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Research article

Social choice functions: A tool for ranking variables involved in action plans against road noise

Alejandro Ruiz-Padillo [a,*], Thiago B.F. de Oliveira [b], Matheus Alves [b], Ana L.C. Bazzan [b], Diego P. Ruiz [c]

[a] Industrial Engineering and Transportation Department, Federal University of Rio Grande do Sul (UFRGS), Av. Osvaldo Aranha, 99, 5°andar, Porto Alegre CEP 90.035-190, Rio Grande do Sul, Brazil
[b] Instituto de Informática, Universidade Federal do Rio Grande do Sul (UFRGS), Caixa Postal 15064, CEP91.501-970 Porto Alegre, Rio Grande do Sul, Brazil
[c] Information Technology and Communication Research Center (CITIC-UGR), Applied Physics Department, Faculty of Sciences, University of Granada, Spain

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ABSTRACT

Traffic noise is gaining importance in planning and operation of roads in developing countries, and particularly in Europe and Latin America. Many variables with different degrees of importance influence the perception of noise from roads. Thus, the problem of prioritizing road stretches for action against such noise is an important issue in environmental noise management. For example, it can be addressed using multicriteria methods. However, these methodologies require criteria or suitable variables to be ranked according to their relative importance. In the present study, for this ranking, a list of nine variables involved in the decision-making process (called "road stretch priority variables") was presented in the form of questionnaires to high-level experts from Andalusia, southern Spain. These experts ranked the variables by relevance. Using the same data, seven social choice functions (Plurality, Raynaud, Kemeny-Young, Copeland, Simpson, Schulze, and Borda) were used in order to rank the variables. The results indicate that the most important variables were those that take into account the parameters of greatest exposure for the citizens, followed by variables related to the intensity of the problem analyzed. The results show that a combination of the use of social choice functions on aggregated information from expert panels can provide a consensus for ranking priority variables related to road stretches.

1. Introduction

In recent years, the density of road networks has rapidly increased in developing and developed countries and design parameters have improved. This development has been accompanied by progressively denser and faster traffic.

The primary objective of road administrations worldwide is a road network that connects different points of a territory, that satisfies transportation needs, and that can be maintained in an adequate state of conservation (Manaugh et al., 2015). However, this approach is significantly changing in developed countries in that users (and, ultimately, society) are beginning to require a high level of quality of the road services, in addition to providing a connecting path between destinations (Ruotolo et al., 2013; Tochtermann, 2001). This increasing demand also involves consequences for the environment (Demirel et al., 2008; Madireddy et al., 2011). Traffic noise is considered one of the major causes of environmental degradation in urban environments (Öhrström et al., 2006; Sato et al., 1999). Road traffic noise must be taken into account as an important factor in the planning of transport and its infrastructure within a global environmental management. Also, large populated areas already exposed to traffic noise need measures to reduce the problem. Therefore, the current legislation in the European Union requires administrations responsible for road networks to study and analyze road stretches that have excessive traffic noise levels affecting nearby populations (European Union, 2002; King et al., 2011). Consequently, the initial step in the formulation of a Noise Action Plan is the identification and sorting of these so-called "hot spots" by priority. This arises as an important issue for environmental managers (Licitra et al., 2011).

In this context, a well-defined decision-making process is

* Corresponding author.
E-mail addresses: aruizp@correo.ugr.es, aleruizpadillo@hotmail.com (A. Ruiz-Padillo), tbfoliveira@inf.ufrgs.br (T.B.F. de Oliveira), matheus.alves@inf.ufrgs.br (M. Alves), bazzan@inf.ufrgs.br (A.L.C. Bazzan), druiz@ugr.es (D.P. Ruiz).

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needed to reach an efficient and well-justified sorting for these problematic road stretches (Cafiso et al., 2002; Chan, 2002; Choocharukul, 2004; Herbsman et al., 1995). As in most decision problems, several criteria are involved in the planning process, requiring a discrete multicriteria analysis. Thus, it is important to adequately assess the variables that take part in the sorting process studied, from the point of view of both noise exposure, and road characteristics and traffic (Filho et al., 2004). However, this process is not obvious, since variables used in sorting road stretches by priority for action have different degrees of importance. Moreover, these are initially unknown to the planners or difficult to define. An important issue thus arises, i.e., establishing the relative influence of the variables to perform an adequate decision-making.

Therefore, in the present study, the opinions of experts were compiled by the expert panel technique (EPT). Numerous studies using EPT can be found in all areas of knowledge, particularly in medicine, psychology, and other social sciences as well as in environmental and engineering fields (Beecham et al., 2005; Carpio et al., 2015; Wang et al., 2008; Mahboubi et al., 2015; Varho et al., 2013; Zhang and Huang, 2011). The use of expert panels enables decisions to be confirmed in the light of existing experience in the topic of study when empirical testing is not feasible. However, the results should maintain objectivity and rigor, making it necessary for the information collected to be submitted to aggregation techniques in order to generate a single decision.

