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Determination of total road traffic noise annoyance

Summary of the PhD thesis

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Contents

1. Introduction

The increase in mobility, the spread of car ownership the increase of road use can be observed. In Hungary, in the past half century the vehicle stock reached the 3 million item, which uses at daily basis the Hungarian road network therefore contributes to the environmental pollution (Fenyős, 2001a,b, 2002a). The car ownership per capita almost doubled between 1995 and 2010 (Eurostat2011), which is far behind the EU average (Eurostat, 2011). The dramatically expansion of car ownership, the rate of urbanization, the 21st century's mobility behavior leaded today that noise pollution level in mostly all cities reached the unacceptable level (Fenyős, 2002c). Nearly 60% of European population lives in urban area consequently it is understandable that the problem of road traffic noise emission is causing much more concern (Fenyős, 2002b).

2. The aim of the study, background

The concept of noise is well-known. It can we often heard that people are complaining about the noisy streets, the neighbor's lawn mower. the children scream. It is probably less known that noise is based on subjective annoyance which is influenced much more factors than the source itself. Noise is an unwanted, annoying or unpleasant sound. Noise annoyance is the response to the noise level of a person exposed to the noise. Noise pollution can cause trouble, hypertension, high stress levels, hearing loss, and other harmful effects. People being exposed to high noise level become aggressive, cardiovascular and heart disease are more frequent, a decrease of concentration is noticed.

Many research work deals with the measurement of noise emission level, the active and passive protection against noise (Fenyős, 2003; Hunyadi, 2009). However less scientist are dealing with the topic of annoyance, the subjective response to noise level of an individual. During the state of the art period it was realized the complexity and the lack in the traffic noise annoyance topic(Fenyős, 2004). The basis of psychoacoustics was founded by Schultz (1978), Kryter (1982), Fidell és Barber (1991) and Miedema és Oudshoorn (2001). The exact calculation of the annoyance is problematic.

Due to its lack the assessment of noise complaints, the localization of the intervention area can be hardly defined. The state of the art showed that road traffic noise annoyance system can be describe by the combination of three distinguished factors: the emission noise level (=objective annoyance), the subjective and the visual annoyance. The aim of the dissertation was to elaborate a calculation method which contributes to the quantification and qualification of the road traffic noise annoyance. Calculating the weight of the system components. may help road operators to identify tools for the increase of population well-being. The level of service used as the qualitative measures for characterizing road operational conditions can be enlarge to road traffic noise annoyance

3. The basic concept of psychoacoustics

Schultz was the first who dealt with the theme of psychoacoustics related to transportation noise. The Schultz curve includes the results of several noise annoyance surveys and elaborated a dosage-effect relationship, the rate of highly annoyed (%HA) Schultz (1978). Schultz defined the concept of rate of highly annoyed as the upper 27-29% cut off of the annoyance dose-response curve, the later so-called Schultz curve. Moreover he stated that when the noise level is less than 45 dB(A) there is no perceptible annoyance. Kryter (1982) launched an intense discussion on Schultz's findings and he proposed to take into account not only the upper cut-off of the dose-response curve but all the annoyance categories, from not at all annoying to extremely annoying. According to that idea he scaled the dose-response curve into five equal parts, from the highly annoyed to the not annoyed at all categories. Kryter (1982), Schultz (1978) and Grandjean (1973) found that aviation noise is the most annoying from all transportation noise. Therefore Kryter suggested that separating transportation noise into ground traffic and air traffic, which was evidenced by Grandjean research, saying that aviation noise cannot be compared due its singularity to ground transportation noise. Fidell és Barber (1991) extended the original Schultz curve with some additional data sets and elaborated a new dose-response relationship. Subsequently, Finegold et al. (1994) reviewed Schultz (1978) and Fidell és Barber (1991) work and updated them with a logarithmic relationship between the transportation noise level and the annoyance rate (Fig. 1).

Miedema és Oudshoorn (2001) argued for three separate quadratic functions

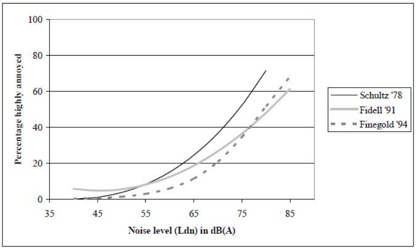

Figure 1: Exposure-effect-relationships for the relation between noise exposure and annoyance derived by Schultz (1978), Fidell és Barber (1991) and Finegold et al. (1994) (Kempen et al., 2005)

to fit data from rail, road, and air traffic in place of a single generalized function for all transportation noise (Fig. 2). Figure 2 represent the annoyance curves, %HA[1], %A[2] and %LA[3] respectively from the lower to the upper curve.

