Multicriteria Model to Support A Definition of a Maintenance - Spare Parts Policy

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Abstract. The maintenance became one of the primaries factors in guaranteeing the proper functioning of a productive system. Despite this, some assumptions assumed by maintenance planning are not fully complied with, such as the availability of spare parts whenever its need. Hence, the integrated models of inventory maintenance and management came out, used to seek the levels that best fit for the two policies. Integration is usually based on the criteria of total costs, but not always this factor is the only interest of the decision maker. Therefore, the present work aims at the construction of a multicriteria model to support an application of an integrated model developed in a previously work. New criteria have been introduced as choice dimensions and an outranking method was developed using PROMETHEE II to generate an order of values that reflects the interests of the decision maker.

1. Introduction

Maintenance is an activity that seeks to ensure the full functioning of the components and, consequently, the achievement of quality. Therefore, through maintenance policies, it is sought to reduce the impact of machine breaks in production (Chen et. al. 2006).

Traditionally, maintenance policies only consider repair or replacement as a consequence of the failure occurrence. That is the reason why the existence of spare parts in stock is a premise (Yoo et al 2001). In practice, the planning and execution of the maintenance model adopted in the production unit directly affects the availability of spare parts in the inventory. Thus, if the level of spare parts was below the quantity requested to make the replacements, the reliability of the system would be affected. On the other hand, if the level was over dimensioned, the maintenance costs of the stock would be high (Rodriguez et al 2016).

For Horenbeek et al. (2013), the joining of maintenance and spare parts takes into account the trade-off between maintenance and stock policies. Authors such as Panagiotidou (2013) and Horenbeek et al. (2013), among others, has studied policies that integrate maintenance planning with the planning of spare parts. However, a fact observed when studying integrated maintenance and inventory policies is what the great majority takes into account only the cost criterion to justify such integration.

According to Jajimoggalla and Beela (2012), some criteria may interfere in decision making regarding spare parts, such as costs, availability and demand. Moreover, according to Triantaphy et al. (1997), maintenance can take into account criteria such as availability, reliability and maintainability. Thus, it is possible to perceive that cost is not necessarily the only criterion that should influence the integration of a maintenance policy with the management of spare parts, since the integration involves two plans that can already be influenced by several criteria.

For Xie and Wang (2008) there is no optimal policy if there is a separate or sequential treatment between dependent models. Therefore, conventional policies are not efficient when they are treated in isolation, being necessary, for a better representation of real problems, an approach that seeks integration between the areas of interest (Panagiotidou, 2013).

As a result of this, authors such as Sarker et al (2000), Armstrong and Atkins (1996), Kabir and Al-Olayan (1996), Elwany and Gebraeel (2007), Xie and Wang (2008), among others, developed models with only one criterion to be achieved to justify the integration. Horenbeek et al. (2013) surveyed the main types of integrated models, which in essence vary according to the premises and conditions established.

Authors such as Panagiotidou (2013) and Rodriguez et al. (2016) integrated the maintenance planning with the management of spare parts defining as the only criterion to be reached the service cost and, thus, find its best alternative using mathematical methods, which are based on the search of the compromise solution of this criterion. However, there is a barrier in optimizing the problem and finding the best alternative when the interest is in more than one criterion. An alternative to this approach is the use of multicriteria models, whose approach is used in some policies of maintenance and management of spares acting in isolated way, as can be seen in Ferreira et al. (2009), Almeida (2001), Wheel et al. (2014), Jajimoggala and Beela (2012), and Shafiee (2015), among others.

Therefore, since an integrated policy is the combination of several models, it can provides a large number of important criteria for the decision maker who wants a comprehensive view on the problem faced. In this sense, it is observed the relevance of the multicriteria approach to support the decision in the context of an integrated maintenance policy and stock of spare parts.

This work has the purpose of using multiple objectives to support the use of integrated policy. According to Almeida et al (2015) it is possible to affirm that multiobjective problems can be approached using MCDM (Multicriteria Decision Models) or Multiobjective Optimization. For this, multicriteria modeling by offering an interaction with the preferences of a decision maker and including its judgment of value was seen as more advantageous for the situation. Since such preferences are obtained from subjective evaluations from the decision maker and they are inherent to reality, thus approaching the modeling of the real problem in order to meet the following objectives: efficiently use resources, increase system availability and reliability, and increase productivity.

