Environmental Modelling & Software 81 (2016) 45–55

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

Application of the fuzzy analytic hierarchy process in multi-criteria decision in noise action plans: Prioritizing road stretches

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ARTICLE INFO

Article history:
Received 8 October 2015
Received in revised form
6 February 2016
Accepted 10 March 2016
Available online 24 March 2016

Keywords:
Road traffic noise
Strategic noise maps
Road noise action plans
Multicriteria decision-making
Road stretch variables
Fuzzy analytic hierarchy process

ABSTRACT

Traffic noise is one of the major environmental impacts of road infrastructures. Critical study of published Noise Action Plans (NAP) signals a widespread lack of objective criteria and methodologies for prioritizing actions against noise as well as the suitability of solutions. The present paper develops a methodology to sort, by priority, road stretches included in a NAP. In obtaining and allocating weights to variables involved in the decision-making problem ("Road Stretch Priority Variables") to define a normalized numerical index ("Road Stretch Priority Index"), Fuzzy Analytic Hierarchy Process (FAHP) with two different defuzzification methods is applied to the results of an expert panel. Comparison of the outcomes of both FAHP versions, plus analysis of the results of a case study, enables to determine the relative influence of these variables in the problem. An objective and reasoned methodology for the prioritized classification of road stretches according to noise problems is thereby validated.

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1. Introduction

The road traffic noise exposure problem has intensified in recent years, and stands out over the other environmental and urban noise sources, such us industry, aircraft, railway, or leisure activities. In Europe, initiatives and current legislation respond by providing tools for local Administrations and society as a whole in order to combat this serious adverse effect of road infrastructure on the environment and the health of inhabitants (De Vos, 2009; WHO, 2011; EEA, 2014).

The main objectives of the European Parliament and of The Council of 25 June 2002, on the assessment and management of environmental noise (or "European Environmental Noise Directive") (European Union, 2002) included the evaluation of this problem in the biggest European road infrastructures, assessing the number of exposed people, and mapping sound levels using simulation software and specific noise indicators (De Vos, 2008; Licitra and Ascari, 2014).

The problem appears to be getting out of hand in several European countries. This negative trend can be seen through the data of road traffic noise exposure reflected in the Strategic Noise Maps (SNM) generated in application of the Environmental Noise Directive, and the design and implementation of numerous measures against road traffic noise. The Public Administrations involved have furthermore approved and adopted several measures in their plans for action against noise (EEA, 2014; Mileu et al., 2010). The Noise Action Plans (NAP) published in Spain up to date (available at sicaweb.cedex.es) were analyzed, and a critical review of them served us to confirm a widespread lack of prioritization criteria for pertinent actions, both at the level of management of stretches and suitability of solutions. Moreover, all these NAPs dealt with a narrow spectrum of possible alternatives.

Decision-making concerning the actions included in these NAP as a result of the SNM must take into account several variables and criteria, such us traffic data, noise levels and exposure values, the

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http://dx.doi.org/10.1016/j.envsoft.2016.03.009
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environment characteristics and local constraints (WG-AEN, 2007; Silence project, 2009; De Vos, 2008). These elements are often in conflict and not clearly defined, and may have an impact of diverse intensity or nature (Torija et al., 2010; D'Alessandro and Schiavoni, 2015; Licitra et al., 2011). Moreover, the different methods employed by the Member States in the noise simulation and the estimation of the noise exposure values imply that the reported data are not directly comparable, and action plans may be heavily dependent on these issues (Licitra et al., 2012; D'Alessandro and Schiavoni, 2015). Therefore, in the current engineering panorama, planning processes are highly complex due to such associated uncertainties and their eventual significance (De Vos, 2009; Brown and Elms, 2015).

Moreover, many Member States and researchers have developed different approaches to determine the priority for action against noise among the so-called "hotspots" considering various criteria and procedures (De Vos, 2008; Licitra et al., 2011). Some of these experiences define single or aggregated indicators, that are very useful to technicians and policy makers to understand and express reasoned decisions and comparisons in a more comprehensive way (Licitra and Ascari, 2014; D'Alessandro and Schiavoni, 2015). However, a considerable controversy still exists concerning which the most important principles must be in the noise action planning (De Vos, 2009).

A previous paper (Ruiz-Padillo et al., 2014) presented a preliminary methodology to sort, by priority, road stretches included in a particular NAP. Based on the so-called "road stretch priority index" (*RSPI*), the method combines the weighted influence of several "road stretch priority variables" (*RSPV*) through a few weights and intervals defined for this purpose, obtained from the *RSPV* bibliographic review and in the light of the results of Naish (2010). But there is a need to determine them in a more objective way. The value allocation system using intervals might also be improved to avoid sensitivity problems in the methodology.

