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Maintenance policy selection from a limited number of decision criteria
A case study: an application of the ELECTRE II method for selecting the best maintenance policy for hydraulic couplings.

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***Résumé*- Le travail présenté dans ce document fournit une analyse intégrée de la contribution de l'aide multicritère à la décision (AMCD) pour la sélection de politiques de maintenance. Les principaux points nécessaires pour répondre à la question de la sélection de politiques de maintenance sont explorés. Le but de cette recherche est principalement orienté pour dresser un inventaire et une structure des principaux critères de décision qui peuvent être considérés pour l'évaluation et la comparaison des différentes politiques de maintenance. Un aperçu du processus des méthodes multicritères les plus utilisées dans le contexte actuel est aussi présenté. Il se termine par une application d’une méthode de surclassement (ELECTRE II) pour le choix adéquat d’une politique de maintenance aux coupleurs hydrauliques installés dans une usine minière de traitement de phosphate.**

***Abstract*- This paper provides an analysis of the contribution of multi-criteria decision analysis (MCDA) methods in the case of maintenance policy selection. The main elements needed to address the issue of maintenance policy selection are explored. The purpose of this research is mainly given for establishing an inventory and classification of the main decision criteria which may be considered for assessing maintenance policies. An overview of the process of the most used MCDA methods in the current context is presented. It concludes with an application of an outranking method (ELECTRE II) for selecting the most suitable maintenance policy for hydraulic couplings located in a mining phosphate plant.**

***Mots clés* – Politiques de maintenance, critère de décision, méthodes multicritères AMCD.**
***Keywords* - Maintenance policies, decision criteria, MCDA methods.**

1 INTRODUCTION

For the maintenance manager or the equipment owner’s, the decision making process for selecting the most suitable maintenance policy is far from an easy thing. This is due to the availability of various numbers of maintenance policies, combined with their assessment on several numbers of decision criteria. A maintenance policy is defined by a set of actions (monitoring, repair, shutdown, replacement, etc.) executed and ordered in a well-defined strategy. Aside from the corrective policy, new maintenance policies have appeared. Today we find applied in the most industrial units, various forms of maintenance policies: the preventive (or scheduled) maintenance, the condition based maintenance, the opportunistic and the predictive maintenance, etc. For each selected policy result a set of maintenance actions. A wrong choice of maintenance policies led to the development of non-appropriate actions, and therefore inappropriate maintenance program. Thus, it becomes very important to find a methodology which may facilitate the selection of the appropriate maintenance policy in a given industrial context. In the following, the second section is devoted to the identification of the most important decision criteria and their classification into a limited number of categories. The third part deals with an overview of MCDA methods and their application in the context of the maintenance policy selection. Finally, we conclude with an application of the MCDA method (ELECTRE II method) for selecting the suitable maintenance policy to a specific industrial case.

2 DECISION CRITERIA FOR MAINTENANCE POLICIES SELECTION

2.1 Bibliographical survey of decision criteria for maintenance policies selection

In the literature, some researchers have identified several numbers of decision criteria in order to assess a specific problem of maintenance policy selection. We can take the example of [Bevilacqua and Braglia, 2000], who have chosen to work on four main criteria: "the applicability", "cost", "the effect of a default" and the "added value of the maintenance policy" to compare different maintenance policies. Similarly, [Bertolini and Bevilaqua, 2006], have used the three well known indicators of criticality as decision criteria: "the occurrence", "severity" and "detectability". Otherwise, [AL Najjar and Alyousf, 2003], before applying "the fuzzy logic" as a method of decision making, compared different kind of maintenance policies on a set of thirteen criteria. However, for overcoming the assessment of large number of maintenance policies, he used a synthetic super criterion as to find "*the most informative strategy*" of the fault appearance. In a combined application of "*Analytic Network Process*" and the "*fuzzy logic*" methods for choosing the suitable maintenance policy, [Sadheghi and Manesh, 2012] have used five decisions criteria: "*the quality", "the safety", "feasibility", "cost" and "delivery"*. While in the article of [Wang and al, 2007], they identified four main criteria, which are: *"security", "cost", "feasibility" and the added value of the policy"*. Thereafter, they subdivided these four main criteria into ten sub-criteria. [Mishra and al, 2007] compared the set of maintenance alternatives on a dozen factors, through an analysis of the strengths and weaknesses of each alternative on all factors. In the case of maintenance performance measurement, [Parida, 2006] has developed a framework of multi-criteria for maintenance performance measurement indicators. This framework was structured in seven main groups of criteria which are: *cost or financial related, Equipment related, Maintenance task related, Learning growth related, customer satisfaction related, Health and safety related and employee satisfaction related.* The work of [Van Horenbeek and al, 2010] constitutes an important bibliographical study from several authors whose have been worked in the case of multi-objective optimization of maintenance. In this case, the author has been summarized fifteen criteria. Recently, [Goosssens and Basten, 2014] have conducted a huge analysis to determine the most important criteria in the case of maritime and naval ship industries. In their study, they retained twenty nine decision criteria for maintenance policy selection. Given the above, it is clear that the issue of maintenance policy selection is a multi-criteria problem. In the following, for better visualizing, we'll list all of the decision criteria proposed from the literature per reference and per specific industrial application in the appendix A.

