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APPROACH TO THE ESTIMATION OF ROAD
TRANSPORT EXTERNAL COSTS – NOISE COSTS

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Abstract: Means of transportation could make positive and also negative influence on human
existence and on global ecosystem as well. Good way to minimize the negative influences of transport
could be to operate according to the idea of sustainable transport. In this research work are presented
the results of noise and traffic measurements that were taken on the road S69 at the chosen places
near the Zwardoń town. Also, in this work is discussed the target of this measurements and selection
of the road section in the context to the road transport external costs. And, are shown the results of
calculations of the correlation coefficient between level of noise and level of traffic according to
algorithm (that also is presented) of estimation of road transport external costs related with noise.

Keywords: external costs, noise, traffic.

1. INTRODUCTION

At the beginning of XX century the mass production of the cars had started and it was
the first step of the revolution in transport technique. Simultaneously it caused necessity to
improve road infrastructure for transport production and also for quality of movement. In
the last decade of XX century, human activity has extremely increased [1].

Transport contributes significantly to economic growth and enables a global market. Unfortunately, most forms of transport do not only affect society in a positive way but also
give rise to side effects. Road vehicle for example contributes to congestion [2], air
pollution and noise as well. In contrast to the benefits, the costs of these effects of transport
are generally not borne by the transport users and hence not taken into account when they
make a transport decision. Therefore these effects are labeled as external effects. Important
effects of external costs of transport are noise, congestion and air pollution.

Generally it can be said that that the External costs are costs to society and without
policy intervention they are not taken into account by the transport users. Transport users
are thus faced with incorrect incentives for transport supply and demand,
leading to welfare losses [2]. Also it can be said that transport users should pay the whole social cost (reflecting all costs occurring due to the provision and the use of transport infrastructure, such as wear and tear costs of infrastructure, capital costs, congestion cost, accidents costs, environmental costs) which occur due to transport activity [2].

So, the external costs, especially the road transport costs, should be taken into huge consideration and it can be done by internalization of external costs.

2. INTERNALIZATION OF THE EXTERNAL COSTS IN TRANSPORT

Internalization of the effects that are mentioned in the introduction means making such effects part of the decision making process of transport users. This can be done directly through regulation, i.e. command and control measures, or indirect through providing better incentives to transport users, namely with market-based instruments (e.g. taxes, charges, emission trading). Combinations of these basic types are possible: for example, existing taxes and charges may be differentiated [2].

Estimation and internalization of external costs of transport have been important issues for European Commission has raised the issue of internalization in several strategy papers, such as the Green Book on fair and efficient pricing (1995), the White Paper on efficient use of Infrastructure, the European Transport Policy 2010 (2001) and the it’s midterm review of 2006. Following a number of research projects, the approaches of the Commission are based on the economic theoretical concepts of marginal social cost pricing. The EC White book of the overall transport strategy (Time to decide, 2001) and the midterm review (Keep Europe moving, 2006) underline the need of fair and efficient pricing considering external costs [2] especially of the road transport. For the road sector, in the amendment of Directive 1999/62/EC (Eurovignette Directive) on road charges, adopted on 27 March 2006, the European Union allows Member States to levy tolls on all road. This Directive is a significant step towards the implementation of a European road charging policy [2], [3], [4]. One constraint of the current Directive is the requirement that ravenous may not exceed related Infrastructure costs. The Directive only allows limited differentiation of charges according to capacity or environmental criteria. Only for mountainous areas, a mark up (up to 25%) is possible, considering the higher level of infrastructure costs [4].

Thus, it is certain that easy tool of internalization is highly needed – it allows identification exactly in which places (roads) the additional payment is necessary to be paid in an honest way. Also, it can show what are the real costs of road transport which could enable making the decision of what other types of transport could be used e.g. rail and air transport.

