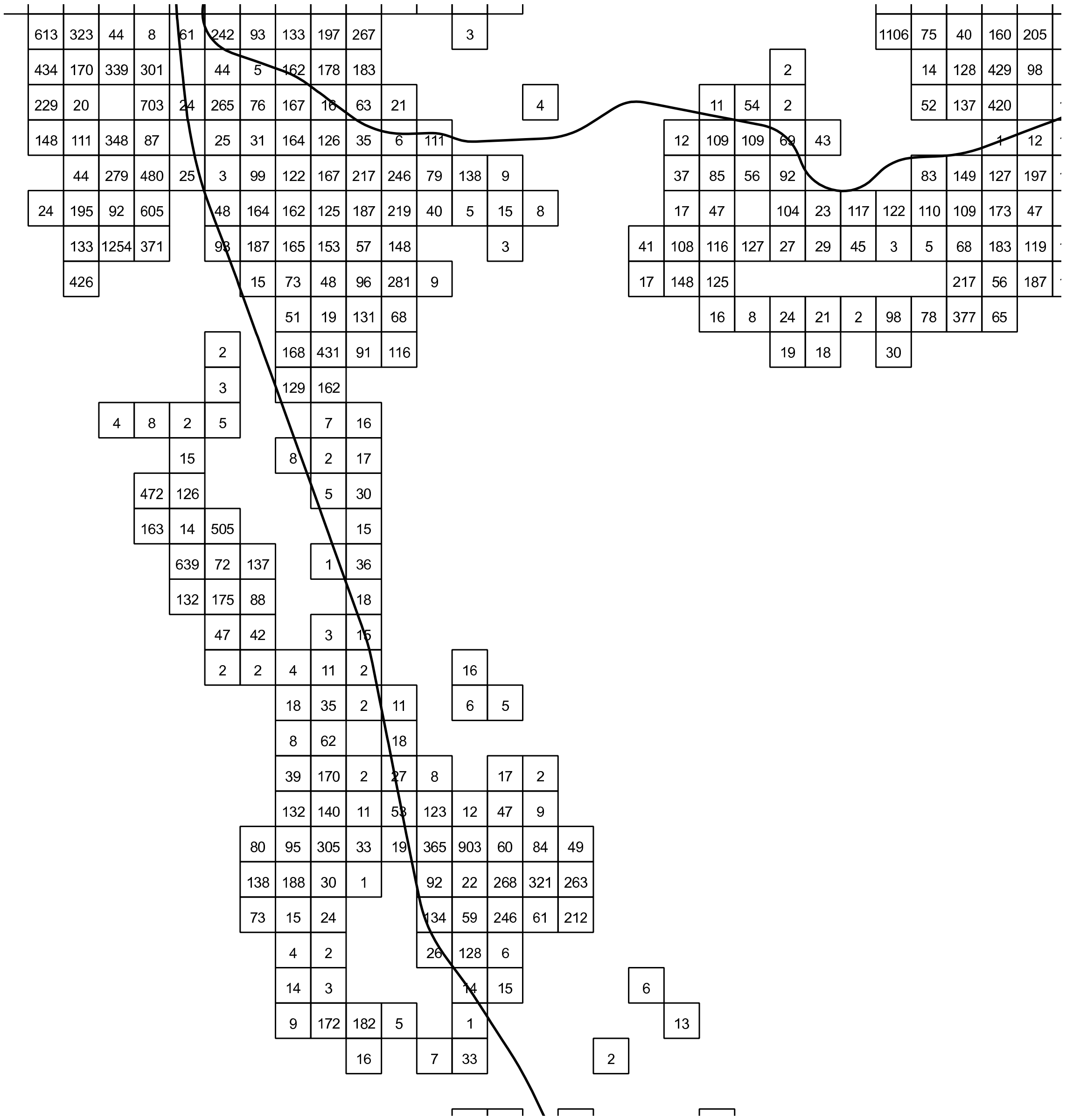

Figure 1: Example of railway lines and selected population data in squares (250 m side).

2.3 Simplified noise calculations

In order to make a useful noise prediction scheme for such large areas 740 calculations including all details were normalized according to traffic and plotted against the distance from the railway. The calculation results then form a band, and the slope and distribution was determined using a least squares approach, see Fig. 2. The model then predicts that the noise level at a distance d from the railway as

$$L(d) = L_{25m} - 15.74 \log_{10}(d) + 15.94, \tag{4}$$

where L_{25m} is the equivalent sound level calculated at a distance of 25 m using the Nordic method (Ringheim, 1996) without any screening or ground effect. Furthermore the simplified model predicts a uniform distribution from $L-3$ to $L+3$ dB.

