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Decision aid system founded on nonlinear valuation, dispersion-based weighting and correlative aggregation for wire rope selection in slope stability cable nets

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ABSTRACT

This paper presents a decision aid system to address hierarchically structured decision-making problems based on the determination of the satisfaction provided by a group of alternatives in relation to multiple conflicting subcriteria grouped into criteria. The system combines the action of three new methods related to the following concepts: nonlinear valuation, dispersion-based weighting and correlative aggregation. The first includes five value functions that allow the conversion of the ratings of the alternatives regarding the subcriteria into the satisfaction they produce in a versatile and simple manner through the Beta Cumulative Distribution Function. The use of measures of dispersion to weight the subcriteria by giving more importance to those factors that can make a difference due to their heterogeneity is revised to validate it when the values are not normally distributed. Dependencies between subcriteria are taken into account through the determination of their correlation coefficients, whose incorporation adjusts the results provided by the system to favour those alternatives having a balanced behaviour with respect to conflicting aspects. The overall satisfaction provided by each alternative is determined using a prioritisation operator to avoid compensation between criteria when aggregating the subcriteria. The system was tested through a novel field of application such as the selection of wire rope to form slope stability cable nets.

1. Introduction

Selecting the most preferred alternative from a group depending on the satisfaction degree they provide in relation to a set of conflicting and hierarchically structured aspects is a recurrent problem in many real-life applications. These problems are normally formulated in terms of a group of alternatives $A_l = \{A_1, \ldots, A_p\}$ having different ratings x_{ki} regarding a set of subcriteria $SC_{ki} = \{SC_{11}, \ldots, SC_{nm}\}$ belonging to several criteria $C_k = \{C_1, \ldots, C_n\}$, so that the overall satisfaction s_l produced by each alternative in relation to that hierarchy made up of criteria and subcriteria is the final output being sought. A decision aid system consists of a set of interacting components forming a whole aimed at helping to solve decision-making problems under complex environments.

The need for several components stems from the need to solve each of the different phases that constitute this kind of problems. The first phase seeks the valuation of the ratings of the alternatives with respect to the subcriteria in terms of the satisfaction they generate. These ratings normally have different units of measurement, which suggests that scaling them into a standard range of values, e.g. [0, 1], is desirable. The concept of satisfaction is beyond the basic normalisation step included in many decision-making methods, which assume linearity of variables (Opricovic & Tzeng, 2004; Teixeira de Almeida, 2007; Önüt & Soner, 2008). Other methods, based on the concepts of multi-attribute utility theory (MAUT) and multi-attribute value theory (MAVT) (Edwards, 1977; Keeney & Raiffa, 1976) derived from Utility Theory (Neumann & Morgenstern, 1953) and Value Engineering (Miles, 1961), respectively, represent the utility or value of an alternative l with regards to a subcriteria SC_{ki} through a function $f(x_{ki})$.

The Integrated Value Model for Sustainable Assessment (MIVES) and the Preference Ranking Organization METHod for Enrichment of Evaluations (PROMETHEE) are the two most relevant methods that propose specific functions to model the value (preference degree in PROMETHEE terminology) associated with the performance

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Fig. 1. Outline of the decision aid system proposed.

of the alternatives in terms of the set of subcriteria. MIVES (Jato-Espino *et al.*, 2014; Pons & Aguado, 2012; Pons & De La Fuente, 2013; San-José Lombera & Garrucho Aprea, 2010) is based on an cumbersome equation that defines four different functions (concave, convex, linear, S-shape) according to three parameters (C_i, K_i, and P_i) and two bounds (x_{min} and x_{max}). Each of the nonlinear functions place the largest increase in satisfaction in three different sections (final, initial and central, respectively), which means that the method cannot model a variable whose increase in satisfaction is located in both the initial and final sections of a function. This behaviour is typical in many real-life variables, wherein lower values represent the area to exceed the threshold of minimum satisfaction (initial section) and the excellence corresponds to the highest values (final section). PROMETHEE (Behzadian *et al.*, 2010; Dagdeviren, 2008; Herngren *et al.*, 2006; Wang & Yang, 2007) has six different preference functions to translate the difference between the evaluation of two actions for a certain criterion into a preference degree according to two parameters named the indifference and preference thresholds (q_j, p_j). Apart from two functions also present in MIVES (linear and S-shape, here known as Gaussian), this method considers four additional shapes: usual, U-shape, V-shape and level. These functions are variants of constant and linear shapes with the only exception of considering different bounds. Therefore, PROMETHEE functions have insufficient flexibility to model nonlinear variables. These considerations prove the need for a new approach to value the degree of satisfaction provided by a group of alternatives in a versatile and simple manner.

The next phase to solve a decision-making problem formed by a series of hierarchical and conflicting factors is the aggregation of the elements in both levels of the hierarchy to determine the ranking of alternatives in terms of their overall degree of satisfaction. The relationship between the criteria is often of a form such that the aggregation process must not allow their compensation. The incorporation of the prioritisation operator developed by Yager (2008) into the decision aid system prevents that compensation from happening. Another key factor within the procedure is the calculation of the weights of the subcriteria. The standard deviation has been proposed by some authors (Wang et al., 2007; Wang & Luo, 2010; Zardari et al., 2014) as an objective weighting method that assigns small weights to those subcriteria having similar values across the alternatives. However, the application of this measure of spread in this context must be revised, since its validity depends on the distribution pattern of such values. The final step consists of the quantification of the conflicts between subcriteria. Despite its importance, no method has been developed for the characterisation of this operation, which is still excluded from decision-making processes.

Under these premises, the aim of this paper is twofold. First, to build a decision aid system capable of addressing all the operations required to solve hierarchical decision-making problems based on the valuation of the satisfaction degree provided by a set of alternatives in relation to multiple conflicting subcriteria grouped into several criteria. Such system seeks to overcome the deficiencies found in current decision-making approaches in terms of three main aspects in these problems (valuation, weighting and conflicting subcriteria) through the Beta Cumulative Distribution Function (CDF), the interquartile range and the statistical correlation. The second aim is to demonstrate the applicability and usefulness of the decision aid system through a decision-making problem consisting of the selection of wire rope to form slope stability cable nets. This is a novel field of application defined by having prioritised criteria arranged into conflicting subcriteria with respect to which the satisfaction produced by some alternatives cannot be modelled using current valuation methods, which justifies the suitability of the proposed system to address it.

2. Methodology

A decision aid system based on the measurement of the satisfaction degree provided by a set of alternatives upon a group of hierarchically structured criteria and subcriteria can be designed through the combination of a series of methods as depicted in Fig. 1.

First is the conversion of the performance of the alternatives under consideration into the satisfaction they produce using the value functions stemmed from the Beta CDF. The second operation consists of the prioritisation of criteria such that their compensation is avoided. Next, the set of subcriteria forming each criterion is weighted according to the degree of variability of the ratings of the alternatives in relation to them. Finally, the interactions between subcriteria are incorporated into the system through the concept of statistical correlation. The combination of these operations yields the final ranking of alternatives being sought. The following subsections delve into the working principles that characterise each of the four steps on which the decision aid system is based.

2.1. Valuation

The satisfaction s_{ki} provided by an alternative can be expressed as a function of its rating x_{ki} in relation to the subcriterion SC_{ki} under consideration ($s_{ki} = f(x_{ki})$). Since this rating is often not proportional to the satisfaction it generates, there is a need for a method that allows the modelling of nonlinear relationships.

The Beta CDF enables not only the characterisation of these areas are wherein the satisfaction variations are more or less