An example of a tool for the estimation of the external costs concerning noise are presented below.
3. NOISE AS THE ELEMENT OF ROAD TRANSPORT EXTERNAL COSTS

Noise costs consist of costs for annoyance and health. Noise can be defined as the unwanted sounds of duration, intensity, or other quality that causes physiological or psychological harm to humans. In general, two types of negative impacts of transport noise can be distinguished:

- **Costs of annoyance:** transport noise imposes undesired social disturbances, which results in social and economic costs like any restrictions on enjoyment of desired leisure activities, discomfort or inconvenience (pain, suffering), etc.
- **Health costs:** transport noise can also cause physical health damages. Hearing damages can be caused by noise levels above 85 dB(A), while lower levels above 60 dB(A) may result in nervous stress reactions, such as change of heart beat frequency, increase of blood pressure and hormonal changes[4].
- In Tab.1 the acceptable level of noise (from the road transport) on a different kinds of terrain according to the Polish law can be seen. In addition, noise exposure increases the risk of cardiovascular diseases (heart and blood circulation). Finally, transport noise can result in a decrease of subjective sleep quality.

The negative impacts of noise on human health result in various types of costs, like medical costs, costs of productivity loss, and the costs of increased mortality.

The basis measurement index for noise is the decibel (dB). This index has a logarithmic scale, reflecting the logarithmic manner the human ear responds to sounds pressure (1). Since the human ear is also more sensitive at some frequencies than at others, a frequency weighting is applied to measurement and calculations. The most common frequency weighting is the ‘A weighting’, hence the use of dB (A).

The logarithmic nature of noise is also reflected in the relationship between noise and traffic volume. By halving or doubling the amount of traffic the noise level will be changed by 3 dB, irrespective of the existing flow. This means that an increase of traffic volume from 50 to 100 vehicles per hour will result in the same increase in the noise level (3 dB) as a doubling of the transport volume from 500 to 1000 vehicles per hour.

Due to the logarithmic nature of the relationship between noise and traffic volume, marginal noise costs are extremely sensitive to existing traffic flows or more general to existing (background) noise. Marginal noise costs are defined as the additional costs of noise caused by adding one vehicle to the existing traffic flow. If the existing traffic levels are already high, adding one extra vehicle to the traffic result in almost no increase in the existing noise level. Due to this decreasing cost function marginal noise costs can fall below average costs for medium to high traffic volumes. On the other hand, in road traffic they may in some cases exceed average costs since road traffic leads frequently through densely populated areas and the alternation of traffic loads over day vary considerably between the modes [4].

In the next chapter, a proposition of estimation of external noise costs using algorithm is presented on the fig.1. After presentation of the algorithm the short description of every block is shown.
4. ALGORITHM OF ESTIMATION OF THE EXTERNAL COSTS OF NOISE TRANSPORT

Fig. 1. Flow diagram of noise cost estimation

Data and short description for the algorithm of estimation of road transport external noise costs are:
4.1. Block 1

- distance between measurement point and the source of noise, in meters.
- middle level of noise according to formula:

\[
L_m = 10 \log\sum_{i=1}^{n} 10^{0.010L_i}
\]

where:
- \(L_i\) - level of noise in exact point in a place of measurement.
- acceptable level of noise (from the road transport) on a different kinds of terrain according to the Polish law (Tab. 1) - \(L_{max}\),
- data that consider information about valuation of exceeding the maximum level of acceptable level of noise. Usage of methods WTP (the willingness to pay) and WTA (the willingness to accept) – WTPA (WTP + WTA),
- information about distance between family dwellings and the source of noise in meters.

4.2. Block 2 and Block 3

– the distance between measurement point and the source of noise is being checked,

4.3. Block 4

– checking if the correlation between level of noise and number of cars exist (using the multiple correlation coefficient \(R^2\)) , according to the formula:

\[
R = \frac{\sum_{i=1}^{n} x_i y_i - \bar{x} \bar{y}}{\sqrt{\sum_{i=1}^{n} \left( x_i - \bar{x} \right)^2 \left( y_i - \bar{y} \right)^2}}
\]

\[
\bar{x} = \sum_{i=1}^{n} \frac{x_i}{n} ; \quad \bar{y} = \sum_{i=1}^{n} \frac{y_i}{n}
\]

Where: \(x_i\) - data: level of noise; \(y_i\) - data: number of cars; \(n\) – numbers of observations

Critical value for correlation coefficient for level of relevance \(\alpha = 0.95\) is \(r_{c} = 0.184\) [5].