2. Structuring and application of the model

The construction of the multicriteria model was based on the integrated policy of maintenance and spare parts developed by Rodriguez (2016), which developed it with focus only as a criterion the total costs. The multicriteria model seeks to determine the best values of the decision variables that determine the option that best answers the preferences of the decision maker. In Figure 1 (Almeida et al. 2015) describes a methodology based on twelve steps presented for the creation of a multicriteria model, starting from the simplest, such as the definition of criteria, to defining the type of problem and method to be used, and the possibility of returning to an earlier stage as a form of refinement and improvement.

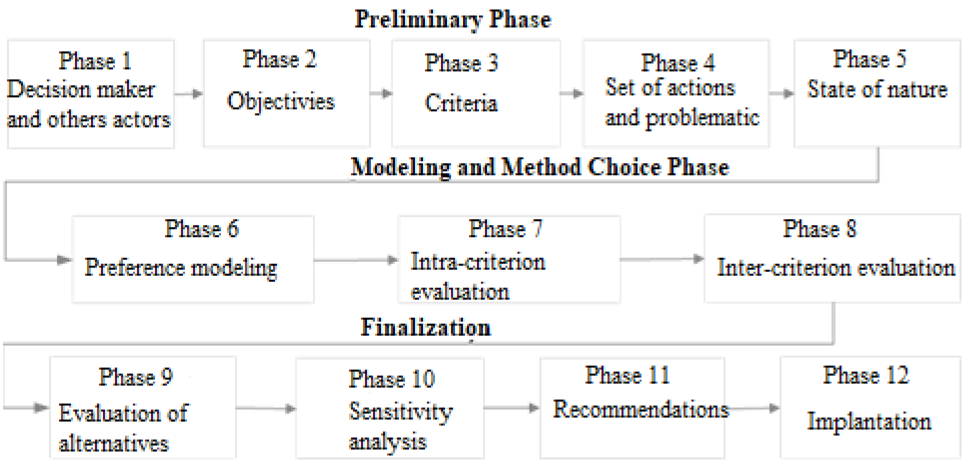

Figure 1: Methodology for the creation of the Multicriteria model (Adapted: Almeida et al 2015)

3. Multicriteria model

Based on the methodology presented by Almeida et al. (2015) for the determination of a multicriteria model, a proposal to support the use and definition of an integrated maintenance and inventory management policy was developed.

3.1. Preliminary phase

The core of the preliminary phase is the determination of possible objectives and evaluation criteria. In this case, the objectives to use the integrated model of the policies presented above can be translated as increasing the effectiveness and efficiency of the maintenance activity and the management of spare parts acting in a synchronous way. So that it is possible to obtain reduction of costs, attend the demand; reduce the time the system is without spare parts in stock, in addition to increasing preventive maintenance by maximizing the useful life of the component. Finally, the decision maker seeks to increase the average life of the system to ensure greater system uptime and uninterrupted operation. From the definition of the objectives of the decision-maker, the criteria for measuring the performance of this objective are defined (Keeney 1992). With this, it is possible to associate nine criteria or attributes that can represent them (Table 3.1).

C_1, Cost-life relation	**C_4,** System vulnerability	**C_7,** Preventive maintenance rate
C_2, Loss due to unavailability	**C_5,** Average number of times the stock remains zero	**C_8,** Average system life
C_3, Average number of breaks due to lack of inventory	**C_6,** Corrective maintenance rate	**C_9,** Reliability of maintenance policy

Table 3.1: Criteria for the multicriteria model

The multicriteria problem, in this case, is to find values that best satisfy the needs of the decision maker. Therefore, because we believe that an order of possible alternatives must be made, in view of the presented options, the ordering problem is the one present in the multicriteria model in question. In addition, believing that there is no compensatory relationship between the criteria, that is, the performance of one criterion does not interfere or compensate for the other, since, despite being related, the impacts caused in the decision are not compensatory, the model developed is not-compensatory, being this characteristic conserved in the outranking methods.

