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Selection of suitable alternatives to reduce the environmental impact of road traffic noise using a fuzzy multi-criteria decision model

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ABSTRACT

Road traffic noise is one of the most significant environmental impacts generated by transport systems. To this regard, the recent implementation of the European Environmental Noise Directive by Public Administrations of the European Union member countries has led to various noise action plans (NAPs) for reducing the noise exposure of EU inhabitants. Every country or administration is responsible for applying criteria based on their own experience or expert knowledge, but there is no regulated process for the prioritization of technical measures within these plans. This paper proposes a multi-criteria decision methodology for the selection of suitable alternatives against traffic noise in each of the road stretches included in the NAPs. The methodology first defines the main criteria and alternatives to be considered. Secondly, it determines the relative weights for the criteria and sub-criteria using the fuzzy extended analytical hierarchy process as applied to the results from an expert panel, thereby allowing expert knowledge to be captured in an automated way. A final step comprises the use of discrete multi-criteria analysis methods such as weighted sum, ELECTRE and TOPSIS, to rank the alternatives by suitability. To illustrate an application of the proposed methodology, this paper describes its implementation in a complex real case study: the selection of optimal technical solutions against traffic noise in the top priority road stretch included in the revision of the NAP of the regional road network in the province of Almeria (Spain).

1. Introduction

Traffic noise has become a major environmental impact in the current global context, largely as a result of the transport infrastructure development. Particularly in Europe, the growing volume of road traffic is generating noteworthy impacts on its infrastructures, environment and resources, in many cases in conflict with the EU's aim to encourage more sustainable modes of transport and to meet certain requirements for reducing greenhouse gases and noise emissions (Mayer et al., 2012). Roughly 65% of the inhabitants of the large European cities are exposed to high noise levels (D'Alessandro and Schiovani, 2015), and about 80 million people in the EU (around 20% of the population) suffer harmful effects related to excessive noise exposure (Oltean-Dumbrava et al., 2013).

Therefore, in addition to legal, administrative and educational measures to ensure the safeguarding of human health, it is important to come up with technical solutions to address this problem, and abate the noise endured by populations adjacent to roads. In the European context, the application of Directive 2002/49/EC of the European Parliament and of The Council of 25 June 2002, on the assessment and management of environmental noise (commonly called "European Environmental Noise Directive") requires Public Administrations of the EU member countries to generate substantial strategic noise mapping (SNM - a map designed for the assessment of noise exposure in a given area due to the different noise sources) and noise action plans (NAP - plan designed to manage noise issues and its effects, particularly by noise reduction in the exposed area) to cope with this problem (Directive 2002/49/EC, 2002; Garg and Maji, 2014).

At the present stage of the European Environmental Noise Directive, every five years, departments responsible for roads must prepare and publish the SNMs and NAPs corresponding to the major road infrastructures of the network (more than 3 million vehicles a year). When

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developing noise management action plans, Member States' authorities are required to consult the concerned public (Directive 2002/49/EC, 2002). However, environmental noise due to road traffic continues to increase (Mayer et al., 2012).

Moreover, there are not harmonized methodologies to help in the decision-making of the choice and planning of the solutions against noise when elaborating the NAPs, according to the objective of the Directive. Essentially for this reason and political issues, the NAPs are often not adequately implemented, or the planned measures prove ineffective under some circumstances because the chosen criteria for action prioritization and selection are not the most appropriate from the standpoint of managers (King et al., 2011).

Therefore, it is important to apply appropriate decision methodologies to define necessary actions to be included in the NAPs, as required by the European Environmental Noise Directive. Up to now, each EU member country or administration set their own criteria to identify the most critical areas for action against noise (hot spots) and to select solutions for the problem of road traffic noise. Recently Ruiz-Padillo et al. (2014) proposed a methodology for the prioritization of action with regard to the generation of a NAP for the road stretches identified as troublesome due to traffic noise. According to the present contribution, after sorting out stretches for action based on the "Road Stretch Priority Index" (RSPI) improved in Ruiz-Padillo et al. (2016), specific measures against noise may be proposed and the most suitable ones selected for each road stretch (or individual case). This suitability includes not only performance for reducing noise, but also other factors such as economic, social, environmental and functional aspects. This second stage effectively completes the overall process of environmental impact assessment (EIA) with the proposal of mitigation measures, which is the aim of the paper. So, this EIA does not derive from the study of the construction of a new infrastructure, as usual, but from the acoustic assessment of the operation of an existing road through noise mapping. Furthermore, the developed methodology may also be useful for the decision-making about the measures to mitigate the impact of the road traffic noise, as result of other environmental assessments.

