Available online at www.sciencedirect.com
ScienceDirect
Transportation Research Part D 12 (2007) 423–436
TRANSPORTATION RESEARCH PART D
www.elsevier.com/locate/trd

A Fuzzy Multi-Criteria Model applied to the management of the environmental restoration of paved highways

Sandro Filippo *, Paulo Cezar Martins Ribeiro, Suzana Kahn Ribeiro

PET/COPPE/UFRJ – Transportation Engineering Programme, Rio de Janeiro Federal University, Centro de Tecnologia, Cidade Universitária, Bloco H, sala 106, CEP 21945-970, Rio de Janeiro, RJ, Brazil

Abstract

This paper presents a procedure for ranking environmentally valid highway restoration by priority, using a Fuzzy Multi-Criteria Model that supports decisions on which road segments require these works and services. This is a matter of much concern for the Brazilian Government, due to rising awareness of soil degradation and the depletion of plant cover, as accident rates and transport costs rise steadily. The criteria used are: risk of accidents, economic and strategic importance, environmental degradation and the risk of erosion and landslides along the highway. In order to apply the proposed model, an example compares two highway segments, conducting sensitivity analyses through weighting the sub-criteria and criteria.

Keywords: Highway maintenance; Environmental impacts; Multiple criteria decision-making; Fuzzy logic

1. Introduction

There is concern about the precarious conditions of paved highways in Brazil, from the joint standpoints of safety and environmental conservation. Road safety is undermined mainly because of inadequate surface conservation, in addition to poor markings and signposting. A survey of 82,000 km, carried out by Brazil's National Transportation Confederation (2005) showed that only 25% of Brazilian highways were rated as good or excellent in terms of conservation conditions. Limited investments in highway conservation have resulted in serious deterioration of much of Brazil's road network, undermining user safety and severely affecting cargo shipments.

These road safety issues are paralleled by environmental problems, originating largely in the road-building phase, including abandoned work-yards, dump-sites and quarries, as well as excessive land clearing and deforestation (Fogliatti et al., 2004). Added to these issues are excessive land clearing, causing soil erosion, alterations to surface run-off patterns resulting in the silting-up water-courses, with landslides and other road

* Corresponding author.
E-mail address: filippo@pet.coppe.ufrj.br (S. Filippo).

1361-9209/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.trd.2007.05.004

accidents directly affecting highway users and neighbouring communities, together with other problems caused by inadequate maintenance or poor quality construction.

Managing and monitoring environmental impacts requires ranking by priority to reflect the constant shortage of funds. Investments in environmental enhancement of paved highways, however, often encompass diverse stakeholders and specialists with many different viewpoints and concerned with a broad range of social, economic, technical and environmental variables, making such ranking difficult.

Fuzzy logic can be a useful tool for this type of situation because it allows engineering and environmental specialists to use their experience and experiences when taking decisions. Despite numerical calculations, human thought usually functions in linguistic terms, through words such as ''Low'', ''Medium'' or ''High'', generally associated with experience and expertise. When complex models cannot be used, specialists take decisions based on the closest analysis, heuristics and personal experience (Schon, 1993; Liebowitz, 1995).

2. Fuzzy logic applied to environmental studies and decision-making

There is an increasing use of fuzzy logic in decision-making involving technical, economic and environmental parameters. Decisions are usually based on multiple criteria, and may be taken with the aid of traditional methods such as the analytic hierarchy process (AHP) or the ELECTRE family of methods. Fuzzy logic, however, is being used more frequently, sometimes with other techniques for taking decisions on issues whose variables involve a relatively high degree of uncertainty.

Fuzzy logic involves a mathematical treatment of systems where subjectivity and the ambiguous characteristics of the variables hamper the use of classic logic. Together with heuristics, it may be used to build up the architecture of consensual human thought, encompassing the experience of specialists. Its use for assessing environmental impacts was prompted mainly by the uncertainties involved in environmental system modelling and in relationships among system components.[1]

In the crisp or classic sets theory, the transition between membership and non-membership of a given element in a set takes place in an abrupt and well-defined manner (Ross, 2004), meaning a specific element belongs or does not belong to a given set. In fuzzy logic, an element may belong partially to a set, indicated by a degree of membership or value within a numeric interval, generally $[0,1]$. A fuzzy set is characterised by its membership function. The types of function most commonly found in applications are triangular and trapezoidal because of the ease with which they can be generated. Several processes or techniques employing specialists or users may be used to determine membership functional forms and values: analysis of the behaviour of the variables being through intuitive reasoning or logical operation or algorithm. As with conventional logic, fuzzy logic rules may be defined that associate inputs with outputs.

The general structure of a fuzzy inference system is seen in Fig. 1 and consisting of a collection of input variable sets, a collection of output variable sets and a selection of inference rules associating them.

The fuzzification process consists of associating a linguistic array to the input parameter value. After using inference procedures, a defuzzification process is applied that consists of converting fuzzy numbers into crisp numerical output values. This may be handled in several ways and may involve centroids and centre-of-maximums.

The inference rules for fuzzy reasoning are normally expressed in the *IF-THEN* format, blending different implication and composition techniques using fuzzy relations. One of the most widely used techniques is max–min inference, known as the Mamdani Fuzzy Inference Method.

Fuzzy logic is useful for looking at the environmental management of roads because of its ability to handle the uncertainties or subjectivities involved. In fuzzy sets, the transitions between members and non-members are gradual, ''modelling'' pertinence curves that associate numerical values with linguistic terms and reflecting human perceptions of a certain aspect to be analysed. This is the case of variables such as rainfall, the average

[1] The use of fuzzy logic in environmental studies includes: risk and impact analysis (Dixon, 2005; Sadiqa and Husainb, 2005; Uricchio et al., 2004; González et al., 2002); decision-making involving multiple criteria or multiple objectives (Hung et al., 2006; Panou and Sofianos, 2002; Genga et al., 2001, Liang and Wang, 1991); modelling environmental systems (Özesmi and Özesmi, 2004) and environmental pollution reduction process control (Chana and Huang, 2003).