A selective maintenance model based on FITradeoff method

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Abstract. Some aspects of a system operation dynamics may prevent excellence in organizations performance. This is imperative for mission-oriented systems since all necessary interventions have to be undertaken during the stoppages between successive missions. Maintenance models that deal with it, however, do not take into account that aspects, such as the length of stoppages or constraints on the maintenance resources. These constraints limit the set of actions that can be carried out during each stoppage. Thus, it should be selected the maintenance actions that would best improve system performance, observing constraints. Traditionally, models that address this issue seek to optimize one of the performance indicators of a system. Thus, an original contribution of this paper is to optimize conflicting indicators through a multicriteria perspective by considering the preferences of the decision maker. Therefore, it has been used FITradeoff (Flexible and Interactive Tradeoff) method in order to asses a global performance value to each alternative. At last, the obtained plan is compared to the one obtained in a traditional way.

1. Introduction

The performance of organizations depends on the choice of an appropriate maintenance strategy (BOGONOVO, MARSEGUERRA and ZIO, 2000). This is evident for mission-oriented systems, since the set of maintenance actions to be executed in this system depends on the duration of stoppages between missions (PANDEY et al., 2013).

In addition to the fact that the majority of the models dedicated to determining maintenance strategy, in that case, neglect the length of the stoppages, they ignore constraints on the maintenance resources, which also limits the set of actions to be performed (MAILLART et al., 2009).

Thus, one should identify, among the possible actions, those that best improve system performance, while not violating constraints. This problem is called Selective Maintenance Problem (LIU and HUANG, 2010). The traditional formulations of this problem aim to determine a subset of actions that produces a great system performance in terms of maintenance cost, average system reliability or maintenance duration.

Depending on the context, system performance is better described in terms of one of those indicators. Therefore, it the indicators sometimes as the objective function, sometimes as a constraint. In a complementary way, Ribeiro, Cavalcante and Rodriguez (2017) embedded the decision maker (DM) aspirations into the model as a reliability constraint. Besides, authors pointed the importance of contemplating DM preferences in a deeper perspective - through treating selective maintenance as a multiple objective problem. This insight figures out as the original contribution of this paper.

2. Methodology

Multicriteria Decision Aid (MCDA) approach considers DM preferences in order to unify objectives in a multiple objective environment. Preferences, in turn, are based on a subjective evaluation of each decision criteria (DE ALMEIDA et al., 2015).

This evaluation, however, is not an easy task since it depends on the knowledge and understanding of the objectives and preferences by the DM (GUSMÃO and MEDEIROS, 2016). This fact, combined to the compensatory characteristic of the selective maintenance criteria, delimitate the choice of a Multicriteria Decision Method to tackle with the problem.

Among the possible choices, we elect FITradeoff (Flexible and Interactive Tradeoff) method to elicitate DM's preferences. This method, developed by (De Almeida et al., 2015), is based on the traditional trade-off procedure, conserving its axiomatic structure, but demanding less cognitive effort from the DM, due to the use of partial information (DELL'OVO et al., 2017). Thus, instead of requiring an indifference relation between two values, this method requires a strict preference, turning the process softer.

FITradeoff uses a decision support system (DSS) to achieve results. While the DM shows their preferences, the DSS evaluates the alternatives through a linear programming problem (LPP). The process finishes when a unique solution is found. This process is illustrated in Figure 1.

