A multi-decision makers approach to select the maintenance plan for a multi-component system

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Abstract - The present paper proposes an approach integrating two multi-criteria decision methods in order to select the maintenance plan for a multi-component system. 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 by ensuring the simultaneous minimization of both the total maintenance cost and the system unavailability. In particular, the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods are proposed in a multi-decision-makers environment.

1. Introduction

The tackled problem concerns a group decision regarding the selection, among more maintenance plans, of the one to be carried out within a finite horizon. The choice has to be made on the basis of different criteria that reflect the point of view of the analysts. 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.

In particular, the dealt problem regards the selection of the maintenance strategy to implement. Such an issue has been tackled by means of different approaches based on multi-criteria decision making methods. Bevilacqua and Braglia [1] propose the use of the Analytic Hierarchy Process (AHP) [2] 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 [3] proposes a model for the selection of the diagnostic techniques and instrumentations in the predictive maintenance programs. The proposed approach consists in the combination of AHP and the Factor Analysis. Pariazar *et al.* [4] 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 [5] propose an approach based on the AHP and goal programming for the maintenance policy selection applied to a case study related to a benzene extraction unit of a chemical plant. Papakostas *et al.* [6] propose a multi-criteria methodology to support the decision maker about maintenance actions to be carried out on an aircraft, aiming at high fleet operability and low maintenance cost. Ahmadi *et al.*[7] 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.

The present research constitutes a development of a previous one [8] in which a multi-objective approach to find a set of non-dominated maintenance policies for a multi-component system has been proposed. In particular, the research aims at suggesting a structured method to support the decision makers group in the choice of the best Pareto solution, *i.e.* the best maintenance plan. Since diverse decision makers are involved and different criteria have to be considered, the AHP method is proposed as a tool to assign weights to criteria, while the TOPSIS method is suggested as a tool to select the maintenance plan. In other fields of research like transport [9], water management [10], software selection [11] the AHP method is proposed as a tool to make group decisions when more stakeholders, having interests conflicting one with each other, are involved with the aim to derive the priorities regarding the aspects in respect of which to make decisions.

As stressed by Escobar *et al.* [12], the main characteristics of this approach regard the possibility to measure the inconsistency of the decision maker about his/her judgments and the possibility that the AHP offers in group decision making.

As already said, the TOPSIS method is proposed for the selection step. As recently stressed by Kumar and Agrawal [13], 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 to environmental management [14], cell formation and intracellular machine layout problem [15], risk management process [16], [17], project portfolio management [18]. The TOPSIS is suggested by Sachdeva *et al*. [19] also as an alternative method to the traditional approach of failure mode and effect analysis (FMEA) for prioritizing failures causes for a pulping system of a paper mill.

2. Proposed approach

The procedure previously introduced is applied to select the best maintenance plan among the set of alternatives belonging to the Pareto frontier.

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 both the expected total maintenance cost and the expected global system unavailability. The Pareto frontier has been obtained in the already cited work [8] by formulating the problem as a multi-objective nonlinear integer mathematical programming and applying the ε-constraint method. The latter method assures the exploration of the entire Pareto frontier also in the presence of non convex region [20]. Since the decision could be made by more than one decision maker and the Pareto optimal frontier includes lots of solutions, Analytic Hierarchy Process and TOPSIS are proposed 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

In a group decision making process, the AHP method requires that each decision maker expresses the pairwise comparison judgments on a set of elements (in this case the criterion and the solutions assessment in respect to the managerial complexity aspect). Successively, the methods provides to aggregate these judgments into a matrix and to derive the relative priorities on the evaluated elements.

2.2 Selection of the maintenance plan by TOPSIS method

The Topsis method was originally proposed by Hwang and Yoon [21] and further developed by Hwang *et al.* [22].

The Topsis is a multi-criteria method that provide an ordered ranking of alternatives by a compensatory aggregation on the base of different criteria.

The fundamental concept of the TOPSIS is that the choice of the alternative to be selected has to be made on the base 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:

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

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

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

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

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

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

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 these metrics:

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

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

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

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

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. Numerical example

The final step of the proposed approach is to determine the more satisfying maintenance plan with relation to the considered criteria. As said before, the Pareto frontier solutions herein analyzed (table I) are those ones obtained in the previously cited paper [8] by optimizing both the related system cost and the unavailability. By analyzing the maintenance plans, for the sake of simplicity not reported here, decision makers become more aware of the different complexity in managing the maintenance plan. Thus they consider worthwhile in the process selection of the best solution another criterion that reflect this aspect. After all, this is one important advantage of the optimization process based on two steps: preliminary determination of alternatives on which pay attention (Pareto solutions) and successive detailed analysis of the Pareto solutions on the base of further aspects that often derive from the knowledge of the alternatives. Thus, in table I the third criterion is added. Then, the decision makers have to supply the pairwise comparisons between alternatives with relation such a criterion. Also in this case, the AHP method is employed and results are reported in the third column (matrices of pairwise comparisons are not reported here just for lacking of space).

TABLE I. ASSESSMENT OF THE ALTERNATIVES

Solution	Cost	Unavalibility	Managerial complexity
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 (tables II-IV) show the pairwise comparison judgments on criteria weights expressed by each decision maker and the corresponding aggregated matrix (table V). 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 II. DECISION MAKER 1 - PAIRWISE COMPARISONS

	C.	U.	Compl. Manag.	Weights
C.	1	3	4	0.63
U.	0.33	1	0.5	0.15
Compl. Manag.	0.25	2	1	0.22

TABLE III DECISION MAKER 2 PAIRWISE COMPARISONS

	C.	U.	Compl. Manag.	Weights
C.	1	0.25	3	0.21
U.	4	1	7	0.71
Compl. Manag.	0.33	0.14	1	0.08

TABLE IV DECISION MAKER 3 PAIRWISE COMPARISONS

	C.	U.	Compl. Manag.	Weights
C.	1	1	0.5	0.23
U.	1	1	0.25	0.18
Compl. Manag.	2	4	1	0.59

TABLE V DECISION MAKERS GROUP AGGREGATED PAIRWISE COMPARISONS

	C.	U.	Compl. Manag.	Weights
C.	1	0.91	1.81	0.39
U.	1.1	1	0.95	0.34
Compl. Manag.	0.5	1.04	1	0.27

By applying the TOPSIS method, taking into account the weights obtained by means of the group decision (table V), the ranking of table VI is obtained. Thus the maintenance plan related to the solution 2 is selected as maintenance plan representing the best compromise.

TABLE VI 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 search for the optimal maintenance plan in a finite horizon is carried out in two steps. Firstly, a set of non-dominated solutions is obtained and subsequently, based on further information, the group of decision makers select the best compromise among the objectives. Starting from the results obtained in a previous paper for the first step of the methodology, in this paper a procedure for the selection of the best alternative is proposed. It is emphasized as the analysis of the Pareto solutions, obtained as output of the first step, permits to the decision makers to take into account to a further aspect on the base of which to select the best maintenance plan. The combined employment of the AHP and TOPSIS methods has shown its effectiveness into to support the decision makers in the decision making process. In particular, it allowed to aggregate judgments expressed by the decision makers respect to a qualitative criterion as the complexity in managing the different maintenance plans (by means of the AHP) and also to aggregate the assessments of the alternative on the base of this criterion and quantitative criteria as cost and unavailability associated to each maintenance plan (TOPSIS).

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