2.2 Synthesis of limited number of the decision criteria

One of the crucial steps of decision making problem is to determine or fix in advance the relevant criteria which may influence the choice of a maintenance policy. The question that we will address in this section is the ability to use all of the different decision criteria advanced in the literature. The criteria shown in the appendix A, are too numerous (more than 130), and are varying from one application to another. Indeed, an important notice is that some types of criteria are used in the same form (name) or under another similar meaning from one application to another. For example, the "maintenance cost" criterion is often present in all applications or at least the majority. The latter is used in the direct designation of "cost" or either in a detailed name as "spare parts cost" or "capital investment cost", etc. The same remark is possible for the "risk and security" criterion, which is often used from one application to another. Same to the criteria related to the "working conditions", the "quality" and "availability". Those criteria are certainly found in different applications, but with a less proportion of presence than the "cost" criterion. Some applications such as [Bevilacqua and Braglia, 2000] have focused on a less visible but very important criterion, which is the "applicability" of the maintenance policy. Due to this fact, we thought for a first categorization of decision criteria into seven major groups of decision criteria: the criteria related to the "**cost**", the "**availability**", the "**risk and security** (criticality)", the "**operating conditions**", the "**applicability**" of maintenance policy, and those which are related to the "**quality**", and last category of criterion related to the "**reliability**". It is observed that criteria listed in the appendix A cannot be classified all of them into the seven families criteria previously mentioned. We have therefore chosen for grouping them, into a dynamic category (which can vary from one application to another) and qualified as a category of "other criteria" or simply "others". Although, these criteria are used in a particular application only, and they are not used in all of the applications. For this reason, they are certainly less relevant in terms of wide application for the construction of decision criteria for maintenance policy selection. In the following we will base our study on the eight decision criteria formulated in figure one. Figure two gives us an idea of the relevance level (number of related criteria in the bibliography) of each category of decision criteria.

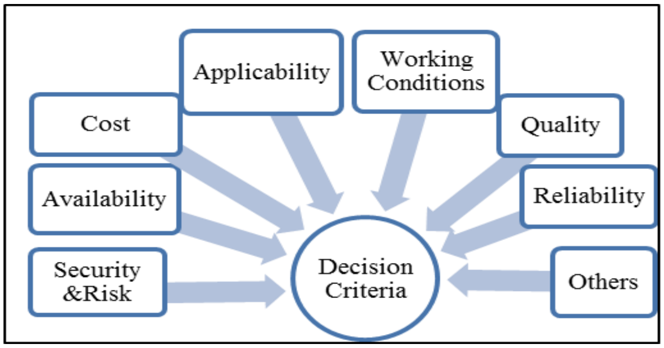


Figure 1. The main categories of decision criteria for maintenance policy selection

