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A peer IF-TOPSIS based decision support system for packaging machine selection

Davide Aloini *, Riccardo Dulmin, Valeria Mininno

University of Pisa, L.go L. Lazzarino, Pisa, Italy

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ABSTRACT

Selecting the appropriate manufacturing machine is a very important and complex problem for firms which usually have to deal with both qualitative and quantitative criteria and involve different decision makers whose knowledge is often vague and imprecise.

This paper proposes a peer-based modification to intuitionistic fuzzy multi-criteria group decision making with TOPSIS method (peer IF-TOPSIS) and applies it to a packaging machine selection problem. Intuitionistic fuzzy weighted averaging (IFWA) operator has been selected both to obtain the group opinion on the relevance of the single decision makers and to aggregate individual opinions of decision makers for rating the importance of criteria and alternatives.

A case study illustrates the application of the modified IF-TOPSIS method in order to select a Vertical Form Fill and Seal (VFFS) for Double Square Bottom Bag (DSBB) machine in food packaging.
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1. Introduction

Manufacturing companies worldwide are forced to undergo transformation processes in order to improve their ability to succeed with their products on extremely competitive international markets. In this perspective, an adequate selection of the appropriate machine tools if often crucial but very difficult to achieve.

Advanced manufacturing technology, in fact, requires a high level of initial investment and usually deals with both qualitative and quantitative benefits which make the traditional investment model based on Return On Investment (ROI), Cash Flow Analysis (CF), Pay-Back (PB) and Net Present Value (NPV) not really suitable. Arguably these models emphasize quantitative and financial analysis, but fail to capture many of the "intangible" benefits such as greater manufacturing flexibility, improved product quality, quick response to customer demand and better employee safety and motivation (Abdel-Kader, 1997; Chen & Small, 1996; Kaplan, 1986) which are typically more challenging to measure and monetize, or they are not at all.

The high investment risk inherent in advanced manufacturing technology often leads to the use of arbitrarily high hurdle discounts rates (Accola, 1994; Kaplan, 1986; Kaplan & Atkinsons, 1989). Moreover, adjustments to the discount rate are affected by decision maker's attitude toward the specific risk rather than by an explicit representation of the risks inherent in the investment alternatives (Accola, 1994). Finally, also when risk is explicitly assessed and systematically included into the investment evaluation, as for example by using innovative evaluation paradigms such as Real Option Approach (ROA), the problem of estimating returns from intangibles still remain unsolved. This condition often results in a severe and sometime irreparable evaluation bias affecting the final decision.

In order to solve this gap and according to Lefley (1996), we think a more sophisticated (and not financial) approach is needed to the appraisal of a machine selection, which could take into account the strategic nature and the full benefits from such investments. The most adopted procedures in literature are Multi Criteria Decision Analysis (MCDA) or Multi Criteria Decision Making (MDCM) methods, often combined with fuzzy logic or subsequent evolution of fuzzy set theory in order to deal with the vagueness and imprecision inherent with advanced manufacturing technology selection problem.

This paper proposes a modified version of Boran, Genç, Kurt, and Akay (2009) fuzzy multi-criteria decision making with TOPSIS method which is inspired by a peer-based view of judgments. Differently from the previous version of the algorithm we advance a peer procedure for determining the weights of Decision Makers' opinions. Thus, Intuitionistic Fuzzy Weighted Averaging (IFWA) operator is used to obtain the group opinion on the relevance of the single decision makers. In a high uncertain environment, in fact, a single supervisor can be subjected to a significant bias when assessing weights to the subjects involved in the decision process,

* Corresponding author. Address: Department of Energy, System, Land and Construction Engineering, University of Pisa, L.go L. Lazzarino, 56122 Pisa, Italy. Tel.: +39 50 2217088; fax: +39 50 2217333.

E-mail addresses: Davide.Aloini@dsea.unipi.it (D. Aloini), Riccardo.Dulmin@dsea.unipi.it (R. Dulmin), Valeria.Mininno@dsea.unipi.it (V. Mininno).

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as in Boran et al. (2009). A peer voting procedure among DMs supported by IFWA operator could be very important to support the aggregation of the expert opinions and finally achieve consensus in group decision making problems. The method is then demonstrated through an application to the case of selection of an innovative machine for food packaging.

The following sections are going to present: a focused theoretical background on the evolution of TOPSIS methods and Fuzzy sophistications (Section 2), the decision context for the machine selection (Section 3), theory and application to the case study of the modified IF-TOPSIS procedure (Section 4), and finally conclusion (Section 5).

2. Theoretical background: a focused review on TOPSIS

Among the numerous MCDA/MCDM methods, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) continues to work satisfactorily in different application areas. The standard TOPSIS method aims to choose alternatives that simultaneously have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution accordingly to predefined evaluation criteria which are usually divided into cost and benefit criteria (they are respectively minimized/maximized or maximized/minimized in the two cases). See Behzadian, Otaghsara, Yazdani, and Ignatius (2012) for an in-depth review of the literature on TOPSIS methods and related applications. The main reason of a so wide acceptance is because its concept is reasonable, easy to understand and compared with other MCDM methods, like AHP and ELECTRE I, it requires less computational efforts, and therefore can be applied easily (Kim, Park, & Yoon, 1997; Shih, Shyur, & Lee, 2007).