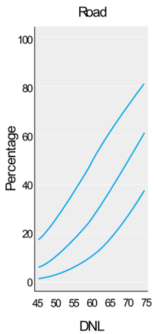

Figure 2: The estimated curves related to road traffic noise annoyance (Miedema és Oudshoorn, 2001)

4. Research methodology

For the characterization of road traffic noise annoyance three types of measurements are necessary:

[1]%HA= "highly annoyed”
[2]%A= “annoyed”
[3]%LA= “little annoyed”

- road traffic noise emission level measurement,
- road traffic counts,
- public survey.

Measurement sites were chosen inner Budapest for the above mentioned three measurements. In all sites the road pavement was in a very good or good condition as the goal was not the determination of the surplus of noise emission level due to deteriorated pavement but the annoyance itself. Measurement sites were chosen according to some predetermined criteria:

1. urban tissue: residential area, downtown area, mixed or spacious built-up area,
2. traffic flow (100-90000 PCE),
3. green area: yes or no,
4. percentage of heavy vehicles (0-25%),
5. very good or good pavement conditions,
6. number of traffic lanes (1-6).

Traffic flow was recorded by using a video camera. The traffic flow count was adjusted to the traffic noise emission level measurement with an interval of 10 s time period. The 10 s time period is a relatively short period so the bypass of one vehicle can be easily distinguished and isolated. All noise event was extracted from the noise emission level series which are crucial for the self reported annoyance but sound effects are not representing the everyday traffic conditions (Hunyadi, 2005). Traffic flow count was done with the help of a traffic flow count aided program elaborated especially for the need of the current research work. In parallel to the road traffic noise emission level measurement and traffic flow count public survey was carried out at the same sites (Hunyadi, 2014c).

Different questionnaires were elaborated for the survey, one for those living in the investigated area, the other for those working there. This distinction was necessary because of the fact that the expected noise event differs by sites, thus the questionnaire was different (Muntág, 2008). Three group of questions were in the questionnaire, type A related to the person (age, gender, level of education, toleration level of noise, etc.), type B1 related to home place (size, location, number of windows, etc.) and type B2 related to work place (working hours, noisiness of area, etc.) (Hunyadi, 2006). Based on the person-specific data pairs of individuals were formed. A pair of individual was formed by one person having its home place and another having its workplace near the investigated area and they have the same person-specific characters. Forming pair of individual allowed to cover the whole day, so self-reported annoyance was given for the 24h. It was supposed that every person filled out the questionnaire were in good health condition. Having approximately 1500 returned questionnaires leaded to have 40 pair of individuals. Public survey uses different annoyance scales which conducted to the elaboration to a standardized answer scale done by the working group of ICBEN[4], in 1993 (Fields, 2001).

The percentage of highly annoyed used in the present dissertation is only taking account those reported the worst score, so on a 5-point numeric scale the score 5 or in a 5-point verbal scale the extremely annoyed score. In the Hungarian school institution system marks are used on a 5-point scale, therefore the self reported annoyance was done with a great safety (Hunyadi, 2007).

4.1. Measurement results

Measurement results was treated based on standards, directive in force. Figure 3 shows the result of the survey related to the question "How do you rate the different environmental pollution factors?". It can be seen that from all pollutant elements noise emission is rated the most annoying using a 5-point numeric scale.

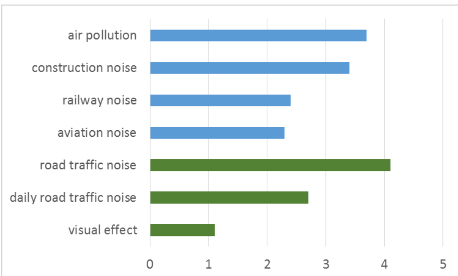

Figure 3: Annoying rate of environmental factors based on the survey (blue=related to road traffic noise annoyance data, green=other data)

[4]ICBEN = International Commission on the Biological Effects of Noise

All other research results are describe in details in the PhD thesis.

5. Scientific results

New scientific results detailed in the thesis are summarized below.

5.1. 1st result

A flow chart model (Figure 4) was established to the road traffic noise annoyance. A newly used method was elaborated for the harmonized road traffic count and road traffic noise emission level measurement, in inner Budapest.