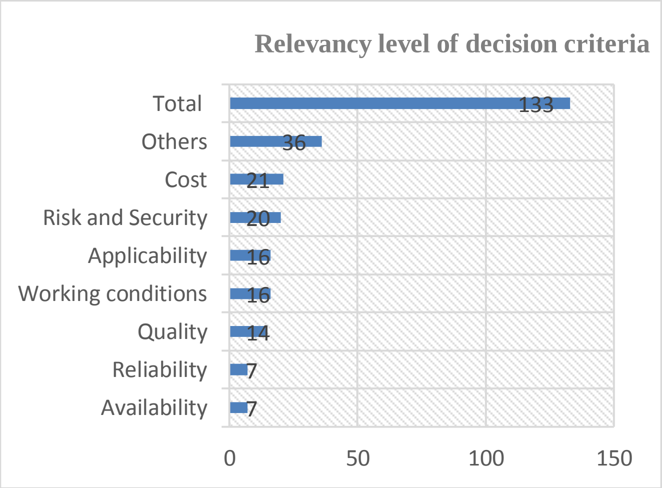


Figure 2. Classification of the main important categories of decision criteria for maintenance policy selection

2.3 *Maintenance policies*

Maintenance policy may be defined as a rule or set of rules describing the triggering mechanism for the different maintenance actions (monitoring, repair, replacement and shutdown, etc.), [Pintelon and Van Puyveld, 2006]. The huge development of the industries and the complexity of the process have led to the development of new technics of maintenance policies. Thousands of maintenance models have been developed and they can be classified into certain kinds of maintenance policies of the one-unit systems in accordance with [Wang, 2002]. He classified the maintenance policies into six main groups: *age-dependent policies, sequential policies, block replacement policies, repair limit policies, failure limit policies, and repair numbers counting policies*. Similarly the recent review conducted by [Sarkar and al, 2011, 2012] has established the same classification. These policies inscribed above may be seen as main categories of different classes of policies. Otherwise, the different types of maintenance policies maybe generally subdivided into two main categories: corrective (or reactive) policies and preventive policies in accordance to the maintenance actions undertaken before or after the failure occurrences. The object of this paper is not to define the different types of maintenance policies, indeed the reader may find an important classification and definitions in the bibliography: [Pintelon and Van Puyveld, 2006], [Richet and al, 1996], [Manchy et Vernier, 2012], [Wang, 2002], [Bevilacqua and Braglia, 2000], [AL Najjar and Alyousf, 2003], [Mishra and al, 2007], [Goosssens and Basten, 2014], and [Sarkar and al, 2011, 2012], etc. Thus, in the following we will consider only the most formalized and most famous maintenance policies and their classification given in figure 3.

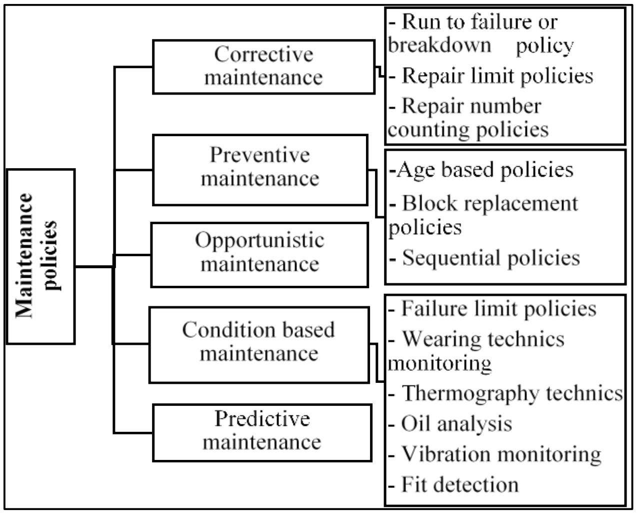


Figure 1. Different types of maintenance policies

In this step of the problem to facilitate the decision making process, we identified the most important decision criteria and resumed them into a limited number of categories (figure 1.). Similarly, the most famous and formalized maintenance policies are listed (figure 3.). In the following to be complete as much as possible in our work, the question arises is: how to evaluate or to assess or to compare, the different maintenance policies on the decision criteria? In the operational research field, resolving multiple criteria decision making problems is well established and a lot of multiple criteria decision analysis (MCDA) methods have been developed. In the paragraph three, we will analyze the opportunity of using MCDA methods in the case of maintenance policy selection.

