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Multi-criteria weighted decision making for operational maintenance processes

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ABSTRACT

This paper proposes an approach towards multi-criteria decision making (MCDM) for operational maintenance processes. It focuses on decision alternative identification and evaluation for short time horizons, thereby addressing problems that need to be resolved in hours or a few days at maximum. This addresses a gap in literature, where MCDM methods are predominantly proposed for strategic maintenance decision making. The proposed approach addresses two distinct steps of decision making: 1) identification of decision alternatives and 2) evaluation of decision alternatives. For identification of decision options, the Boolean Decision Tree (BDT) method is selected to accommodate for the qualitative and discrete operational factors that determine the available, feasible decision alternatives in operational maintenance processes. The feasible alternatives are subsequently evaluated using the weighted sum method (WSM). The approach is applied to a Boeing 777 outboard flap damage case, using real maintenance and operational data. A decision tool has been developed and verified, showing the capability of the approach to systematically identify and evaluate operational maintenance decision making problems in a few minutes. The results suggest that the proposed approach could save in excess of 50% on decision process time, with added benefits in full identification of the available set of decision alternatives at problem onset. In addition, sensitivity analysis on the basis of a global evaluation of the weight space is provided to investigate the impact of weight settings on the decision outcomes.

1. Introduction

1.1. Context

Maintenance, repair and overhaul (MRO) organizations face difficult decisions on a daily basis, having to judge the appropriate course of action in case of events which necessitate maintenance activity, such as component failures and impact damages (Garnier et al., 2011). Maintenance decision making is complicated by scheduling constraints and resource availability, which limit the number of feasible maintenance options while adding to the complexity of identifying and selecting an optimal solution (Cassady et al., 2001). An additional problem is the fact that maintenance events are often intermittent in nature (Ghobbar and Friend, 2002): occurrences are spread far apart in time – sometimes years apart – and are related to individual components. As a result, maintenance operators lack aggregated (historical) data and experience to systematically approach maintenance event resolution: in essence, for each non-routine event, the wheel is invented again and again. This can and does lead to informal decision-making processes, with poorly defined criteria and lack of a systematic approach to choose between competing alternatives for event resolution (Stewart, 1992). As a consequence, sub-optimal decisions may result (Rastegari et al., 2013), potentially leading to significant losses in money and time. Though estimates of cost impact are sparse, several authors have highlighted the time spent searching for the right information to support maintenance decision making (Lampe et al., 2004; Taylor, 2008), indicating that 15–30% of total process time is wasted on retrieving the correct supporting information. In terms of costs, making an incorrect decision has significant implications for repair and delay costs (Cook and Tanner, 2011; Cook et al., 2009). To prevent these losses, a systematic and formalized approach for maintenance decision making has to be in place, provided that it addresses the right level of application. Theory from the field of Multi-Criteria Decision Making (MCDM) can be employed to fill this gap.

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1.2. Existing approaches to MCDM in maintenance

The current state-of-the-art in MCDM provides many methods that can serve to set up a systematic approach towards maintenance decision making. Indeed, MCDM has been employed to this purpose in the maintenance domain, but its use focuses primarily on strategic decision making and policy selection, considering the question of what is optimal in the long run, with time horizons of years rather than days (Al-Najjar and Alsyouf, 2003; Bevilacqua and Braglia, 2000; de Almeida, 2001; Pintelon and Gelders, 1992; Shyjith et al., 2008). In stark contrast, supporting decision making on the operational level in the maintenance domain – i.e., considering the question "what to do now?" with associated time horizons which are measured in days rather than years (Dekker and Scarf, 1998) – has not been covered in the state-of-the-art.

MCDM process formalizations can be boiled down to three critical characteristics as defined by Triantaphyllou (Triantaphyllou, 2000; Triantaphyllou et al., 1997).

1. Identify all possible decision alternatives
2. Establish criteria and importance in the form of weights
3. Use quantifiable evaluation of the criteria to rank each decision

With respect to the first characteristic, existing literature frequently assumes decision alternatives to be available at the beginning of the decision making process. For maintenance processes at the operational level, these alternatives are usually not known, or only partially (Stewart, 1992; Triantaphyllou, 2000; Triantaphyllou et al., 1997). Hence, a method is required to identify the full set of decision alternatives at the onset of a maintenance event.