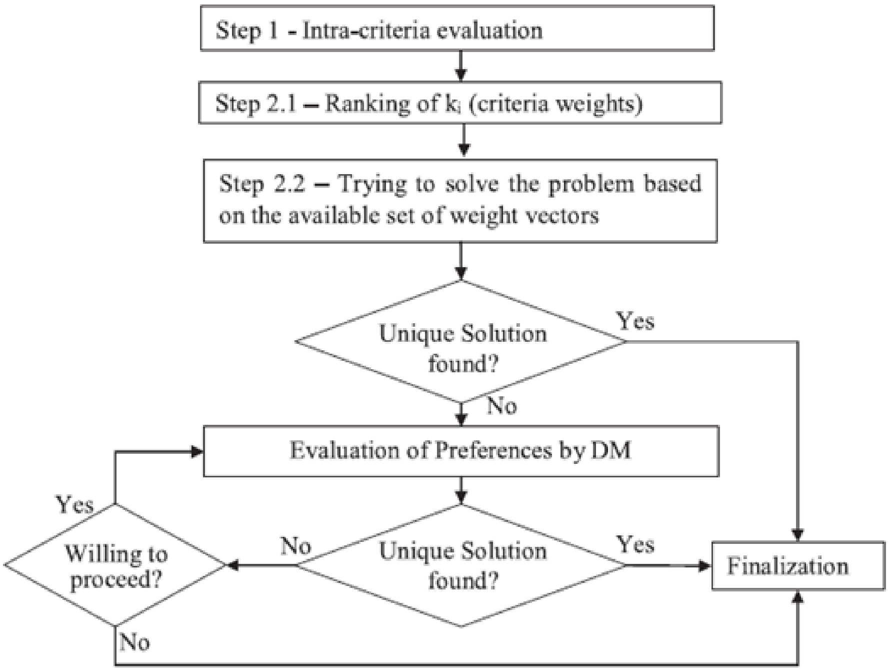

Figure 1 - Source: De Almeida et al (2015)

2. System Description and Criteria Definition

Consider a system *S* composed by *n* subsystems S_i (i=1, ...,n) connected in series, each consisting of N_i components C_{ij} (j=1,...,N_i) arranged in parallel. This system operates *M* missions, with known duration *U(m)* (*m=1,...,M*), such that, after a mission, a stoppage, also with known duration *D(m,l)* (*m=1,...,M-1; l=m+1*), figures as an opportunity for executing maintenance.

Assume that each of the components may be in operational or failed state. Failure occurs within a mission and is related to the component's virtual age (NAKAGAWA, 1988). Setting $A_{ij}(m)$ and $B_{ij}(m)$, the virtual ages of component C_{ij} , respectively, at the beginning and at the end of the *m*-th mission, the reliability $R_{ij}(m)$ of component C_{ij} is obtained from:

$$R_{ij}(m) = \exp\left(-\int_{A_{ij}(m)}^{B_{ij}(m)} h_{ij}(t)dt\right). \quad (1)$$

where $h_{ij}(t)$ corresponds to the risk function of component C_{ij}. From equation 1, it follows that the subsystem S_i and system *S* reliabilities, denoted by $R_i(m)$ and *R(m)*, are given by:

$$R_i(m) = 1 - \prod_{j=1}^{N_i}\left(1 - R_{ij}(m)\right). \quad (2)$$

$$R(m) = \prod_{i=1}^{n} R_i(m). \quad (3)$$

Such system is minimally repaired, if a component fails during a mission. This intervention restores the operational state of the component, has negligible duration and a cost cmr_{ij} inherent to component C_{ij}. Within a stoppage, components can be preventively maintained, either perfectly or imperfectly. These effects are modeled by an age reduction coefficient $\alpha(p) \in [0,1[$, inherent to action *p*, that updates components' virtual ages.

In this sense, the *P* preventive actions that can be performed on system's components are displayed in vector *VPM* = [a_1,...,a_p, ..., a_P]. For every action a_p (p = 1,...,P) it is defined an age reduction coefficient $\alpha(p)$, a cost $cpm(a_p)$ and a duration $dpm(a_p)$, as well as a set of components on which the action can be performed $Comp(a_p)$.

The total maintenance cost C_{total} consists in the sum of three parcels: the minimal repair cost CMR; the preventive maintenance cost CPM; and a penalty cost CPAR, related to the system failure probability during a mission. These values are explicit by the equations:

$$CMR = \sum_{m=1}^{M}\sum_{i=1}^{n}\sum_{j=1}^{N_i} cmr_{ij}\int_{A_{ij}(m)}^{B_{ij}(m)} h_{ij}(x)dx. \quad (4)$$

$$CPM = \sum_{i=1}^{n}\sum_{j=1}^{N_i}\sum_{m=1}^{M-1}\sum_{p=1}^{P}\left(cpm(a_p).a_p(C_{ij},m)\right). \quad (5)$$

where $a_p(C_{ij},m)$ is a binary decision variable which assumes non-zero value if the action a_P is performed on component C_{ij} at the m-th stoppage.

$$CPAR = \sum_{m=1}^{M}\left(1-\prod_{j=1}^{n}(1-\prod_{j=1}^{N_i}\left(1-R_{ij}(m)\right))\right) cpar. \quad (6)$$

where *cpar* is a fee, related to system failure probability.