3 MCDA METHODS AND THEIR APPLICATIONS FOR MAINTENANCE POLICY SELECTION

3.1 *An overview of MCDA methods*

Decision analysis is defined as a scientific approach to provide solutions into decision problems which arises in all contexts: socioeconomic, environmental, safety, etc. The decision analysis becomes multi-criteria decision analysis (MCDA) problematic when the issue requires an assessment on several targets (decision criteria), which can be both contradictory and incommensurable. MCDA is far from being trivial, because aspects to be considered may be conflicting. A simplest example would be, when you are looking for the equipment, a maintenance policy at a minimum investment cost, with a high level of availability with complete safety measures. Thus the aim of MCDA is to provide a satisfactory or compromised decision in the eyes of stakeholders by overcoming difficulties mentioned above. The MCDA is quite new with an enormous progress. Hence the growing number of MCDA methods and theirs varieties observed since the late seventies. The first question comes is: why there are so many MCDA methods, near a hundred according to [Maystre and al. 1994] in scientific research? And why not one that can respond to all multi-criteria decision problems? This question is raised previously in the literature and some answers were especially formulated by [Schärlig, 1985], highlighting the lack of a comprehensive approach in its entirety. But each method could have advantages and limits. The work of the latter in this sense has resulted in an interesting categorization of MCDA methods in three main categories: *"the complete aggregation methods (using value function theory)", "partial aggregation or outranking methods" and "methods of local and iterative aggregation"*. This classification is related to the main common difference between different methods. The main difference arises in the aggregation (computation) step of the MCDA process. Another distinction of MCDA methods is also possible. The latter is related to the kind of decision problem which going to be resolved. Indeed, whatever the issue of decision problem, we may be confronted to choose in front of a decision alternatives: *a choice* (search for the best action) or an *arrangement:* store or sort by category of classes (A-good category, B-average and C-bad category) and finally to rank: ranking alternatives from the best one, to the worst. This is what we call the problematic formulation in MCDA problem by Roy [Roy, 1996]. In accordance to Roy, the real problems of decision-making can be categorized into four basics formulations: the problem of choice denoted (*P*α*)*, the problematic of sorting (*P*β*)*, the problematic of ranking (*P*γ*)*, and finally last one called problematic of description (*P*δ*)*. The last category (*P*δ) can be seen as a place of passage for the other three by [Bouyssou and Roy, 1993]. While for [Schärlig, 1985], it does not lead to any method, and simply retain the three others to categorize MCDA methods. Finally, MCDA methods can be categorized according to the kind of decision problem (Pα, Pβ and Pγ). The purpose of the multiple criteria decision-maker is to support by proposing one alternative or a set of alternatives which satisfies the maximum compromise by *aggregating* all aspects (criteria). In the decision support analysis problem, the *aggregation* phase, also called synthesis or global computing occurs, when all data (decision criteria and alternatives) of the problem are well specified and after realizing their ***assessments (or judgment step).*** At this stage, MCDA problem may be structured as a process consisting of the following four major steps:

- Formulation of the problem (criteria and alternatives identifications),
- Evaluation of the problem data (weighting criteria and preference assessment),
- Choice of the method or process of aggregation,
- Analyzethe results to formulate decision(s).

For a more detailed presentation of MCDA process, the reader may find an important and rich bibliography in the books of [Vincke, 1992], [Scharlig, 1985], [Belton and Stewart 2002], [Roy 1996], [Bouyssou and Roy 1993], and [Ben Mena, 2000], etc.

3.2 Maintenance policies selection using MCDA methods

One of the most often used MCDA method in the case of maintenance policy selection is the AHP (Analytic Process Hierarchy) or the Saaty's method [Saaty, 1980]. We find among those who used this method, [Bevilacqua and Braglia, 2000], [Carnero, 2005], [Triantaphyllou and al, 1997], Bertolini and Bevilacqua, 2006], etc. Some researchers have meanwhile used other methods and decision support tools such as the fuzzy logic, the Goal Programming (linear programming), etc. These methods may be combined together for the specific needs of applications. That is why we find in some articles such as [Wang and al, 2007], the combination of the AHP with fuzzy logic. Similarly, [Sadheghi and Manesh, 2012] have used a combination of the ANP (Analytic Network Process, a variant of the AHP method for the specific problems of criteria inter-dependencies) with fuzzy logic. In their recent work, [Goosssens and Basten, 2014] presented a synthesis of applications of the AHP method for maintenance policy selection. The main advantage of the AHP method is the hierarchization (hierarchy scheme) of the decision problem, which constitute a very important step for structuring firstly the problem, and secondly for detecting the relative importance between the criteria. However, we must not forget that this method was criticized by an important number of researchers in the field of operational research. We can find among those who was criticized on the theoretical basis of the latter, [Belton and Gear, 1983], [Barzilai, 2001] and [Bana and Vansnick, 2008]. Thereby, using a unique MCDA method (such as AHP) shows that the issue of decision making in the case of maintenance policies selection is not treated well in its chosen field (multi criteria decision analysis). Indeed, two other categories of MCDA methods, which are the methods of 'outranking' and methods of 'local iterative aggregation' are not explored for maintenance policy selection problem. While the 'outranking' methods such as ELECTRE are appreciated for their low degree of compensation between criterions according to [Pirlot, 1997]. The outranking methods are also considered more realistic than the complete aggregation methods (such as AHP or Weighted sum, etc.) in the case of multi-criteria decision analysis process according to [Schärlig, 1985]. Particularly, one of the important advantages of the ELECTRE I and ELECTRE II methods is their simplicity to understand the decision process, and to allow a full participation of the stakeholders during the decision making process.

