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A Multi-Criteria Group Decision To Support The Maintenance Service: A Case Study

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Abstract

The present paper wants to propose a methodology to support a group of decision makers into the choice of actions, to implement on a multi-component system, regarding the maintenance service. The choice has to be made on the basis of several criteria, namely the total maintenance cost, the system unavailability and by considering the maintenance actions feasibility. In particular, with the aim to select the maintenance service that represents for the group the best comprise among the criteria to satisfy, the proposed methodology consists of two multi-criteria decisions methods to apply in two successive phases. The first one regards the application of the Analytic Hierarchy Process (AHP) to assigns weights to the different considered criteria and the second one concerns the implementation of the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method.In order to illustrate the proposed methodology, a case study is presented.

Keywords:maintenance service quality, AHP, TOPSIS, multi-criteria-decision-method

1. Introduction

The tackled problem concerns a group decision to make among more possible maintenance actions defined by the maintenance service. Each action represents a maintenance planto be carried out within a finite horizon. The choice has to be made on the basis of several criteria that reflect the point of view of the analysts responsible of the maintenance service (Lupo, 2013a). Since these aspects are fundamentally conflicting one with each other, the multi-criteria decision methods represent a valid supporting tool, especially when there are diverse decision makers involved in the choice as herein hypothesized.

The present research is developed on the basisof previous researches (Certaet al., 2013; Certaet al., 2012a; Lupo, 2014a).In particular, the dealt problem regards the selection of a maintenance plan to implementon a multi-component system. In particular, the maintenance plan to be selected suggests the set of the maintenance actions to be performed at each scheduled inspection of the system within a finite time horizon. The choice has to be made among different solutions, previously determined (Certa et al. 2012b) by ensuring the simultaneous minimization of both the total maintenance cost, the system unavailability and the actions feasibility to implement. The proposed methodology consists into a combined approach based on AHP (Saaty, 2000) and TOPSIS multi-criteria decision methods (Hwang and Yoon, 1981; Hwang et al. 1993).In particular, since diverse decision makers are involved and different criteria have to be considered, AHP is suggested as a tool to assign weights to criteria, while TOPSIS is proposed as a tool to select the maintenance plan.

AHP is a multi-criteria decision method widely used in several research area for its simplicity and the opportunity to take into account different qualitative-quantitative and also conflicting factors. Recently, AHP has been applied in logistic field (Opasanon and Lertsanti, 2013), educational field (Certa et al. 2015; Lukman, 2010), transport field (Berrittellaet al.,2008; Lupo 2015a;Lupo 2013b), partner selection in a scientific collaboration environments (Shall, 2014), water management (Srdjevic, 2007), *etc.*.As stressed by Escobar et al. (2004), one of the main characteristics of this approach regards the possibility to measure the inconsistency of the decision maker about his/her judgments and the possibility that AHP offers in group of decision makers.

Regarding the maintenance field, Bevilacqua and Braglia (2000) propose the use of the AHP for selecting the best maintenance strategy among preventive, predictive, condition-based, corrective and opportunistic for the critical items of an important Italian oil refinery. Carnero (2005) proposes a model for the selection of the diagnostic techniques and instrumentations in the predictive maintenance programs. Pariazaret al. (2008) suggest the use of the AHP to select the maintenance strategy by considering cost, safety, execution capability as evaluation criteria. Given the high number of considered criteria, the Authors propose a methodology to reduce the inconsistency of the comparison judgments that often affects the AHP method. More recently, Arunraj and Maiti (2010) apply an approach based on the AHP and goal programming for the maintenance policy selection by proposing a case study related to a benzene extraction unit of a chemical plant. Papakostaset al. (2010) propose a multi-criteria methodology to support the decision maker on the choice of maintenance actions to be carried out on an aircraft, aiming at high fleet operability and low maintenance cost. Ahmadi et al.(2010) present a method to rank the maintenance policies alternatives by using the benefit-cost ratio, TOPSIS and VIKOR. The weights of the criteria to evaluate the maintenance strategies are determined by the use of AHP. Recently, also suitable statistical tools based on for attributes (Inghilleri et al 2015; Lupo, 2015b) or for variables (Lupo, 2014b) controlcharts are considered to support the choice of maintenance actions to be performed on a multi-component system