Studying and making decisions about technical alternatives is a particularly complex issue, involving many factors that may themselves come into conflict, or may depend on uncertain information (Garg and Maji, 2014; Ruiz-Padillo et al., 2016). In this paper a methodology based on multi-criteria decision methods is adopted. In recent years, the use of multi-criteria decision methods in engineering and environmental fields has increased significantly in terms of both the frequency and range of applications. There are studies regarding waste treatment (Soltani et al., 2015), urban sustainability (Egilmez et al., 2015), environmental management and evaluation (Awasthi et al., 2010; Herva and Roca, 2013), air pollution (Vlachokostas et al., 2011), energy production and consumption (Arce et al., 2015; Sun et al., 2015), water pollution (Zhang and Huang, 2011) and linear infrastructure impact assessment (Sayers et al., 2003; Gardziejczyk and Zabicki, 2014; Nogués and González-González, 2014), or specifically traffic noise (Oltean-Dumbrava et al., 2013; D'Alessandro and Schiovani, 2015).

The objective of this paper is to achieve a scientific, rigorous and firmly supported approach for the choice of alternatives against road traffic noise, a further step under the prioritization methodology presented in Ruiz-Padillo et al. (2016). In view of the characteristics of the problem mentioned above, a multi-criteria procedure was devised, making it possible to study each particular road stretch in connection with its potential noise control engineering solutions. As a result of this analysis, the proposed methodology allows the decision-maker to identify the best alternative from an ordered list of feasible alternatives for assessment.

Generally, multi-criteria decision problems of this sort call for evaluating alternatives with respect to each criterion involved, the criteria being weighted by a vector that expresses the relative importance among them (Wang et al., 2009). For example, many examples of multi-criteria decision problems related with EIA developed in the area of civil engineering contain a significant shortcoming, which comes from the definition of the weights assigned to the criteria used in the problem (Sayers et al., 2003). Thus, numerous studies apply the chosen method by estimating weights or taking them from earlier cases, without a detailed and specific study of the analyzed problem. Due to this fact, classical multi-criteria analysis methods may not be very effective for complex decision problems. This is, indeed, a key issue —special care must be taken for the selection of weights.

Consequently, this research tries to avoid the arbitrary actions behind selecting weights, applying hybrid methods, yet combining advantages from different methods (Awasthi et al., 2010; Herva and Roca, 2013; Nogués and González-González, 2014; Arce et al., 2015; Soltani et al., 2015; Sun et al., 2015). First, a weighting method based on a fuzzy analytical hierarchy process strictly on preferences from experts is implemented to obtain the weights of the criteria defined for the problem, and then several multi-criteria decision methods are applied to the set of alternatives. In this case, the objective is to provide the decision-maker a complete ranking of the technical solutions according to their suitability for solving the analyzed problem. This procedure can therefore aid practitioners, policy-makers and managers in assessing the impact of action plans, and to make decisions based upon these assessments derived from systematized expert knowledge.

The paper is organized as follows. In Section 2, the elements of the decision-making process are presented, with emphasis on the suitable criteria and the alternatives proposed as technical solutions to the noise control problem. Section 3 presents the weighting and multi-criteria methods used in developing the proposed methodology, and their main features are analyzed and discussed in the context of their application. Section 4 presents the methodology developed for prioritizing alternatives against road traffic noise, and how the data and the weights assigned to the criteria were obtained. In Section 5, a case study illustrates the application of the methodology: an analysis of alternatives to address the noise problem of a road stretch in the Regional Network of Roads in the province of Almeria, in southern Spain. Finally, in Section 6, some conclusions are drawn and the main results achieved through this research are summarized.

2. Elements of the decision-making process

The assessment of every decision-making process needs the initial determination of the fundamental elements that define the problem studied. Thus, firstly, the set of feasible alternatives for inclusion in the proposed multi-criteria methodology are defined in the context of noise impact reduction. Secondly, the list of criteria and sub-criteria for the assessment of the alternatives found as relevant for the noise reduction problem are introduced and described.

2.1. Alternatives for noise reduction

Technical solutions for noise abatement can act (Ruiz-Padillo et al., 2014): (i) by reducing the emission of noise at the source (on the engines and tires of the vehicles; on the traffic behavior, composition or speed; and on the pavements); (ii) on the transmission medium of the noise (by modifying this medium or applying obstacles between the source and the receiver, as acoustics barriers, changing the road design or the land uses and their characteristics); and (iii) directly on the receiver (sound insulation on facades and windows).

In order to ensure the applicability of the methodology presented, the alternatives of difficult or unfeasible implementation should be discarded. This is the case of measures that lie beyond the scope of local authorities responsible for NAP implementation, such as changes on the vehicles type or the land uses and major new constructions. Thus, from an extensive catalog of currently available technical solutions against noise studied in Ruiz-Padillo et al. (2014), as result of a rigorous bibliographic review, five categories of alternatives were preselected for the methodology (in addition to the "zero alternative", i.e.