4 A CASE STUDY: AN APPLICATION OF THE ELECTRE II METHOD FOR MINING POWERFULL COMPANY

Our case study consists of selecting the suitable maintenance policy for the hydraulic couplings to the phosphate processing plant of the Office Cherifien of Phosphates (OCP) in Morocco. The plant is located in Youssoufia city, it is called the Calcination plant and uses near a forty hydraulic couplings placed on the driving engine of the conveyors for transporting the ore. This study was initiated after, the first project to evaluate the possibility of substitution of all the hydraulic couplings by electronic speed controllers which was found economically, not interesting. The aim of the project of the substitution by the electronic controllers was to reduce the charge of the maintenance department of the plant. This project was conducted by the author during four months, from March to June 2010 [Mahamoud, 2010]. Thereafter, for improving the maintenance effectiveness of the plant, the ELECTRE II method was used to select the suitable maintenance policy for these mechanical components.

4.1 Brief description of ELECTRE II method

The ELECTRE II (Elimination Et Choix Traduisant la Réalité) [Roy et Bertier, 1971] method is an outranking method which comes after the first method ELECTRE I initiated by [Roy, 1968]. But the main difference with the latter, the ELECTRE II method is built for the gamma problematic ($P\gamma$): It has the ultimate aim to rank the set A of alternatives from the best to the worst. The principle of the method is based on building an outranking relation (S) on all the potential alternatives by using the concepts of concordance and non-discordance. Considering two alternatives (a) and (b) of set A of alternatives, the concordance index denoted C (a, b) may be defined by the following formula:

$$\mathbf{C\ (a,\ b)} = \frac{\sum_{g_i(a) \geq g_i(b)} k_i}{\sum_{i=1}^{n} k_i} \qquad (1)$$

Where k_i, i=1...n, are the criteria weights.

The concordance index is used to express the relevance of the assumption: "alternative (a) is at least as good as (b)". It is obtained by adding the weights of the criteria on which alternative (a) is better than alternative (b), divided by the total sum of the criteria weights. While $g_i(a)$ denotes the performance of alternative (a) on the criterion (i). And similarly $g_i(b)$ the value of the alternative (b). After calculating for each pair of alternatives the concordance index values may be represented by the concordance matrix:

$$\mathrm{C}=\begin{bmatrix} c(a_1, a_1) & \cdots & c(a_n, a_1) \\ \vdots & \ddots & \vdots \\ c(a_1, a_n) & \cdots & c(a_n, a_n) \end{bmatrix}$$

The concordance matrix (C) is obtained by filling both rows and columns the alternatives, and completing each position (i) and (j), the concordance index $C\left(a_i, a_j\right)$ of the alternatives at line (i) to those reported by column (j). Similarly for each pair of alternatives (a) and (b) the discordance index **di** (a, b) for criterion (i) is defined as follow:

$$\mathrm{D}i\ (a,\ b) = [gi\ (a) - gi\ (b)] \qquad (2)$$

The discordance index can measure the level of divergence on the criteria on which (a) is worse than (b). We are talking about divergence keeping in mind, the assumption that one alternative is better than another on a majority of criteria, and the remaining criteria on which it is not the best, to assess how much it is worse. Once calculated, the values of discordance index can be similarly represented by a discordance matrix D_i per criterion ($\boldsymbol{i}$).