This paper seeks to estimate the order of importance for the variables influencing the decision problem of prioritizing road stretches in a Noise Action Plan and to introduce the results for hot-spot sorting. The main objective is to propose an easy and comprehensive method to rank the variables involved in an automated and consistent manner. In this method, data is gathered from responses of a panel of experts, who selected and compared the relative importance of the variables involved in the problem of prioritizing actions against road traffic noise. For this, several social choice functions (SCF) were applied to the various orderings determined by each expert to establish an average consensus ranking. Therefore, improvements in the decision-making methodology based on these ranked variables (called "road stretch priority variables") can be then proposed. Additionally, a calibration test was achieved in the Spanish context.

The "Road Stretch Priority Variables" (RSPV) were identified in a previous work (Ruiz-Padillo et al., 2014), providing a starting point to the present study. These are briefly presented in Section 2 for the sake of completeness. Then, Section 3 (Methodology) shows both the expert panel technique used to compile the data necessary for the study, and the social choice functions employed in this work. Also, some references and practical indications are given, which related to the implementation of these SCF (programmed in R software and Python library). In Section 4, the results of the methodology used are presented and critically discussed, considering the consistency of the results and the meaning of the variables. Finally, Section 5 highlights the main conclusions drawn in this research, i.e., the possibility of applying SCF with some changes for this problem and the consistency and applicability of the results.

2. Road stretch priority variables

RSPV are variables used by the planners as criteria for prioritizing the road stretches included in a Noise Action Plan. They were determined and defined in Ruiz-Padillo et al. (2014), and are used here with some refinements taking into account the previous experience. These variables are as follows:

- Stretch traffic data: in this category the intensity of vehicles (average daily traffic – *ADT*) and the percentage of heavy vehicles (*%hv*) are considered. In addition to Ruiz-Padillo et al. (2014), the average speed of the vehicles in the stretch (s) is now added, since it also bears influence on the generation and reduction of noise, as is in noise mapping (Naish, 2010; Ouis, 2001).
- Complaints about traffic noise produced in a particular road stretch, if existing, would be covered in the variable E_C (taking on a binary indicator, either "yes" or "no").
- The RSPV noise level of necessary attenuation (ΔL) is obtained from the difference between the existing sound level and the acoustic quality objective, in view of the corresponding noise zoning of the stretch studied under the current legislation (European Union, 2002; King et al., 2011). The noise levels indicators are calculated from the day-evening-night noise indicator weighted for overall annoyance (L_{den}), as in Eq. (1), where L_{day}, $L_{evening}$ and L_{night} are the A-weighted long-term average sound level determined over all the day, evening and night periods of a year, respectively (7:00–19:00, 19:00–23:00 and 23:00–7:00).

$$L_{den} = 10\log\left(\frac{12\cdot 10^{\frac{L_{day}}{10}} + 4\cdot 10^{\frac{L_{evening}+5}{10}} + 8\cdot 10^{\frac{L_{night}+10}{10}}}{24}\right) \tag{1}$$

- Exposed surface (S_{exp}) and exposed population (P_{exp}) to excessive noise level (i.e. sound levels above legislation limits in terms of L_{den} descriptor).
- Noise sensitive centers. In Ruiz-Padillo et al. (2014) this is considered as a binary variable (E_{SC}) taking into account its importance in the acoustic quality objectives for determining noise zoning (European Union, 2002). However, sensitive centers exposed to high levels of noise must be taken into account not only with the regard of its mere existence. Therefore, the formulation of this variable was adapted to count the number of exposed noise sensitive centers (SC_{exp}) just as the previous variables.
- Finally, the existence of anti-noise measures —both previously established and planned— was still considered in the binary variable E_{ANM}.

The nine RSPV are summarized in Table 1.

3. Methodology

An expert panel was generated through surveys, where participants were asked to sort the RSPV by the criterion of the relative importance of each variable in the decision-making problem of sorting road stretches by priority for action against road traffic noise. Because every SCF employs various logic principles and algorithms, a set of SCF was used to reach different ordered lists of the RSPV. Then, they were compared to define a more

Table 1
List of road stretch priority variables.

No.	Road stretch priority variables	
1	ΔL	Noise level of necessary attenuation
2	P_{exp}	Exposed population
3	S_{exp}	Exposed surface
4	*ADT*	Average daily traffic
5	*%hv*	Percentage of heavy vehicles
6	s	Average speed of vehicles
7	E_C	Occurrence of citizens' traffic noise complaints
8	SC_{exp}	Exposed noise-sensitive centers
9	E_{ANM}	Existence of previous measures of acoustic attenuation