To count multiple correlation coefficient \(R^2\) the Microsoft Office tools has been used (Tab2).

4.4. Block 5
– checking if the level of measured noise level $L_m$ is higher or equal to the acceptable level of noise $L_{\text{max}}$.

4.5. Block 6

– the difference $p_L$ between $L_{\text{max}}$ and $L_m$ is being counted.

4.6. Block 7

– estimation of costs of noise ($K_{CH}$) using methods WTPA (WTP + WTA) - more of this methods is written below in the next section.

4.7. Block 8

– estimation of road transport external noise cost ($K_{WTH}$) counted for a number of people living ($\sum Os$) in the range of noise of traffic.

Tab. 1. Acceptable level of noise

<table>
<thead>
<tr>
<th>No.</th>
<th>Kinds of areas</th>
<th>Acceptable level of noise (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$L_{\text{AeqD}}$ (16 hours)</td>
</tr>
<tr>
<td>1.</td>
<td>a) safe zone “A” health – resort,</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>b) area of hospitals which are not placed in the cities,</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>a) single family dwelling area,</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>b) area with still or temporary presence of youth,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>c) area of houses of the welfare care,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>d) area of hospitals which are placed in the cities,</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>a) multiply family dwelling area,</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>b) croft area,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>c) recreation and rest area,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>d) living and services area,</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Terrains in the city that has more than 100 000 inhabitants.</td>
<td>65</td>
</tr>
</tbody>
</table>

Source: [6].
5. WTP AND WTA (WTPA) METHODS – CHOICE MODELLING TECHNIQUES

In economics, the willingness to pay (WTP) is the maximum amount a person would be willing to pay, sacrifice or exchange for a good. Several methods have been developed to measure consumer willingness to pay. These methods can be differentiated whether they measure consumer hypothetical or actual willingness to pay and whether they measure consumer willingness to pay directly or indirectly [7].

Willingness to Accept (WTA) is the amount that a person is willing to accept to abandon a good. It is the minimum monetary amount required for purchase to be accepted by an individual. This term stands in contrast to Willingness to Pay (WTP), which is the maximum amount an individual is willing to sacrifice to procure a good. The Price of any transaction will thus be any point between a buyer's Willingness to Pay and a seller's Willingness to Accept. The net difference between WTP and WTA is the social surplus created by the trading of goods [8].

WTP and WTA are important factors for public policy. Many economic decisions are based upon the implicit assignment of property rights. When looking at a lake which is being polluted by a nearby factory, the WTA and WTP for treatment of an effluent treatment plant may have different consequences based upon how property rights are politically assigned. If lakeside residents have no property right to an effluent-free lake, then their WTP to treat the lake's water supply would be considered. Likewise, if the lakeside residents are found to have a property right to a clean lake, then their WTA compensation for a polluted lake would be considered [8].

Choice modeling attempts to model the decision process of an individual or segment in a particular context. Choice modeling may also be used to estimate non-market environmental benefits and costs. Choice models are able to predict with great accuracy how individuals would react in a particular situation. Unlike a poll or a survey, predictions are able to be made over large numbers of scenarios within a context, to the order of many trillions of possible scenarios. Choice modeling is believed to be the most accurate and general purpose tool currently available for making probabilistic predictions about human decision making behavior. In addition Choice modeling is [regarded] as the most suitable method for estimating consumers’ willingness to pay for quality improvements in multiple dimensions. The Choice experiment itself may be performed via hard copy with pen and paper, however increasingly the on-line medium is being used as it has many advantages over the manual process, including cost, speed, accuracy and ability to perform more complex studies such as those involving multimedia or dynamic feedback. Despite the power and general applicability of choice modeling, the practical execution is far more complex that running a general survey. The model itself is a delicate tool and potential sources of bias that are ignored in general market research surveys need to be controlled for in choice models. A side benefit of correcting for these biases is generally a smaller sample size than would be required for a simple survey [9]. In the near future the research concerning the external costs will be held using web page:
6. NOISE AND TRAFFIC MEASUREMENTS – DESCRIPTION OF THE ROAD

The noise and traffic measurements have been taken at the part of the express road S69 near the Zwardoń city.