Defining the outranking relation (S): In the mindset of ELECTRE methods for defining the outranking relation, the index values of concordance and discordance are compared to the predefined thresholds values. The choice of thresholds differ from one method to another. In the ELECTRE II method, in its original version by [Roy and Bertier, 1971], two thresholds for the test of concordance are used: sc1 and sc2, with sc1≥sc2. And also we use two thresholds for the test of discordance: sd1 and sd2 with sd1≥sd2. The outranking relation (S) in ELECTRE II methods is built by using two types of outranking relations: the strong outranking relation denoted $\boldsymbol{S^F}$ and the weak outranking relation denoted $\boldsymbol{S^f}$. The first outranking relation is based on a solid assumption while the second relation is based on a weaker assumption.

Conditions of strong relation of outranking($\boldsymbol{S^F}$): for each pair of alternatives (a) and (b), we can say that the alternative (a) is as good as (b) (denoted aS^Fb) with a high level of certainty if the following three conditions are verified:

$$aS^Fb \leftrightarrow \begin{cases} C(a,b) \geq sc1 \\ \sum_{\forall\, i:\, g_i(a)>g_i(b)} k_i \geq \sum_{\forall i:\, g_i(b)>g_i(a)} k_i \\ \forall\, i \quad \mathrm{Di}(a,b) \leq sd2 \end{cases} \tag{3}$$

With C (a, b)>sc1, the first condition of a strong outranking relation also called concordance principle. This condition express that the concordance index should be greater than the strong threshold (sc1) of concordance index. The second condition is a necessary condition to admit the hypothesis of strong outranking relation. The third condition expresses the hypothesis of strong discordance principle: it means for the remaining criteria for those alternative (a) is worse than (b), the difference should be as lower as possible ($D(a,b) \leq sd2$): while sd2 is a strong threshold for discordance test.

Conditions of weak relation of outranking ($\boldsymbol{S^f}$): During the test of strong outranking relation among the pairs of alternatives, if one of three conditions is not satisfied (Non $\boldsymbol{S^F}$), it goes directly to verify the conditions of the weak outranking relation n°4:

$$aS^fb \leftrightarrow \begin{cases} C(a,b) \geq sc2 \\ \sum_{\forall\, i:\, g_i(a)>g_i(b)} k_i \geq \sum_{\forall i:\, g_i(b)>g_i(a)} k_i \\ \forall\, i \quad \mathrm{Di}\,(a,b) \leq sd1 \end{cases} \tag{4}$$

With $\boldsymbol{C(a,b) \geq sc2}$ a weak concordance condition while sd1>sd2. After verifying the weak concordance condition we verify similarly a test of weak discordance (D (a, b)>sd1) and do not missing to verify also the second condition (C (a, b)>C (b, a)). The important notice here is that the tests of outranking relation (strong or weak) are imbricated together: if one condition of the strong outranking relation is not verified between two alternatives we try to verify the conditions of weak relation. The process of the method is repeated until comparing each couple of alternatives.

4.2 Application of the ELECTRE II method for maintenance policy selection to the hydraulic couplings

Defining problem: for this case of study, the different alternatives of maintenance policies envisaged by the maintenance department are: corrective maintenance-CM (a_1), preventive maintenance (age based)-PM (a_2), condition based maintenance using thermography technics-CBM (a_3) and predictive maintenance-PRM(a_4). The decision criteria selected for assessing the alternatives are eight criteria: two criteria (C_4 and C_5) related to the maintenance costs, three related to the security (C_1, C_2 and C_3) and last three (C_6, C_7 and C_8) related to the applicability of the policy (see table 1). In the ELECTRE II method, weights of the criteria can be set directly by the stakeholders following several estimations of relative importance between criteria. In our case, taking into account of experience on historical maintenance data units of the plant, it was considered necessary to distinguish between strong and weak criteria. Strong criteria are those considered having a higher impact on the specific decision problem. Thus, the three criteria for the applicability of the maintenance policy were assigned a 2 points as a relative weight and the remaining other criteria are weighted between 0.75 and 1.