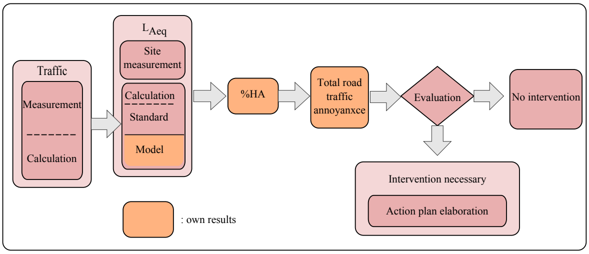

Figure 4: Flow chart model of road traffic noise annoyance

- Measurement sites were chosen according to some predetermined criteria: 1) urban tissue: residential area, downtown area, mixed or spacious built-up area, 2) traffic flow (100-90000 PCE), 3) green area: yes or no, 4) percentage of heavy vehicles (0-25%), 5) very good or good pavement conditions, 6) number of traffic lanes (1-6).
- Questionnaires were elaborated and adapted to the measurement sites, even for the workplaces and for the homes.
- The harmonized measurement method was elaborated.
- Measurement was made during 2 hours and intervals were 10 s. Traffic flow was recorded by a video camera and traffic count was realized separately with the help of a traffic count aided program.

Publication related to the new result: Hunyadi (2006), Hunyadi (2014c)

5.2. 2nd result

During the state of the art period a new approach of the total road traffic noise annoyance system was found and based on the different research work a meta analysis was made.

- It was found that the environment, the person and the traffic forms all together the road traffic annoyance system. For that the objective-, the subjective- and the visual annoyance notions were described (Figure 5).

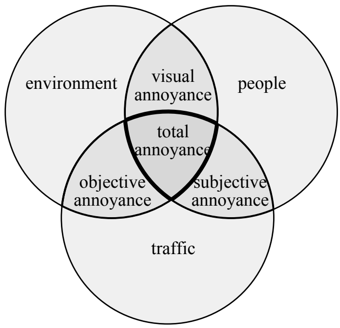

Figure 5: The schematic diagram of the total road traffic noise annoyance model

- The schematic diagram of the total road traffic noise annoyance model. Subjective noise annoyance is the subjective response of a person exposed to the road traffic noise. Visual annoyance is caused by the perception of road infrastructure. Objective noise annoyance is the relationship between the road traffic and the environment. Road traffic noise annoyance is the response of a person due to it.
- Annoyance scale is rated between 0% and 100%.
- The rate of highly annoyed ($\%HA$) is given by

$$\%HA = 50 + \frac{100}{\pi} \arctan[A(x - B)][\%] \quad (1)$$

where x represents the noise level expressed in dB(A), $A = 0{,}0944 \frac{1}{\text{dB(A)}}$ and $B = 75{,}6$ dB(A). The correlation coefficient $r^2 = 0{,}9312$. The Equation 1 is based on the literature data. The monotonic aspect of the function is aligned with the properties of annoyance.

Publication related to the new result: Hunyadi (2013b)

5.3. 3rd result

- The difference between the shape of the two graphs (literature data and measurement data) proofs the need of the necessity of a new calculation model and that annoyance rate is a geographically specific factor. A new model was developed for the total road traffic noise annoyance based on literature and measurement data.
- These difference highlights that factors of the annoyance system are locally specific data. Based on the measurement series it was observed that annoyance depends the traffic volume. Therefore it is suggested to divide into three intervals 1) under 3000 PCE 2) between 3000-40000 PCE and 3) over 40000PCE which are respectively conformed to "rare", "normal" and "dense" flow conditions.
- The new noise level prediction model
$$L_{Aeq} = 9{,}48 \log Q + 41{,}5 [dB] \tag{2}$$
where Q is the traffic volume [Ej/h], $r^2 = 0{,}5516$.
- $\%HA$ is given by Equation 3 as
$$\%HA = 50 + \frac{100}{\pi} \arctan[A(x - B)][\%] \tag{3}$$
where x represents the noise level expressed in dB(A), $A = 0{,}0985 \frac{1}{\text{dB(A)}}$ és $B = 77{,}8$ dB(A) and $r^2 = 0{,}4055$.
- The total road traffic noise annoyance is given by Equation 4
$$\bar{\Psi}_{total} = \Psi_{subj} \cdot z_{subj} + \Psi_{vis} \cdot z_{vis} + \Psi_{obj} \cdot z_{obj}, \tag{4}$$
where $\bar{\Psi}_{total}$ is the expected level of total road traffic noise annoyance, Ψ_{subj} is the subjective annoyance, z_{subj} is the weight of subjective annoyance, Ψ_{vis} is the visual annoyance, z_{vis} the weight of visual annoyance, Ψ_{obj} is the objective annoyance and z_{obj} the weight of objective annoyance. For the beforehand enumerated coefficients:
  - $\Psi_{subj} = \frac{\%HA}{100} \cdot \frac{\%HA_{LAeq,max}}{\%HA_{LAeq,min}}$, where $\%HA$ is the rate of annoyance , $\%HA_{LAeq,min}$ is the rate of annoyance at 45 dB and $\%HA_{LAeq,max}$ the rate of annoyance at 85 dB, $z_{subj} = 0{,}44$.