Subsequently, the decision alternatives have to be evaluated and compared in a structured, reproducible and valid manner, leading to selection of the most appropriate option. Numerous methodologies have been proposed in literature, including numerous applications in the maintenance domain. Examples include the **Weighted Sum Method (WSM)** (Al-Najjar and Alsyouf, 2003; Ben-Arieh and Triantaphyllou, 2002; Bevilacqua and Braglia, 2000; Gorsevski et al., 2012; Govindan et al., 2015; Kabir et al., 2014; Kannan et al., 2013; Liang et al., 2015; Massei et al., 2014; Pohekar and Ramachandran, 2004; Rezaei, 2015; Tacnet and Dezert, 2011; Yager, 1988; Yager and Alajlan, 2016; Yager and Kacprzyk, 2012), **Analytical Hierarchy Process (AHP)** (Al-Najjar and Alsyouf, 2003; Bevilacqua and Braglia, 2000; Cheung et al., 2005; Govindan et al., 2015; Ho et al., 2010; Kabir et al., 2014; Kannan et al., 2013; Macharis et al., 2004; Machiwal and Singh, 2015; Majumder, 2015; Massei et al., 2014; Pires et al., 2011; Pohekar and Ramachandran, 2004; Rezaei, 2015; Saaty, 1990, 2008; Sadiq and Tesfamariam, 2009; Shyjith et al., 2008), **Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE)** (Brans, 1982; Brans and Vincke, 1985; Kabir et al., 2014; Majumder, 2015; Pohekar and Ramachandran, 2004), **Elimination and Choice Expressing Reality (ELECTRE)** (Banayoun et al., 1966; Cheng et al., 2002; Kabir et al., 2014; Majumder, 2015; Massei et al., 2014; Pohekar and Ramachandran, 2004), **Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)** (Al-Najjar and Alsyouf, 2003; Boran et al., 2009; Ching and Yoon, 1981; Govindan et al., 2015; Kabir et al., 2014; Kannan et al., 2013; Liang et al., 2015; Opricovic and Tzeng, 2004; Pohekar and Ramachandran, 2004; Shyjith et al., 2008; Yoon and Hwang, 1995), **Boolean Decision Tree (BDT)** (Aitkenhead, 2008; Barros et al., 2015; Breslow and Aha, 1997; Buhrman and De Wolf, 2002; Freund and Mason, 1999; Guisan and Zimmermann, 2000; Heiman and Wigderson, 1991; Kotsiantis, 2013; Nisan and Szegedy, 1994; Saks and Wigderson, 1986; Tsang, 1995), and **Compromise Programming (CP)** (Ho et al., 2010; Kabir et al., 2014; Majumder, 2015; Pohekar and Ramachandran, 2004). For detailed discussions of the benefits and drawbacks of each method, please refer to Triantaphyllou et al. (Triantaphyllou, 2000; Triantaphyllou et al., 1997).

A general drawback of each of these methods is that the various forms of uncertainty (Sadiq and Tesfamariam, 2009) (including ambiguity and/or vagueness) which are typically present in decision making processes are not or not fully taken into account (Celik et al., 2015; Kahraman et al., 2015; Mardani et al., 2015). To resolve this issue, fuzzy methods have been developed and combined with MCDM methods (Boran et al., 2009; Celik et al., 2015; Kahraman et al., 2015; Mardani et al., 2015). In general, fuzzy methods are used for two reasons (Mardani et al., 2015):

1. To formalize language-based weights by decision makers into a quantified approximation;
2. To aggregate multiple individual decision maker weight sets into a group decision weight set.

Both reasons are of relevance within the maintenance MCDM context. In some cases, quantified information is not available to support criteria weighting efforts. Fuzzy logic can then be used to mesh a quantitative approach with qualitative representation (Al-Najjar and Alsyouf, 2003). Moreover, in many instances it can be necessary to aggregate individual decision maker weight sets into a grouped representation, as decision making processes in maintenance are likely to be pursued in team settings, especially for capital-intensive assets. Within maintenance, application of fuzzy methods is primarily considered for inventory decision making (Kabir and Akhtar Hasin, 2013; Kannan et al., 2013) and for selection of efficient maintenance approaches (comprising strategy, policy or philosophy) (Al-Najjar and Alsyouf, 2003). However, if a single decision maker is involved and he/she can provide quantitative weights or easily explore a range of weights, the use of fuzzy logic to augment MCDM is not necessary.

1.3. Objective and structure

This paper proposes a systematic approach for maintenance decision making at the operational level, considering maintenance events which must be resolved within a time horizon of a few days. This approach is able to identify feasible maintenance options based on operational factors, and subsequently evaluates the options using weighted criteria. It consequently addresses the three gaps in research identified above: 1) maintenance decision making at an operational level, covering 2) option identification and 3) structured comparison and evaluation of decision alternatives. The contribution is application-oriented in nature, emphasizing the integration of existing methods to fill a gap in systematic decision making on an operational level within maintenance processes.

The remainder of the paper is structured in three main sections. First, the methodology section details the selected MCDM models on the basis of several application criteria and functional differences between the models. The proposed multi-criteria decision making model consists of two modules: a Boolean decision tree and a weighted sum multi-criteria decision making model. Subsequently, the Results section demonstrates how the model has been implemented, gives an application of the model on an actual damage of a Boeing 777 outboard flap as a representative example of an operational decision making process in (aircraft) maintenance, and provides sensitivity analysis. Validation with respect to the presented application is discussed in Section 4. Finally, conclusions based on the findings of the research are presented, along with recommendations for future expansion.

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