Table 1. Performance matrix of the MCDA problem

	Corporal Damages (c_1)	**Material Damages (c_2)**	**Environmental Damages (c_3)**	**direct Costs (c_4)**	**indirect Costs (c_5)**	**Investment training (c_6)**	**software Investment (c_7)**	**Material Investment (c_8)**
Corrective Maintenance (CM) a_1	2	2	2	2	2	6	10	10
Preventive –(PM) a_2	4	4	4	4	4	6	6	6
Condition Based-(CBM) a_3	6	6	6	6	6	2	2	2
Predictive-PRM (a_4)	8	8	8	8	8	0	0	0
Criteria ponderation	0.75	1	0.75	0.75	0.75	2	2	2

Therefore, the ponderation of our MCDA problem is shown at the last row of Table 1. In the following it goes to assess each maintenance policy on each criterion (preferences judgments). Firstly, we used a qualitative scale evaluation for filling the lack of precision of the historical data. The qualitative evaluation is then transformed into quantitative values by using a transformation scale (table 2). We can finally obtain preferences judgments or numerical evaluations of each maintenance policy for each criterion (table 1). The data given in table 1 are also called performance matrix of MCDA problem.

Concordances index C (a_i,a_j), and discordances D (a_i,a_j): The concordance index and discordance index are calculated using formulas (1) and (2). For the process of computing, we developed a specific program under SCILAB to generate all the values, and the results are grouped into the concordance and discordance matrix given in the following table 3 and 6.

Construction of outrankings relation of the problem and thresholds: Taking into account the performance matrix of the problem, a following thresholds for the concordances and discordances are chosen:

- Threshold of strong concordance test: Sc_1=0.6;
- Threshold of weak concordance test: Sc_2=0.5;
- Threshold of strong discordance test: Sd_1=6;
- Threshold of weak discordance: Sd_2=5;

How to choose the thresholds for ELECTRE methods is well explicated in the book of [Maystre and al, 1994]. The computational process of the outranking relations is done by using an algorithm program under SCILAB and taking into account the previous thresholds and following the conditions of the outranking relations of the ELECTRE II method given above. The result of the outranking relations (weak and strong relation) is generated in tables 4 and 5. To explore the results of the outranking relations of the ELECTRE method we use the graph theory: alternatives are interconnected by arrows. An Arrow from one action to another means that the latter is dominated by the previous one. By following this principle, the outranking relations expressed previously are transformed into two graphs: graph of strong outranking relation and graph of weak outranking relation (figure 4). Considering graphs of the result of outranking relations, it's not evident to establish directly a ranking of different maintenance policies. For this purpose in the ELECTRE II method we try to establish two types of ranking, [Maystre and al, 1994]: the direct ranking and the indirect ranking.

Direct ranking: in the aim to determine the direct ranking of alternatives we process by successive steps. In the first step, we try to determine the alternatives which are not dominated in the graph of the strong relation of outranking. Then we remove the thoses alternatives on the graph, and trying to distinguish it, by using the graph of the weak relation. Then we go to the second step to determine which are dominated once time. We process by that way until arriving to the last alternatives (which do not dominate any others). All the necessary steps for the direct ranking of alternatives in our specific case are summarized in figure 5.

Indirect ranking: the process of the indirect ranking is the opposite of the direct raking process. Indeed, we start by determining the alternative which does not dominate any other one, to arrive to the once which dominate the maximum. In our case, the result of the indirect ranking of alternative is the same with the one of the direct ranking.

Table 2. Scale transformation

Quantification of the qualitative judgments of the weak criteria (C1 à C5)	
Very weak or inexistent	8
weak	6
High	4
Very High	2
Quantification of qualitative judgments of the strong criteria (C6 à C8)	
Not Necessary	10
Few	6
Necessary	2
Very Necessary	0

Table 3.Concordances Index matrix C (a_i,a_j) between alternatives.