As already said, the TOPSIS method is proposed for the step regarding the selection of the maintenance plan. As recently stressed by Kumar and Agrawal (2009), the TOPSIS method helps the decision maker(s) to organize the problem to be solved and to carry out analysis, comparisons and ranking of the alternatives.The TOPSIS method has been applied in different fields in which its effectiveness has been shown. For example, the method has been applied into the environmental management area (Kalbaret al.,2012), cell formation and intracellular machine layout problem (Ahi et al., 2009), risk management process (Zhang et al., 2013; KamiriAzariet al. 2011), project portfolio management (Kao et al., 2006). The TOPSIS is suggested by Sachdevaet al. (2009) also as an alternative method to the traditional approach of failure mode and effect analysis (FMEA) for prioritizing failures causes.

2. Proposed approach

The combined procedure previously introduced is applied to select the best maintenance plan, among the set of alternatives belonging to the Pareto frontier. The last one is related to objectives that in choice phase herein considered represent the criteria.In particular, each non dominated solution represents the set of system elements to be replaced at each scheduled system inspection, in order to ensure the minimization of the expected total maintenance cost, the expected global system unavailability and the unfeasibility of the maintenance actions.The last one criterion takes into account the difficulties related to the actions indicated by the maintenance plan, to implement. These difficulties are due to operating conditions as availability of maintenance crews and resources, risks for workers, etc..Since the decision could be made by more than one decision maker and the Pareto optimal frontier includes lots of solutions, AHP and TOPSIS areproposed to assign the weights to the criteria and to select the best solution respectively. In the next sections the two methods are shortly described.

2.1. Group decision making procedure for criteria weights assignment

Saaty(2000) provided a theoretical foundation for AHP that is a multi- criteria decision method which can be used to solve complex decision problems taking into account tangible and intangible aspects. The method supports the decision makers to make decisions, by means pairwise comparison judgments, on the basis of their experience, knowledge and intuition. AHP decomposes the decisional problem into a hierarchy structure according to the specific characteristics of the analysed problem.

In a group decision making process as that herein proposed, the AHP method requires that each decision maker expresses the pairwise comparison judgments on a set of elements (in this case the evaluations of the different decision makers on the relative importance of the criteria). Successively, the method provides to aggregate these judgments into a matrix and to derive the relative priorities on the evaluated elements.

2.2Selection procedure

This phase is carried out by means the TOPSIS method. TOPSIS is a multi-criteria method that provides an ordered ranking of alternatives by a compensatory aggregationon the basis of different criteria.The fundamental concept of the TOPSIS is that the choice of the alternative to be selectedhas to be made on the basis of the distance respect to the ideal and the nadir alternatives. That is, the alternative that represents the best compromise has to be characterized, respect to the other alternatives, by a minor distance from the ideal alternative and the major distance from the nadir alternative. This multi-criteria method requires as input data the decisional matrix (related to the assessment of each alternative respect to the all evaluation criteria) and a criteria weights vector that reflects the decisional context in which the decision makers have to operate.

The TOPSIS method is organized into the following steps:

1. To define the decisional matrix in which the scores g_{ij} of each alternative *i* obtained for each criterion *j* are collected;

2. To calculate the weighted and normalized decisional matrix in which the generic element is:

$$u_{ij} = w_j \cdot z_{ij} \quad \forall i, \forall j \tag{1}$$

where w_j is the weight for the generic criterion *j* and $z_{ij}$is the score g_{ij}normalized by:

$$z_{ij} = \frac{g_{ij}}{\sqrt{\sum_{i=1}^{n} g_{ij}^{\ 2}}} \ \forall i, \forall j \tag{2}$$

3. To identify the ideal point **A*** and the nadir point **A⁻** by means of the following equations:

$$A^* = u_1^*, ..., u_k^* = \left\{ \left(\max_{\forall i} u_{ij} \,\middle|\, j \in I' \right), \left(\min_{\forall i} u_{ij} \,\middle|\, j \in I'' \right) \right\},$$

$$A^- = u_1^-, ..., u_k^- = \left\{ \left(\min_{\forall i} u_{ij} \,\middle|\, j \in I' \right), \left(\max_{\forall i} u_{ij} \,\middle|\, j \in I'' \right) \right\} \tag{3}$$

in which *I'* is the subset of the criteria to be maximized and*I''*is the subset of the criteria to be minimized.