Existing part of the roadway that measurements have been taken on has the length of 1350 m, and connects with country road no. 69 from km 46 + 200 with Polish – Slovakian border in km 47 + 550 and is connected with the Slovakian roadway relation Skalite – Żylna. Analyzed part of the roadway is localized in Silesian region in commune of Miłówka and Rajceza. The road is localized in highland region with huge tourist activity. In the future, the chosen S69 road could become a substitute roadway to the S1 express road, as A1 highway will be connected to Slovakian roadway system, especially leading south, for example to Vienna.

The parameters of this road are as it follows:

- Width of the road is changing and is presented below:
  - 3 lines with mutually band of 0,5 m, roadway 10,0 m. (direction from Slovakian border to Poland)
  - 2 lines of 3,5 m each with 1 accident line of 2,5 m,
  - bands of 0,5 m,
  - roadway 10,0 m.
  - from km 46 + 560 to km 46 + 705:
    - roadway from right chock expends from 20,0 m to 30,0 m,
    - left roadway – opposite.
  - rest of the roadway to the direction to Slovakian border has:
    - 2 lines of width of 7,0 m with 1 accident line of 2,5 m and band of 0,5 m.
    - full width of roadway is 10,0 m.
  - left roadway from the Slovakian border from km 47 + 558,3 to km 47 + 550 has:
    - 3 lines of 3,0 m,
    - mutual band of 0,5 m,
    - full width of roadway is 10,0 m.
    - express road has:
      - from km 46 + 200 to km 46 + 320 has roadway section,
      - from km 46 + 320 to km 46 + 890 has street with curb section,
      - from km 46 + 890 to km 47 + 550 has roadway section,
  - divining line has 5,0 m.
- Speed limit is 80 km/h and 50 km/h.
7. NOISE AND TRAFFIC MEASUREMENTS – THE RESULTS

They were 14 measurement points that have been chosen for noise and traffic measurements. The idea behind it was to establish a place where the measure point is placed just before the first line of family dwellings. Chosen points are the nearest as they could be from the S69 express roadway. In tab. 2 it is shown, where the points were established, what was the noise and traffic level measured in specific point, and what is the correlation coefficient between level of noise and volume of traffic. Measurements were taken according to the regulations [10]. The average noise level is not divided into day and night time. Numbers of vehicles are not divided into the types of vehicles.