3.1.1. Extension of the Integrated Model to Obtain Missing Criteria

The multicriteria method requires that alternatives be elaborated, and for this purpose were generated simulated values from the integrated model of Piggyback and inventory management by Rodriguez (2016). Thus, was developed an extension for the modeling and simulation of the integrated model using computational programming, configuring the integrated model to obtain the values to the alternatives of the criteria that the decision maker flagged as relevant.

Therefore, from the development of the integrated model presented, it was possible to simulate the values for the alternatives and criteria, creating the necessary environment for the use of the multicriteria method.

3.2. Modeling and method choice phase

The second phase, preference modeling and method choice, is where the definition of the multicriteria method is performed, which is the most flexible of all, and its three steps must be performed simultaneously to give a better understanding of the situation.

Therefore, because it is a non-compensatory relationship, the intra-criterion evaluation occurs in an ordinal way, that is, ordering values as the importance. The inter-criterion evaluation is given by the determination of weights for each criterion, as seen in Table 3.2. The sum of the values given to the weights must be equal to 1, and, in agreement with the decision maker.

C_1	**C_2**	**C_3**	**C_4**	**C_5**	**C_6**	**C_7**	**C_8**	**C_9**
0,20	0,18	0,08	0,18	0,08	0,05	0,05	0,10	0,08

Table 3.2: Weight of the criteria

The predominant method for the development of the model is the PROMETHEE II, which is used for ordering problems, case presented here, and also establishes a complete pre-order, not assuming the relation of incomparability.

By obtaining the values of each criterion through the simulation it was possible to construct the consequence matrix, which presents the values of each criterion within each alternative. A set of 56 alternatives were established, which are presented in the format (T, s, S), which represents, respectively, the time interval between maintenance, minimum stock and maximum stock. From the consequence matrix and the weights it was possible to apply the PROMETHEE II multicriteria method to generate the order of alternatives.

3.3. Finalization

The finalization phase is when the model is effectively applied in the search of the result. Thus, it is possible to perform a sensitivity analysis and perhaps retrace steps for changes and improvements.

It was possible to ordinate the values that meet the criteria of the decision maker, from the net flow created by PROMETHEE II, as can be seen in Table 3.4. According to the ranking created to order the alternatives, the option presented in the first place is (75, 2, 4), that is, a maintenance interval of B of 75 thousand copies, with minimum inventory, equal to 2, and maximum stock, equal to 4. Being this the scenario that meets the objectives of the decision maker according to the degree of importance given to each criterion, that is, this is the best result.

