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Technology assessment with IF-TOPSIS: An application in the advanced underwater system sector

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ABSTRACT

Technologies are pivotal for firms' success, but also resource consuming. Therefore, managers have to assess and select technologies carefully in order to allocate resources on the most promising ones, grounding their decisions on adequate sets of criteria on which experienced people can express their opinion.

This work proposes an application of Multi Criteria Decision Aids to technology assessment, where Decision Support Systems offer an effective support for evaluating technology impact on firms' success, building on experts' judgments.

The method is based on a peer-based modification to Intuitionistic Fuzzy multi-criteria group decision making with TOPSIS method (peer IF-TOPSIS). A case study in which this methodology is applied to a company operating in the military sector (Advanced Underwater System) is also presented.

Besides the empirical proof of the method's suitability and value in assisting managers in their decision, the paper's contributions are both methodological and theoretical. Methodologically, while allowing a peer-based voting procedure, the method enhances the consensus in the firm and limits the possible biases that a supra-decision maker could introduce. Theoretically, the set of proposed criteria includes many facets of the assessment problem, and avoids being tailored to the investigated technological field, so enhancing its generalizability.

1. Introduction

Technologies play a key role for firms' success as they can positively contribute to create value and to stay ahead in the competitive arena. Nevertheless, technologies consume both resources and managers' attention (Aloini et al., 2011). Therefore, managers have to get most out of technologies, while properly allocating resources between the most promising ones, whatever their origin, either internal, external or co-developed with other partners.

Since the early '80s the scientific debate has proposed different approaches for evaluating and selecting technologies (Foster, 1981; Harris et al., 1981; Chien, 2002; Bitman and Sharif, 2008; Wang et al., 2008; Kester et al., 2009; Chiesa et al., 2008; Van Wyk, 2010). The result of this long debate is that, to date, the literature, on the one hand, has set forth interesting suggestions, but, on the other, has put forward models and methods that present some flaws (Jolly, 2012).

As regards this last point, some models are based on financial analysis (Raju et al., 1995; Chan et al., 2000), such as the net present value or the return on investments (Spradlin and Kutoloski, 1999; Kirchoff et al., 2001), sometimes enriched with probability elements

(Blau et al., 2004). The main limits of these methods dwell in the subjectivity, uncertainty and high variance of the financial judgments (particularly, as regards very far away cash flows), as well as in their inability to cope with non-financial elements, which are typically more challenging to measure and monetize, or they are not quantifiable at all. Another group of models builds on patents and bibliometric analyses in order to identify the potential areas of research interest (Yoon et al., 2002; Kelley and Rice, 2002; Levitas et al., 2006; Lee et al., 2009). The major flaw of this group of models consists of their narrow focus, in that decisions are based on a single indicator. Other models have been proposed in the literature, but usually they build on a very limited set of criteria (Jolly, 2012). For example, Jeong and Kim (1997) suggest that the most attractive technology is the one with a high technological causality or the shortest possible time lag between a seed technology and a goal technology. Therefore, it emerges the need of methods that, while going beyond the only financial or patent analysis, embrace multiple aspects to be measured by means of multiple criteria able to assess technologies developed non-only internally, but also by external partners.

However, as anticipated, the literature also offers interesting

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suggestions. For instance, it emphasizes that the evaluation process of technologies implies to take decisions in environments in which both imprecise and precise values, objective and subjective information co-exist; therefore, methods should be able to cope with subjectivity, imprecision, and vagueness intrinsic in such environments (Byun and Lee, 2005). Technology assessment often requires the involvement of many persons (Torkkeli and Tuominen, 2002): a wide and comprehensive group of experts should participate in a company's technology selection process in order to base the decision on the best available knowledge. Besides, the necessity to rely on multiple experts brings about issues connected with the way the experts' judgments are combined. On this topic, very recent literature has pointed out that peer-based procedures, as opposed to hierarchical ones, bring in important advantages in terms of consensus achievement and avoidance of biases due to the personal impressions that a supra-decision maker may introduce (Aloini et al., 2014).

In order to fill the above gap, while concurrently considering the useful suggestions, this work proposes a Multi Criteria Decision Aids (MCDA) approach to the appraisal of technology assessment, which could take into account the strategic nature of some key advantages of technologies. In fact, MCDA methods are a valuable solution able to include both quantitative and qualitative evaluation factors and to deal with the vagueness and imprecision inherent with technology assessment problem. More specifically, this paper builds on a modified version of Boran et al. (2009) an intuitionistic fuzzy multi-criteria decision making approach based on TOPSIS method which is inspired by a peer-based view of judgments (Aloini et al., 2014). Hence, a peer voting procedure among Decision Makers (DMs) supported by Intuitionistic Fuzzy Weighted Averaging (IFWA) operator (Xu, 2007) is used to obtain the group opinion on the relevance of the single decision maker.