– $\Psi_{obj} = 0{,}5574 \log Q + 2{,}4$, where Q is the traffic volume [PCE/h]. $z_{obj} = 0{,}38$.

Ψ_{viz}	Traffic [PCE/day]
1	0-3000
2	3001-8500
3	8501-29000
4	29001-86000
5	86000-

Table 1: The value of Ψ_{viz}, $z_{viz} = 0{,}18$

- Evaluation system:

$\bar{\Psi}_{total}$	evaluation	
	verbal	numeric
0	no annoyance	0
1	at all	1
2	slightly	2
3	moderately	3
4	very	4
5	extremely	5
5+	unacceptable	5+

Table 2: The evaluation scale related to the total road traffic noise annoyance

Publication related to the new result: Hunyadi (2014d), Hunyadi (2013a), Hunyadi (2014b)

5.4. 4th result

A new evaluation model is given for the extended level of service to road traffic noise annoyance. Based on the result of present research work and the HCM recommendation traffic volume is determined, respectively A1, A2, B1, B2, C1. The extended level of service to road traffic noise annoyance is described as the level of service of the infrastructure resulting a given annoyance level. The Figure 6 shows the function of the running speed, the level of service and the cross sectional traffic volume. Figure 6 is the graphical abstraction of the data given in Table 3.

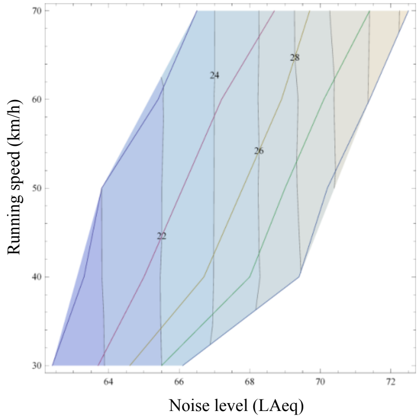

Figure 6: Road traffic noise annoyance based on the level of service of urban one way cross sectional road

LOS	30 km/h		40 km/h		50 km/h		60 km/h		70 km/h	
	$\Psi_{t.}$	%HA	$\Psi_{t.}$	%HA	$\Psi_{t.}$	%HA	$\Psi_{t.}$	%HA	$\Psi_{t.}$	%HA
A1	2,1	16,9	2,2	18,3	2,2	18,8	2,2	19,5	2,3	20,4
A2	2,2	19,5	2,3	21,3	2,4	22,1	2,4	23,0	2,5	24,1
B1	2,3	20,4	2,4	22,1	2,4	23,1	2,5	24,7	2,5	25,4
B2	2,3	21,5	2,4	23,1	2,5	24,7	2,5	25,8	2,6	27,1
C1	2,4	23,4	2,5	25,3	2,6	27,1	2,6	28,4	2,7	29,0

Table 3: Total road traffic noise annoyance in function of running speed and the extended level of service ($\bar{\Psi}_{t.}$=$\bar{\Psi}_{total}$)

Publication related to the new result: Hunyadi (2014a)

6. Outlook of the research

The total road traffic noise annoyance calculation method described previously gives help to noise professionals. It can be implemented for the evaluation of urban road traffic noise effects on human. Population noise complaints can be easily and explicitly be treated. City planners have a tool to design sustainable and viable surroundings. The new model gives the opportunity to identify areas with high rate of annoyance and after the necessary intervention an easy and quick check can be done, if it brought the expected benefits or not.

The results of present dissertation work can be the improvement of current standards, guidelines or directives related to road traffic noise thus the annoyance factor could be taking into account. Designers or decision makers will have a tool to choose the best intervention method for giving our cities less noisy. The external costs of road infrastructure could be extended with the social impact of road traffic noise annoyance.

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