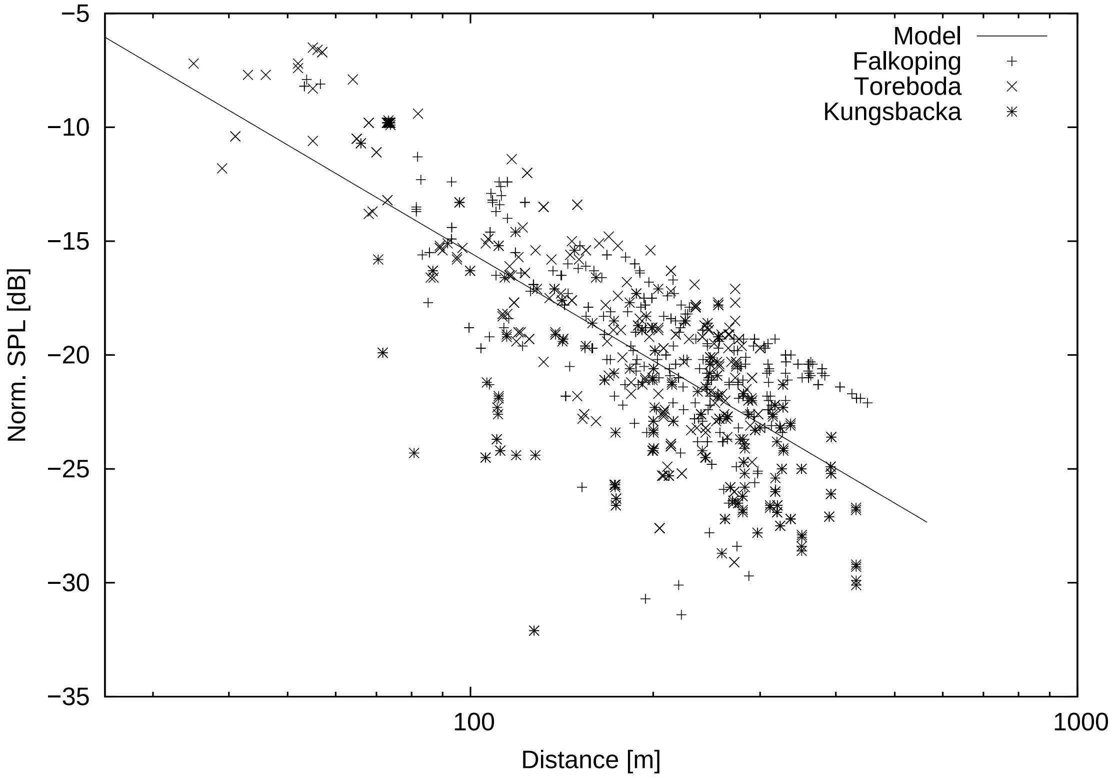

Figure 2: Simplified railway noise model together with data from three areas.

The number of exposed individuals to different noise levels in a 250 m square can then be predicted by integrating the population density over the part of the square that corresponds to the noise level as calculated above.

3 Results

3.1 Results for the reference train

The reference train was arbitrarily chosen as a typical freight train (electrically powered) at 90 km/h with length 500 m. The marginal cost was then calculated by adding this train to all railway lines included in the study, and the results are presented as a map with color according to marginal cost per km (SEK, price level 2011) in Fig. 3. As can be seen the calculated marginal cost varies a lot, being close to zero at many locations and then going above 25 SEK/km at other. This is mainly due to differences in population density, which varies considerably.

The results are also presented in tabular form in Tab. 2, where the strong variations are evident even though the results are averaged over each line (stråk). The estimated number of exposed above 55 dB is also presented, and although this is not the focus of the model the estimate is in line with the official estimate for all of Sweden, which is 225,000 persons (Simonsson, 2009) as compared to 206,000 using the simplified model presented in this paper.

Table 2: Calculated SRMC for the reference train for each line (stråk), SEK per km.