4. To calculate the distance of each alternative from the ideal point A* and the nadir point A^- by means:

$$S_i^* = \sqrt{\sum_{j=1}^{k}(u_{ij} - u_j^*)^2} \quad i = 1, \cdots, n$$

$$S_i^- = \sqrt{\sum_{j=1}^{k}(u_{ij} - u_j^-)^2} \quad i = 1, \cdots, n \tag{4}$$

5. To characterize each alternative by the following expression that favors the alternative characterized by a major distance from the nadir:

$$C_i^* = S_i^- /(S_i^- + S_i^*) \quad 0 \le C_i^* \le 1 \quad \forall i \tag{5}$$

6. To rank the set of the alternatives on the base of the following rule:

if C_l*>C_m*

than
the alternative *l*has to be preferred to the alternative*m*.

3. Case study
The proposed combined multi-criteria approach aiming at selecting one of the Pareto solutions belonging to the Pareto frontier, supposed supplied by the maintenance service and described in table 1. The versus of preference for each criterion is decreasing.

Table 1-Pareto frontier

Solution	Cost (C.)	Unavailability (U.)	Maintenance plan unfeasibility(M.P.UF.)
1	16587.62	54.34	0.026
2	11226.65	61.85	0.061
3	10993.72	70.98	0.112
4	10447.96	71.63	0.166
5	9044.43	75.64	0.246
6	8964.97	86.75	0.338
7	8504.73	92.69	0.051

Three decision makers are supposed to be involved in the decision process. The following matrices show the pairwise comparison judgments on criteria weights expressed by each decision maker and the corresponding aggregated matrix. By observing the values of the weight vectors, it is possible to note as the three decision makers privilege the first, the second and the third aspect respectively.

Table 2- Decision maker #1pairwise comparisons

	C.	U.	M.P.UF.	Weight
C.	1	3	4	0.63
U.	0.33	1	0.5	0.15
M.P.F.	0.25	2	1	0.22

Table 3 - Decision maker #2 pairwise comparisons

	C.	U.	M.P.F.	Weight
C.	1	0.25	3	0.21
U.	4	1	7	0.71
M.P.F.	0.33	0.14	1	0.08

Table 4 - Decision maker #3 pairwise comparisons

	C.	U.	M. P. UF.	Weight
C.	1	1	0.5	0.23
U.	1	1	0.25	0.18
M.P.F.	2	4	1	0.59

Table 5–Decision makersgroup aggregated pairwise comparisons

	C.	U.	M.P. UF.	Weight
C.	1	0.91	1.81	0.39
U.	1.1	1	0.95	0.34
M.P.F.	0.5	1.04	1	0.27

By applying the TOPSISmethod, taking into account theweights obtained by means of the group decision (table 5), the ranking of table 6 is obtained. Thus the maintenance plan related to the solution 2 is selected as maintenance plan representing the best compromise.

Table 6-Ranking of the alternatives

Solution	C*
2	0.81
7	0.75
3	0.71
1	0.64
4	0.60
5	0.47
5	0.35

Conclusions

The research proposes a structured methodology to support a decision makers group in the choice of the best maintenance plan suggested by the maintenance service.In particular, a combined approach that proposes the use of AHP and TOPSIS multi-criteria methods is suggested in a multi-decision-makers environment. The first one, with the aim to assign relative priority to criteria, permits to aggregate judgments expressed by the decision makers, taking into account the different influence of each of them and the second one allows to easily select the plan by means a simple quantitative procedure.

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