Total maintenance duration *DPM* is given by the expression:

$$DPM = \sum_{m=1}^{M-1}\sum_{p=1}^{P}\sum_{i=1}^{n}\sum_{j=1}^{N_i} dpm(a_p).a_p(C_{ij},m). \quad (7)$$

3. Numerical Example

In order to illustrate the application of the multicriteria approach, it have been made a numerical application. Therefore, we used an instance based on that found in Ribeiro, Cavalcante and Rodriguez (2017). The instance consists in a series-parallel system consisting on $n=2$ subsystems, compound, respectively, by N_1 = 2 and N_2 = 4 components. The reliability of each component is established from the risk function of a Weibull distribution, which shapes γ_{ij} and scale β_{ij} parameters, as well as the minimum repair costs cmr_{ij} are detailed in table 1.

Table 1. Parameters of system components.

C_{ij}	C_{11}	C_{12}	C_{21}	C_{22}	C_{23}	C_{24}
β_{ij}	1.2	1.4	2.8	1.5	2.4	2.2
γ_{ij}	26	35	40	35	30	45
cmr_{ij}	3	6	7	4	6	3

This system is oriented to perform 2 missions of 25 time units each, such that between this missions it is planned a stoppage lasting for 5 time units; *cpar,* in turn, is settled in 35 monetary units. Furthermore, Vector VPM and the parameters of the P preventive actions that can be performed on the system are shown in table 2.

Table 2. Vector *VPM* configuration

p	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Comp	C_{11}			C_{12}			C_{21}			C_{22}			C_{23}			C_{24}		
α	1.0	0.6	0.0	1.0	0.5	0.0	1.0	0.6	0.0	1.0	0.4	0.0	1.0	0.3	0.0	1.0	0.4	0.0
com	0.0	8.3	12.5	0.0	9.2	15.4	0.0	6.0	13.9	0.0	7.9	12.0	0.0	6.7	14.0	0.0	7.8	16.5
dpm	0.0	0.3	2.4	0.0	0.4	1.8	0.0	0.3	1.8	0.0	0.5	2.3	0.0	0.5	3.0	0.0	0.5	2.6

Due to the small magnitude of the instance, it was efficient using exhaustive enumeration to list all the maintenance plans that could be executed during the stoppage. Each plan figures as an alternative for the FITradeoff method. Plans are represented by matrices such that a cell value indicates the kind of action to be performed in the component given by the matrix column. For that, components are sorted from the first component in the first subsystem to the last component in the last subsystem.

Overall, 3^6 = 729 alternatives have been generated. of wich 152 were dominated ones. FITradeoff method was applied for the lasting alternatives. For this we used a FITradeoff application software developed by CDSID, a laboratory at Federal University of Pernambuco, Brazil.

As previously announced, the preference relations (instead of indifference relations) of FITradeoff method speed up the decision procedure. We made a simulated application of the method (Figure 2), firstly a rank of the weight criteria was indicated, as presented in Figure 3, and, after three simple questions (Figure 4), it was found the alternative that better fits DM preferences (Figure 5). This alternative is plan number 223 [1 6 9 10 15 16], which indicates that components 2, 3 and 5 should be replaced in the stoppage.