Line	Length km	Traffic /24h	Max Spd. km/h	Exp. ≥55dB	SRMC SEK/km
1	490.4	127	200	25422	6.69
2	587.2	118	200	30541	6.77
3	287.4	74	200	8080	7.77
4	403.2	24	160	1446	4.00
5	394.7	118	200	22165	7.69
6	261.9	30	180	1908	4.51
7	701.9	33	160	2834	1.50
8	344.5	47	200	2719	2.17
9	301.6	55	200	9617	4.69
10	418.3	28	140	2935	3.01
11	295.0	32	200	1888	2.97
12	210.4	43	200	4174	5.83
13	119.8	60	160	2136	7.26
14	116.1	45	160	1974	8.65
15	133.2	20	140	84	2.60
16	214.3	83	200	10860	10.31
17	118.8	35	200	1386	5.67
18	157.2	23	140	638	2.85
19	55.1	92	140	3132	27.06
20	331.0	16	150	374	1.85
21	444.7	20	135	158	0.26
22	21.3	387	200	53070	122.75
23	35.2	99	170	4920	28.81
24	25.9	171	200	11093	43.16
26	99.8	16	140	734	5.42
32	48.7	31	140	79	2.32
33	63.2	15	130	232	3.60
42	57.4	11	90	135	2.31
45	65.3	7	100	117	3.64
53	133.6	9	100	25	0.60
59	1.9	173	70	17	15.39
63	110.1	22	140	81	1.40
65	284.7	12	120	7	0.25
73	176.1	15	140	242	2.75
83	34.1	20	100	0	2.34
84	204.0	11	120	35	0.75
88	128.0	34	160	494	5.11
89	42.2	5	70	9	0.49
90	101.2	44	160	732	5.99
All	8019.5	58	–	206505	4.74

The average over the entire network is 4.74 SEK/km for the reference train. Since the variations are large it is important not to be content with a charge which is a flat rate of 4.74 SEK for each freight train over the whole network, nevertheless it is an important average for instance when comparing against other transport modes.

3.2 Adjusting for train type and speed

The marginal contribution of a certain train type (defined as the increase in equivalent noise level ΔL) can be calculated directly using the Nordic method for railway noise prediction (Ringheim, 1996) and the traffic data. Therefore the marginal cost of a specific train can be adjusted using train speed and length from a reference calculation using a simple table, see Tab. 3. The reference train is a typical freight train at 90 km/h with length 500 m, therefore the entry is 1.0 for this train in the table. Note that this is slightly longer than the average freight train length in Sweden, which is approximately 350 m. To calculate the marginal cost of a train of known type, length and speed simply adjust the calculated marginal cost of the reference train with the factor in the corresponding cell in the table.

Table 3: Adjusting marginal cost for train type and speed.

Train	Length [m]	Speed [km/h] 30	50	70	90	120	140	160	180	200
X60	107	0.001	0.003	0.005	0.009	0.017	0.026	0.037		
Y31	39	0.001	0.002	0.003	0.006	0.011	0.015			
X50-54	54	0.002	0.004	0.008	0.014	0.029	0.045	0.067	0.096	0.134
X31	79	0.003	0.007	0.014	0.024	0.046	0.066	0.092	0.123	
X2	165	0.006	0.016	0.032	0.056	0.112	0.164	0.230	0.311	0.410
X40	75	0.003	0.007	0.015	0.026	0.051	0.074	0.104	0.142	0.186
X10-X14	50	0.004	0.008	0.015	0.025	0.047	0.066	0.089		
Rc Pass	230	0.213	0.268	0.342	0.425	0.564	0.664	0.769		
Freight El.	500	0.581	0.747	0.883	1.000					
Freight Di.	500	0.174	0.296	0.477	0.707					
Fr. El. K-blocks	500	0.092	0.118	0.140	0.158					

The last row in Tab. 3 shows the effect of retrofitting brake blocks to so called K-blocks (from cast iron brake blocks), which improves overall wheel status and substantially reduces rolling noise. This shows that retrofitted freight trains should have approximately 85% lower noise charges.

4 Discussion

In this paper a method to calculate the marginal cost of noise from railway traffic is outlined which is based on the standardized noise prediction method and valuation functions based on hedonic pricing studies. More details of the ideas and mathematics of the method can be found in the references given earlier. The method is then used to calculate marginal costs for the entire Swedish railway network.