<table>
<thead>
<tr>
<th>No.</th>
<th>Side of the road</th>
<th>Distance from the road (m)</th>
<th>Average noise level (dB)</th>
<th>Numbers of cars (24 h)</th>
<th>Correlation $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>RIGHT</td>
<td>99</td>
<td>46.8</td>
<td>1179</td>
<td>0.67</td>
</tr>
<tr>
<td>2</td>
<td>RIGHT</td>
<td>52</td>
<td>56.6</td>
<td>1125</td>
<td>0.55</td>
</tr>
<tr>
<td>3</td>
<td>RIGHT</td>
<td>73</td>
<td>45.8</td>
<td>1125</td>
<td>0.64</td>
</tr>
<tr>
<td>4</td>
<td>RIGHT</td>
<td>25</td>
<td>50.6</td>
<td>1180</td>
<td>0.66</td>
</tr>
<tr>
<td>5</td>
<td>RIGHT</td>
<td>104</td>
<td>51.7</td>
<td>1095</td>
<td>0.32</td>
</tr>
<tr>
<td>6</td>
<td>RIGHT</td>
<td>134</td>
<td>45.7</td>
<td>1095</td>
<td>0.48</td>
</tr>
<tr>
<td>7</td>
<td>LEFT</td>
<td>57</td>
<td>53.6</td>
<td>1187</td>
<td>0.15</td>
</tr>
<tr>
<td>8</td>
<td>LEFT</td>
<td>57</td>
<td>53.5</td>
<td>991</td>
<td>0.27</td>
</tr>
<tr>
<td>9</td>
<td>LEFT</td>
<td>56</td>
<td>45.1</td>
<td>991</td>
<td>0.72</td>
</tr>
<tr>
<td>10</td>
<td>RIGHT</td>
<td>99</td>
<td>45.4</td>
<td>1140</td>
<td>0.31</td>
</tr>
<tr>
<td>11</td>
<td>RIGHT</td>
<td>114</td>
<td>45.1</td>
<td>1146</td>
<td>0.61</td>
</tr>
<tr>
<td>12</td>
<td>RIGHT</td>
<td>109</td>
<td>45.7</td>
<td>1146</td>
<td>0.56</td>
</tr>
<tr>
<td>13</td>
<td>RIGHT</td>
<td>90</td>
<td>49.3</td>
<td>1179</td>
<td>0.59</td>
</tr>
<tr>
<td>14</td>
<td>RIGHT</td>
<td>130</td>
<td>48.3</td>
<td>1604</td>
<td>0.03</td>
</tr>
</tbody>
</table>

8. SUMMARY

Analyzing the results from tab. 2 it is possible to conclude that right now the number of cars that move along S69 roadway is not big enough, but it is highly possible that the number of cars will rapidly rise because of S69 road construction coming to an end, from Żywicel City to the border, as now only few parts are finished. The same situation is on the Slovakian side, because they are also in the process of construction of the express roadway. And now it can be seen that the measured noise level is close to the acceptable level of noise. Only 2 measurement points will not be taken into the consideration, because of the correlation coefficient between level of noise and numbers of traffic on fig. 2 and fig. 3 as an example is shown the disproportion between level of noise and numbers of vehicles on measure point 14 (tab.2). On fig. 4 and fig.5 as well as on fig. 6 and fig. 7 it is
shown as the example the correlation between level of noise and numbers of vehicles on measure point 1 and 9.

Next measurements will take place on S69 road when it will be fully operating, or at least in huge percentage completed. And additionally, using presented algorithm to calculate external costs of noise transport costs it will be possible to estimate that costs in easy way.

![Fig.2. Level of noise – measure point 14](source)

Source: own work.

![Fig.3. Numbers of vehicles – measure point 14](source)
Fig. 4. Level of noise – measure point 1

Fig. 5. Numbers of vehicles – measure point 1

Fig. 6. Level of noise – measure point 9
Fig. 7. Numbers of vehicles – measure point 9

Literature


WSTĘP DO ESTYMACJI ZEWNĘTRZNYCH KOSZTÓW TRANSPORTU SAMOCHODOWEGO – KOSZTY HAŁASU

Streszczenie: Transport w sposób pozytywny jak i negatywny wpływa na egzystencję człowieka, jak i na cały ekosystem. Sposobem na minimalizację wpływów negatywnych generowanych przez transport są działania zgodne z ideą zrównoważonego rozwoju. W pracy przedstawiono wyniki pomiarów poziomu hałasu oraz liczby pojazdów, które zostały wykonane na wybranym odcinku trasy ekspresowej S69 w okolicach miejscowości Zwardoń. Przedstawiono także cel tych pomiarów oraz dobór odcinka do przeprowadzenia pomiarów w kontekście zewnętrznych kosztów transportu samochodowego. W końcu
części artykułu przedstawiono obliczenia współczynnika korelacji pomiędzy natężeniem dźwięku a wielkością przejeżdżających pojazdów zgodnie z zaproponowanym algorytmem do estymacji zewnętrznych kosztów transportu samochodowego związanych z emisją hałasu.

Słowa kluczowe: koszty zewnętrzne, hałas, ruch samochodowy.

Recenzent: Sylwester Markusik