Then, Fuzzy Set Theory started to be adopted conjointly with TOPSIS in order to deal with uncertainty and related concepts such as risk and ambiguity which are prominent in the literature on decision-making and linguistic expressions regarded as the natural representation of the judgment. Evidence of an extensive use of Fuzzy-TOPSIS is available again in Behzadian et al. (2012).

In this perspective, however, it is also valuable to notice that the hybridization of traditional MCDM approaches with the fuzzy logic suffers from the epistemological flaw consisting in considering a fuzzy interval as a simple substitute to a precise number, whereby a direct extension of the standard method consist just in replacing numbers by fuzzy intervals and running a similar computation as in the precise case (Dubois, 2011). To solve this problem the Fuzzy Set concepts have been extended introducing the Intuitionistic Fuzzy Set (IFS) theory (Atanassov, 1986) considered a suitable way to deal with vagueness and solve many decision-making problems under uncertain environment. Accordingly to the "intuitionistic approach/philosophy", vagueness refers to lack of definite or sharp distinction, whereas ambiguity is due to unclear distinction of various alternatives, which is further divided into discord (conflict) and non-specificity (Klir & Yuan, 1995). IFS generalizes the Fuzzy Set Theory introducing another degree of freedom (non-memberships) into the set description together with a third parameter $\pi_A(x)$ which is known as the Intuitionistic Index of Hesitation (Tamalika & Raya, 2008). In this way it is expected coping better with the presence of vagueness and hesitancy originating from imprecise knowledge or information.

Following this major trend in research, IFS theory is considered having enormous chances of success for multi-criteria decision making problems due to the great superiority on dealing with vagueness, so that it has been applied in many areas such as decision-making problems (Atanassov, Pasi, & Yager, 2005; Chen & Tan, 1994; Hong & Choi, 2000; Liu & Wang, 2007; Szmidt & Kacprzyk, 2002, 2003; Wang, Cheng, & Huang, 2009; Xu, 2007a, 2007b, 2007c; Xu & Yager, 2006, 2008).

Only more recently, some studies have combined IFS with TOPSIS in order to better face with subjectivity, imprecision, and vagueness in group decision-making problem under multiple criteria. Boran et al. (2009), as first, developed IF-TOPSIS based on Xu's (2007d) Intuitionistic Fuzzy Weighted Averaging (IFWA) aggregating operator and adapted to supplier selection problem. Then, they also applied IF-TOPSIS to a personnel selection problem concerning with identifying an individual from a pool of candidates suitable for a vacant position (Boran, Genç, Kurt, & Akay, 2011) and to evaluation of renewable energy technologies (Boran, Boran, & Menlik, 2012).

Drawing on Boran et al. (2009) this paper extends the application of IF-TOPSIS to another challenging decision problem usually subjected to uncertainty and evaluation from multiple experts: selecting the adequate manufacturing machine. It also proposes an innovative peer-based procedure for voting the relevance of the single decision makers in to the group decision process. This is in order to skip a centralized assignment of DMs weights.

3. Problem definition

Selecting the adequate manufacturing machine is a complex decision. Multiple decision makers, with different perspective and expertise, are usually involved in the process and have to deal with uncertainty and ambiguity. These uncertainties entail incomplete information, inadequate understanding, and undifferentiated alternatives (Lipshitz & Strauss, 1997; Ahn, Park, Han, & Kim, 2000). At a financial level, this happens because of the difficulty in estimating the impact of unexpected changes on cash flows (Franz, Duke, & Omer, 1995; Sutardi & Goulter, 1995). Moreover, it is often difficult to measure the positive impact on cash flows brought about by the increase in quality and flexibility which would allow quicker reactions to changes in the market (Franz et al., 1995; Kaplan, 1986).

Also when not financial approaches are adopted and intangible criteria are included in to the decision process, uncertainty is still high. Decision making, in fact, involves intangible criteria used to rank the alternatives which are hard to quantify or have no measurements to serve as a guide. As a consequence, creating priorities for the criteria themselves in order to weigh the priorities of the alternatives and add over all the criteria to obtain, for example, the desired overall ranks of the alternatives, is a challenging task. Moreover, as previously stated, this is often a group-decision which needs to achieve consensus among different players, so that assessing the relative importance of single DMs' opinion is another difficult dimension of the problem.

In this context, our study is specifically aimed to the selection of the right DBSS-VFFS packaging machine among a number of identified alternatives.

Vertical Form, Fill, and Seal (VFFS) machines are used in the consumer products industry for a wide variety of packaging applications. Various products like salt, tea, sugar, spices, snack foods, wafers, detergent and candies are placed into formed pouches and then sealed. The pouch material is flexible and typically heat-sealable plastic. Paper is also used and sealed by glue. According to a process perspective, the VFFS machine can be divided into four functional areas: (1) mixing, weighing, dosing; (2) forming, (3) feeding, aligning, registration; and (4) closing, sealing, cutting. Fig. 1 shows the functional scheme of the machine.

DBSS-VFFS machine extend the VFFS process by adding a refinement operation to the closing sealing and cutting phase in order to realize a Double Square Bottom Bag so that the package can stand up on the supermarket shelf.

The choice consists of a multi-faced problem which is subjected to numerous dimensions of analysis, and particularly safety, efficiency, flexibility and innovation of the process.

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