An important but not unexpected finding is that the marginal cost varies a lot along the network. This is in principle due to the local effects of noise, only those living relatively close to the railway are affected, and the population density varies a lot. This is also in contrast to other environmental effects like CO_2 emissions, where it does not matter where on the network the gas gets released, it has a global impact.

The variations also poses a problem when averaging the results. Averaging over to long sections destroys the details, and makes a possible improvement by taking a different route where less people are exposed disappear in monetary terms. If the charge varies, it pays to reroute, if it is constant it does not.

It is also important to design a noise charge system so that quieter trains gets lower charges. It is easy to see in Tab. 3 that the effects are important already with the rolling stock currently in service, and even quieter trains can of course be designed using future low noise technology.

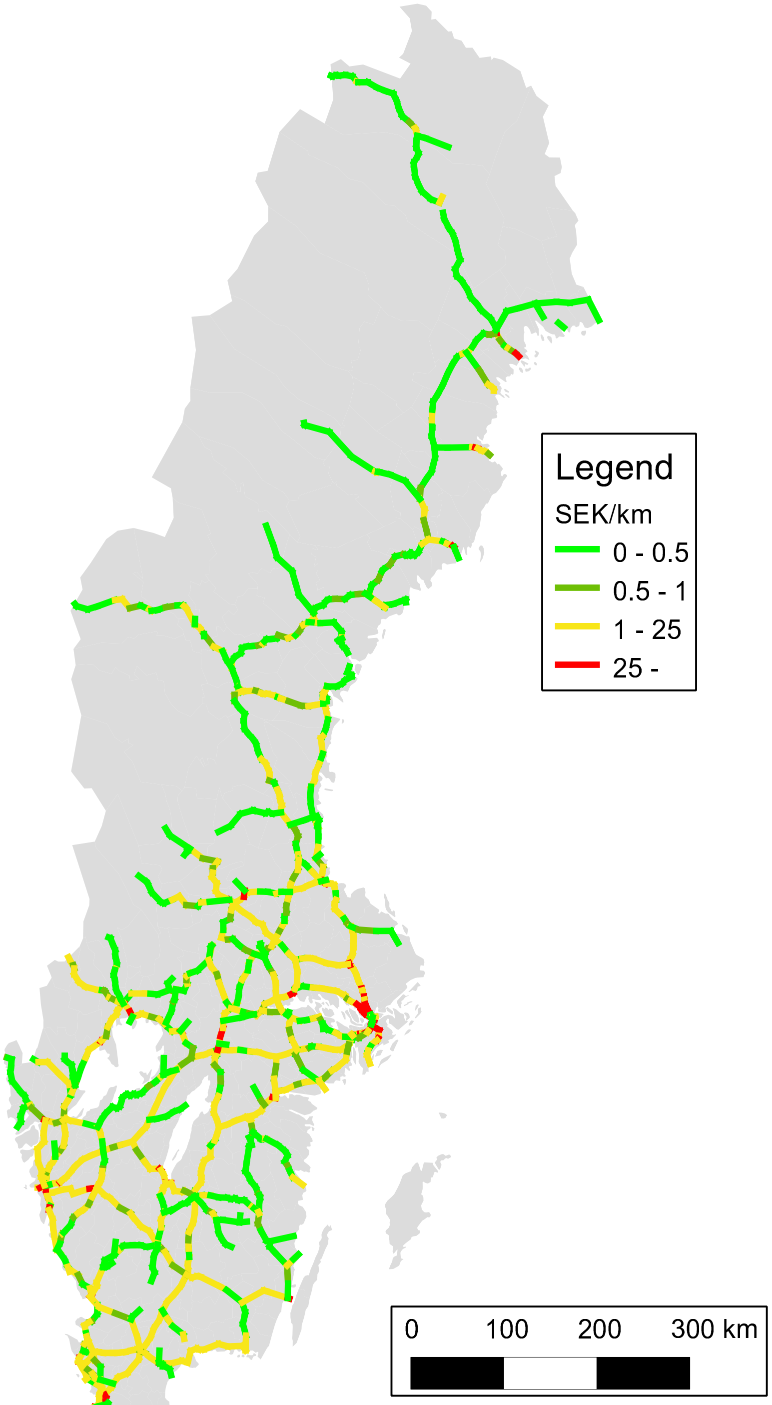

Figure 3: Map showing calculated marginal cost per km for the reference train (freight, 500 m, 90 km/h).

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