Nº	Alternative	φ	φ+	φ-	Nº	Alternative	φ	φ+	φ-
1	**(75, 2, 4)**	**0,6353**	**0,7340**	**0,0987**	29	(45, 6, 8)	0,1198	0,4564	0,3365
2	(90, 2, 4)	0,6051	0,7558	0,1507	30	(45, 4, 6)	0,1038	0,4495	0,3456
3	(60, 2, 4)	0,4805	0,6940	0,2135	31	(45, 8, 10)	0,1020	0,4493	0,3473
4	(90, 8, 10)	0,4751	0,6347	0,1596	32	(45, 3, 5)	0,0758	0,4460	0,3702
5	(90, 5, 7)	0,4422	0,6144	0,1722	33	(30, 1, 3)	0,0635	0,4885	0,4251
6	(90, 1, 3)	0,4242	0,6742	0,2500	34	(45, 7, 9)	-0,0664	0,3776	0,4440
7	(90, 4, 5)	0,3822	0,5816	0,1995	35	(30, 8, 10)	-0,0813	0,3731	0,4544
8	(75, 6, 8)	0,3767	0,5758	0,1991	36	(30, 4, 6)	-0,0831	0,3684	0,4515
9	(45, 2, 4)	0,3718	0,6433	0,2715	37	(30, 6, 8)	-0,1200	0,3436	0,4636
10	(75, 8, 10)	0,3713	0,5822	0,2109	38	(30, 5, 7)	-0,1465	0,3267	0,4733
11	(75, 3, 5)	0,3691	0,5824	0,2133	39	(30, 3, 5)	-0,2265	0,3267	0,5533
12	(90, 6, 8)	0,3671	0,5745	0,2075	40	(30, 7, 9)	-0,2389	0,3184	0,5573
13	(90, 7, 9)	0,3644	0,5969	0,2325	41	(15, 1, 3)	-0,3429	0,2922	0,6351
14	(75, 4, 6)	0,3516	0,5718	0,2202	42	(15, 2, 4)	-0,4464	0,2573	0,7036
15	(75, 1, 3)	0,3476	0,6311	0,2835	43	(15, 5, 7)	-0,4664	0,2344	0,7007
16	(75, 7, 9)	0,3415	0,5578	0,2164	44	(15, 4, 6)	-0,5127	0,2118	0,7245
17	(60, 1, 3)	0,3029	0,6140	0,3111	45	(15, 3, 5)	-0,5129	0,2145	0,7275
18	(60, 7, 9)	0,3004	0,5471	0,2467	46	(15, 8, 10)	-0,5193	0,2075	0,7267
19	(90, 3, 5)	0,2969	0,5495	0,2525	47	(15, 6, 8)	-0,5247	0,2056	0,7304
20	(30, 2, 4)	0,2965	0,6118	0,3153	48	(15, 7, 9)	-0,5365	0,2025	0,7391
21	(75, 5, 7)	0,2869	0,5369	0,2500	49	(0, 4, 6)	-0,6080	0,1729	0,7809
22	(60, 4, 6)	0,2602	0,5235	0,2633	50	(0, 2, 4)	-0,6240	0,1753	0,7993
23	(45, 1, 3)	0,1995	0,5629	0,3635	51	(0, 8, 10)	-0,6262	0,1638	0,7900
24	(60, 6, 8)	0,1956	0,4884	0,2927	52	(0, 6, 8)	-0,6275	0,1645	0,7920
25	(60, 5, 7)	0,1800	0,5255	0,3455	53	(0, 1, 3)	-0,6296	0,1691	0,7987
26	(60, 3, 5)	0,1611	0,4722	0,3111	54	(0, 5, 7)	-0,6395	0,1567	0,7962
27	(45, 5, 7)	0,1587	0,4784	0,3196	55	(0, 3, 5)	-0,6618	0,1469	0,8087
28	(60, 8, 10)	0,1236	0,4667	0,3431	56	(0, 7, 9)	-0,6918	0,1373	0,8291

Table 3.4: Order obtained by the net flow of PROMETHEE II

From the application of the outranking method it was possible to verify that the values differ from the one suggested by the integrated model of Rodriguez (2016). Since in that case evaluated only one criterion was taken into account and a pre-established value was used for the maximum limit of stock, S. With this it was verified that the maintenance interval found is greater and the quantities of spare parts in stock also.

3.4. Sensitivity analysis

For the analysis of sensitivity or robustness IX scenarios were elaborated, in which the weights of the criteria was altered. In each scenario, the focus was an evaluation criterion, either in the increase or decrease of its value, and the values of the other criteria respected proportionality. It is worth noting that in all cases there were few variations in the order of all alternatives, so it is possible to prove that the model converges to the result obtained initially, showing its robustness.

4. Conclusions

The present work dealt with a multicriteria model to support the use of an integrated policy of maintenance Piggyback and management of spares of continuous revision developed by Rodriguez (2016).

The determination of the values of each criterion was made from modeling and simulation in a computational software, as a search for an approximation of reality. It was based on the integrated model developed by (Rodriguez, 2016) to construct an algorithm that determined the values within certain intervals. With this activity, it was possible to construct an consequences matrix to obtain the multicriteria model and to find the values that best met the needs of the decision maker.

As a result, we obtained a configuration different from that found in the integrated model of Rodriguez (2016), showing that evaluating a problem from one perspective alone is not always enough to make the best decision when there is a need to meet other objectives. In the case studied here, an optimal solution was not found, but rather an order of the possible values that the variables can be assumed to meet all the desired objectives, some of them conflicting, for the decision maker.

It was also observed, from the construction of the values of each criterion through the simulation, that the maintenance interval in all the simulated scenarios was one of the most rigid, and the variables referring to the minimum and maximum stock were intermediate values, thus balancing the results objectified by the decision maker. It is worth noting that the present work represents an opportunity to view the integrated models in a different way, through the multi-criteria approach.

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