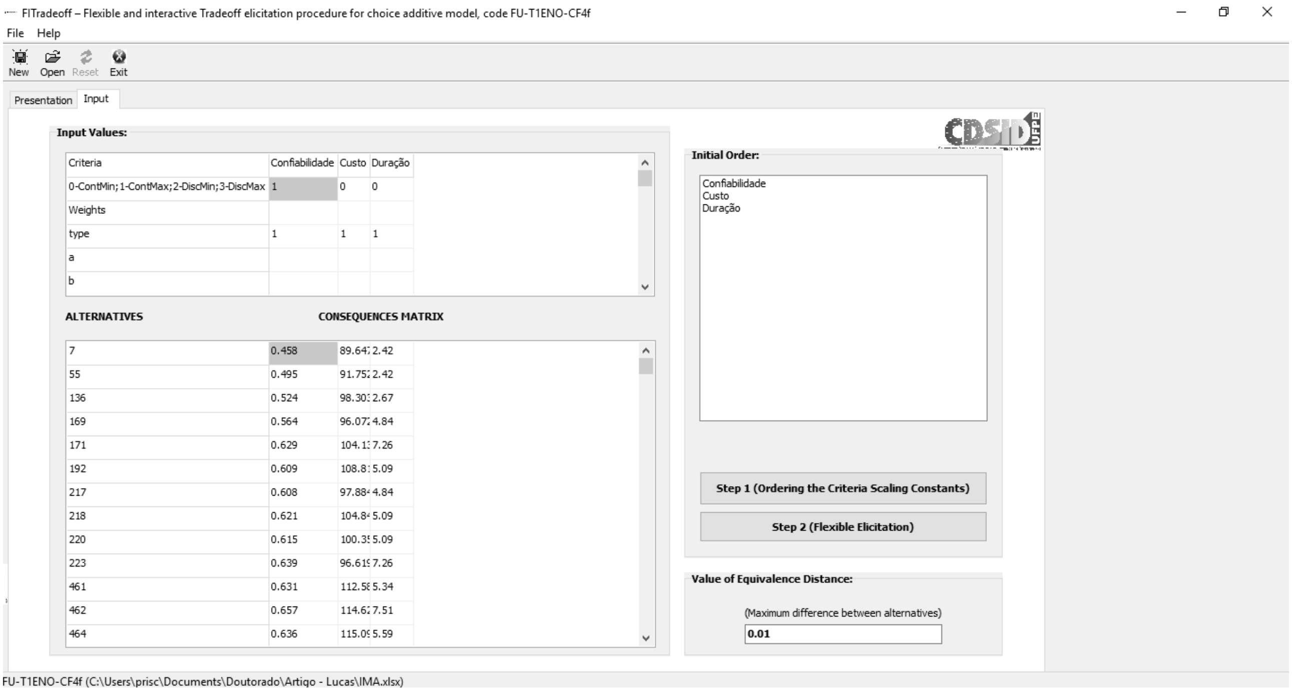

Figure 2 – Interface of FITradeoff software

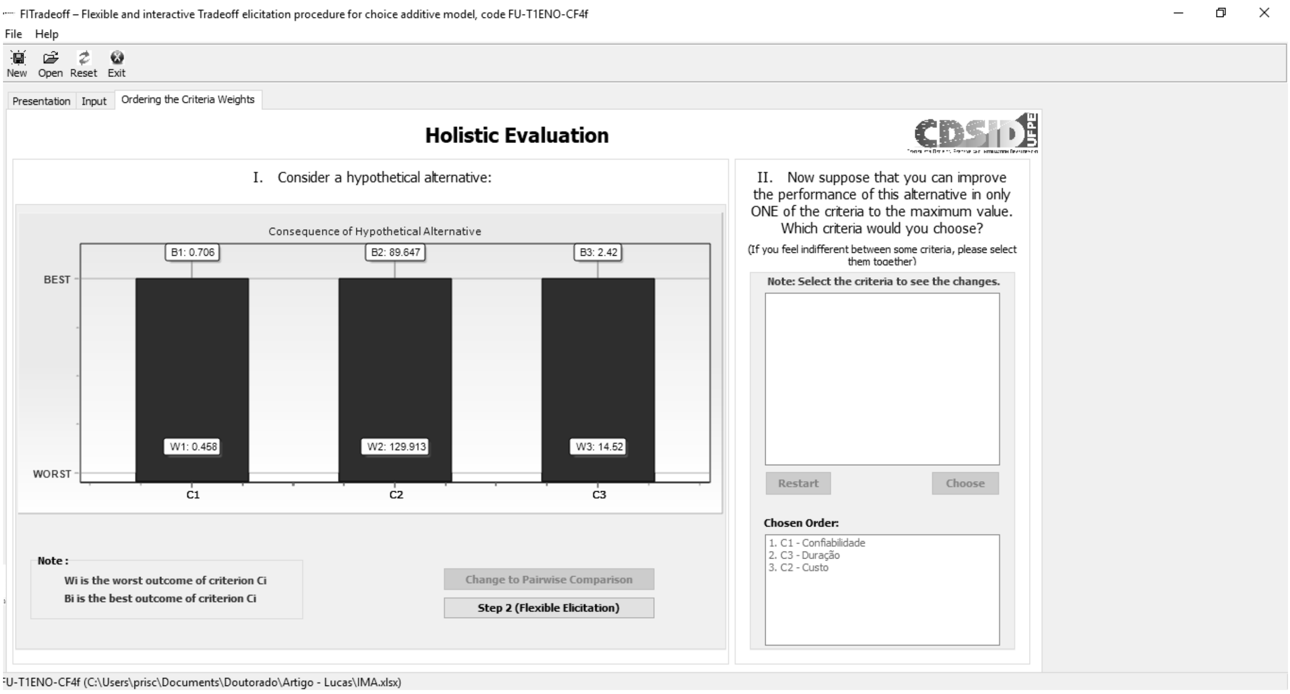

Figure 3: Rank of weight criteria

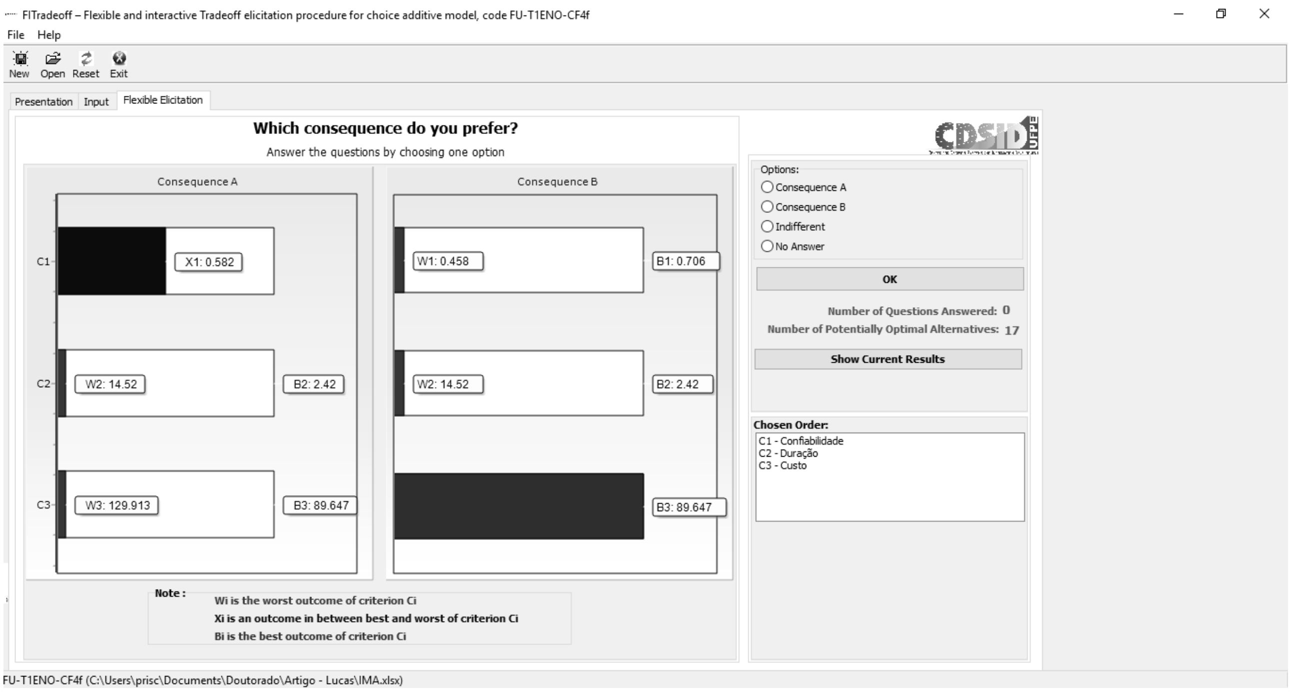

Figure 4 – First question of the elicitation procedure

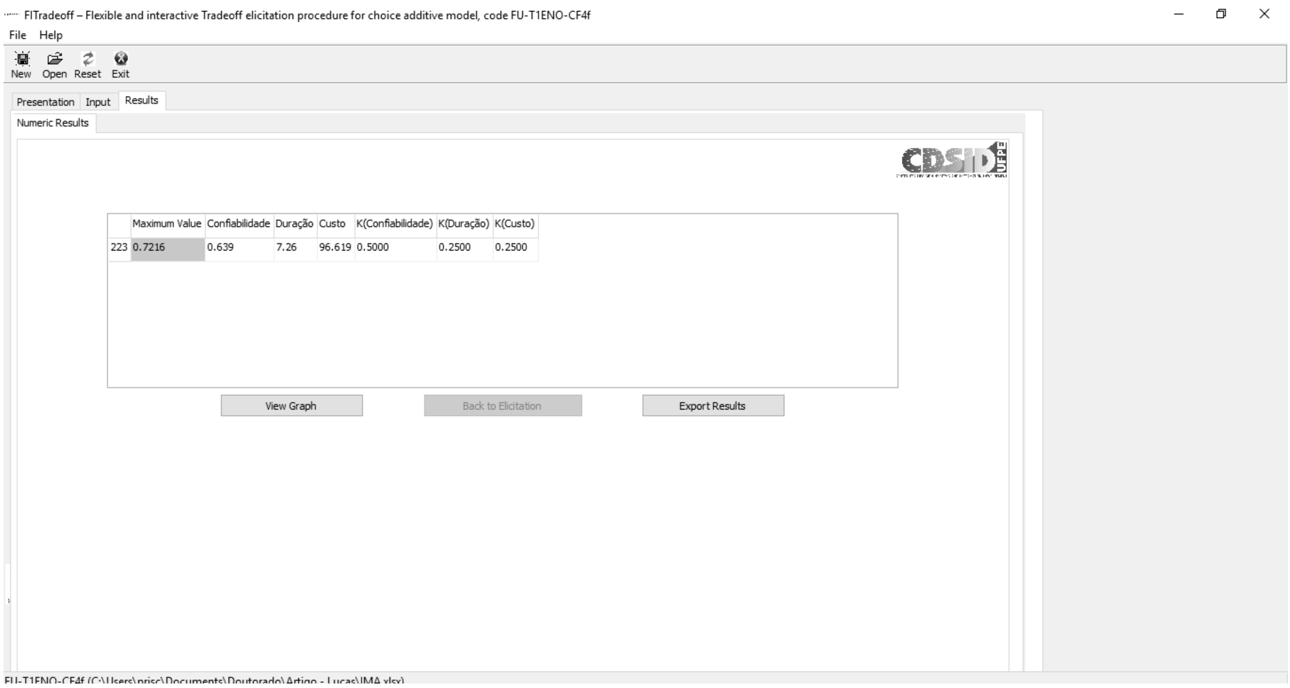

Figure 5 – Results of elicitation

Applying the traditional approach in a service context (minimize maintenance duration, observing cost and reliability constraints), alternative 217 [1 6 9 10 13 16] – that indicates a replacement on components 2 and 3 during the stoppage - figures as the best one. Table 3 states a comparison between the two alternatives.

Table 3. Comparison between the performance indicators for both alternatives.

Alternative	217	223
Reliability	0.61	0.64
Cost	97.9	96.6
Duration	4.8	7.3

While the traditional approach gives the alternative with the smallest maintenance duration, observing the cost (<100) and reliability (>60) constraints; FITradeoff gives an alternative that translates DM preferences. Thus, multicriteria approach clearly modifies problem perspective.

4. Conclusions

This paper contributes to the Selective Maintenance since it brings a new perspective of treatment to the problem. A numerical application illustrate the easy and intuitive use of the method. In comparison to the traditional approach, multicriteria method conducted to a solution that fits DM preferences. Future work should invest in larger horizon (multiple missions) problems, following the literature trend.

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