Therefore, the present study proposes a methodology for weight allocation for these *RSPV* by applying the analytic hierarchy process in its fuzzy version (FAHP) to the results obtained from ad hoc questionnaires prepared for an expert panel. Discussion of the obtained results features a qualitative comparison between the different FAHP versions used to sort and weigh variables. Testing the adaptability of the developed methodology to real cases entailed a practical application involving the reviewed Noise Action Plan for regional roads of the province of Almería, in Andalusia (southern Spain). The proposed methodology can use input data from the SNM, regardless of the method employed to simulate and estimate the road traffic noise. The obtained weights are independent of the origin of the data used for the variable calculation, as presented in section 3.1.

2. Material and methods

2.1. RSPV and RSPI

The main *RSPV* were determined and defined in Ruiz-Padillo et al. (2014), while the present paper introduces the following improvements:

- Stretch traffic data: in addition to the intensity of vehicles (average daily traffic – *ADT*) and the percentage of heavy vehicles (*%hv*), the average speed of the vehicles in the stretch (s) is added, since it also bears influence on the generation and reduction of noise, as evidenced in the 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 value, either "yes" or "no", which translates into respective numerical values of 1 and 0).
- The *RSPV* noise level of necessary attenuation (ΔL) is divided into two sub-variables, depending on the time-slot; this is because sound levels during day- or night-time periods should not be given the same emphasis. A community noise annoyance degree is higher during the night, even at lower sound levels. Thus, two sub-variables are considered: the minimum attenuation in the daytime period, ΔL_d, and the minimum attenuation at night, ΔL_n. Then, taking into account the definition of noise indicators (European Union, 2002; D'Alessandro and Schiavoni, 2015) offered by the SNM, noise levels of necessary attenuations are calculated by Eqs. (1) and (2):

$$\Delta L_d = L_{exist,d} - L_{obj,d} \tag{1}$$

$$\Delta L_n = L_{exist,n} - L_{obj,n} \tag{2}$$

where ΔL_d is the daytime necessary attenuation in dB(A);

$L_{exist,d}$ is the A-weighted long-term average sound level determined over all the day and evening periods of a year (i.e. it includes the daytime period, 7:00 – 19:00, and the evening period, 19:00 – 23:00), obtained from the noise map;

$L_{obj,d}$ is the A-weighted sound level corresponding to acoustic quality objectives for day and evening periods, in view of the corresponding noise zoning of the stretch studied under current legislation;

ΔL_n is the night-time required attenuation in dB(A);

$L_{exist,n}$ is the A-weighted long-term average sound level determined over all the night periods of a year (23:00 – 7:00), obtained from the noise map; and

$L_{obj,n}$ is the A-weighted sound level corresponding to the night-time acoustic quality objective, in view of the corresponding noise zoning of the stretch studied under current legislation.

- Exposed surface (S_{exp}) and exposed population (P_{exp}) to excessive noise level (i.e. sound levels above legislation limits) are also extracted from the SNM, relative to values of the L_{den}, day–evening–night noise indicator, defined by Eq. (3) (European Union, 2002):

$$L_{den} = 10\log\left(\frac{12\cdot 10^{\frac{L_{day}}{10}} + 4\cdot 10^{\frac{L_{evening}+5}{10}} + 8\cdot 10^{\frac{L_{night}+10}{10}}}{24}\right) \tag{3}$$

in which L_{day} is the *A*-weighted long-term average sound level determined over all the day periods of a year (7:00 – 19:00);

$L_{evening}$ is the *A*-weighted long-term average sound level determined over all the evening periods of a year (19:00 – 23:00); and

L_{night} is the *A*-weighted long-term average sound level determined over all the night periods of a year (23:00 – 7:00).

In the SNM these data are distributed by intervals of sound levels, which are usually the following: from 55 to 65 dB(A), from 65 to 75 dB(A), and values higher than 75 dB(A) (European Union, 2002; D'Alessandro and Schiavoni, 2015). In fact, it is reasonable to assume that equal importance should not be given to a surface or people exposed to sound levels close to acoustic quality objective levels as opposed to those who are affected by much higher local sound levels. Therefore, based on the information of L_{den} distributed by intervals obtained from the noise maps, both S_{exp} and P_{exp} variables can be subdivided into three sub-variables according to these intervals, i.e. surface and population exposed to sound levels between 55 and 65 dB(A), between 65 and 75 dB(A), and higher than 75 dB(A). They are denoted, respectively: $S_{exp,55}$, $S_{exp,65}$ and $S_{exp,75}$, and $P_{exp,55}$, $P_{exp,65}$ and $P_{exp,75}$.

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