The paper is structured as follows: theoretical background on the evolution of MCDA methods and particularly on MCDA applications in technology assessment is reported in Section 2, then Section 3 presents the methodology and (for sake of brevity and in order to avoid redundancy) its concurrent application to the case study, finally discussion and conclusion are given in Section 4.

2. Literature background

Multi Criteria Decision Aid and Technology Assessment are two huge, established, yet still very active research topics in the literature. Specifically, MCDA methods have received much attention from both researchers and practitioners for evaluating, assessing and ranking alternatives across diverse problems and industries. This also applies to technology assessment domain where MCDAs are adopted at different decision levels - global, national, sectorial, firm or specific R & D projects. As a matter of fact, most of the technology assessment related decisions can be conceptualized as a multi-objective, multi-criterion problem wherein subjective judgments and uncertainty play a key role.

In this context, the value of MCDA methods is well recognized for its capacity to deal with the complexity of decisions under conditions of uncertainty as it happens for example for technology management problems. Evidence from the literature clearly shows the high dynamism of the field. See for example the review papers by Mardani et al. (2015a, 2015b, 2015c) which exhaustively present the state-of-the-art about MCDA techniques since the '90 in different application areas, including service (Aloini et al., 2010). Accordingly, for sake of brevity it is hard here to make a thorough and comprehensive state-of-the-art analysis. We will just report an overview from the healthcare and energy domain where most recent and interesting developments were manifested.

As far as healthcare, MCDA methods are considered as a suitable way to overcome the limits of traditional technology evaluations, mostly based on a single indicator such as the Incremental Cost-Effectiveness Ratio (ICER), or the Incremental Cost per Quality-Adjusted Life-Year (QALY) (Thokala and Duenas, 2012). Recently, Ivlev

et al. (2014) reviewed more than twenty contributions specifically addressing MCDA for to the assessment and management of medical technologies. In Ivlev et al. (2015), authors also suggest innovative approaches using a combination of health technology assessment (HTA) and MCDA methods.

MCDA has also become particularly popular for energy technology planning and management where complexity and uncertainty are mostly due to the involvement of multiple benchmarks and a high number of conflicting objectives and constraints like technical, social, economic and environmental issues. In this field, early MCDA approaches enriched single criteria approaches (Pohekar and Ramachandran, 2004), whose aim was only the sheer minimization of costs, with environmental and social considerations. Kumar et al. (2017) have recently provided an interesting and extensive MCDA review in the sphere of sustainable energy systems.

From a methodological perspective, researchers have continuously suggested modifications and hybridizations of traditional methods in order to overcome most relevant limitations – e.g. to deal with subjectivity of the experts' judgment and unavailability of exact data on technologies. Linstone et al. (1979) and Tran and Daim (2008) present a taxonomic review of methods and tools applied in technology assessment since 1970, ranging from analytic techniques up to integrated impact-analysis approaches to decision analysis. We report here some relevant contributions in order to draw a brief historical map of the methodology developments.

Evidence shows AHP, one of the most known and adopted MCDA techniques, being among the first methods to be interested to the adaptations (Winebrake and Creswick, 2003). The combination of the Delphi method and AHP was first suggested by Prasad and Somasekhara (1990) for the technology assessment in Indian Telecommunication industry. After them, Khouja (1995) combined DEA and MCDA for supporting technology selection of robotic machines. Later on, Fuzzy Set Theory – in some cases jointly with other techniques such as AHP and TOPSIS – was introduced in support of the technology assessment decision process in order to deal with uncertainty and related concepts like risk and ambiguity, which are prominent in the literature on decision making and the natural representation of the judgment. As an example, Jeong and Kim (1997) adopted linguistic variables for supporting a qualitative analysis of the impact exerted by technologies. After them, Chan et al. (2000) and Prabhu and Vizayakumar (2001) suggested an application of the fuzzy sets to hierarchical structural analysis for quantifying both tangible and intangible benefits in technology selection processes. More recently, Dereli and Altun (2013) developed a Fuzzy Inference System to evaluate and prioritize technologies with respect to their innovation potentials. Finally, Tavana et al. (2013) adopted a hybrid fuzzy/group decision support framework (Fuzzy-ANP and Fuzzy-TOPSIS) to address the need for a transparent, structured and analytical method for assessing and prioritizing the advanced-technology projects at the Kennedy Space Center.

In this context, last research directions seem to propose Intuitionistic Fuzzy Set (IFS) theory (Atanassov, 1986) as a valuable tool to better cope with the presence of vagueness and hesitancy originating from imprecise knowledge or information. However, while potentially promising, applications of the IFS related methods are to our best knowledge still neglected in the technology assessment.

3. Methodology and application

We adopt a peer-based modification to intuitionistic fuzzy (IF) multi-criteria group decision making with TOPSIS method (peer IF-TOPSIS). Drawing on IF-TOPSIS method by Boran et al. (2009), it seems suitable in order to face with subjectivity, imprecision, and vagueness in group decision making problem under multiple criteria. Also coherently with Aloini et al. (2014), the IFWA operator is here modified accordingly to a peer approach in order to skip a centralized assignment

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