Concordance index: C (a_i,a_j)	CM	PM	CBM	PRM
CM	-	0.6	0.6	0.6
PM	0.6	-	0.6	0.6
CBM	0.4	0.4	-	0.6
PRM	0.4	0.4	0.4	-

Table 4. Strong outranking relation S^F (a_i/a_j) between maintenance alternatives

Strong outranking relation: S^F (a_i,a_j)	a_1 (CM)	a_2 (MP)	a_3 (CBM)	a_4 (PRM)
a_1 (CM)	-	S^F	S^F	Non S^F
a_2 (PM)	S^F	-	S^F	S^F
a_3 (CBM)	Non S^F	Non S^F	-	S^F
a_4 (PRM)	Non S^F	Non S^F	Non S^F	-

Table 5. Weak outranking relation between maintenance alternatives

Weak outranking relation: S^f (a_i,a_j)	a_1 (CM)	a_2 (PM)	a_3 (CBM)	a_4 (PRM)
a_1 (CM)	-	S^f	S^f	S^f
a_2 (PM)	S^f	-	S^f	S^f
a_3 (CBM)	Non S^f	Non S^f	-	S^f
a_4 (PRM)	Non S^f	Non S^f	Non S^f	-

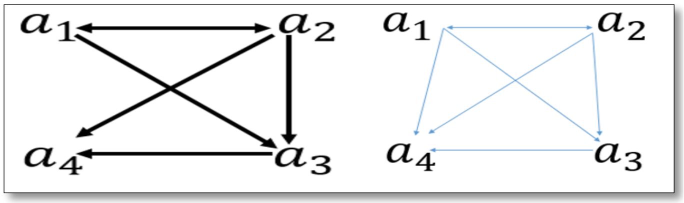


Figure 4. Graph of strong relation of outranking S^F (a_i/a_j) (left) and graph of weak relation of outrankingS^f (a_i/a_j)

Table 6. Example of the discordances index D_i ($a_{i,}a_j$) between alternatives (CM and PM) on each criterion (i)

Criterion Ci	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
D_i(CM, PM)	2	D_2=2	D_3=2	D_4=2	D_5=2	D_6=0	D_7=0	D_8=0

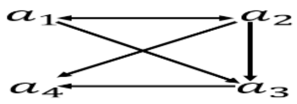
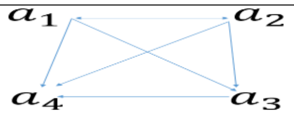
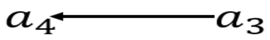
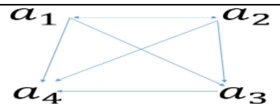
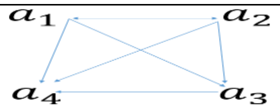
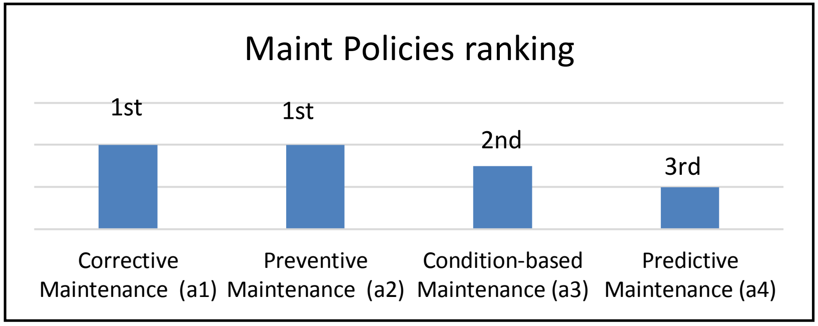
Steps	Strong graph of outranking relation	Weak graph of outranking relation
Step 1 : No dominated alternatives: $a_1$et a_2		
Step 2 : No dominated alternatives: a_3		
Step 3: No dominated alternatives: a_4	a_4	
Step 4 : Result of direct ranking of alternatives		

Figure 5. Process of direct ranking of alternatives

Results discussion: In the second step of the process of direct ranking (figure 5), we should stop to decide between the equal alternatives (a_1) and (a_2), but unfortunately in both graphs of outranking there are equivalence between them. Therefore, this shows that the two first alternatives are corrective maintenance (CM) and preventive maintenance (PM), followed by the condition based maintenance (CBM). The last alternative is the predictive maintenance (PRM). Finally, the recommendation for choosing a maintenance policy for the hydraulic couplings according to the result of the ELECTRE II method is a combination as much as possible of the preventive (age-based) and the corrective maintenance. This is perfectly consistent with the negative result of the first project, which consisted to study the possible economic growth by replacing the hydraulic couplings by the electronic speed controllers (elements without maintenance program, but expensive). Even more, if it becomes necessary to choose between these two policies, it will be possible to use another method such as ELECTRE I which don't allow the incomparability relation between alternatives. The result of the latter is also studied by the author in [Mahamoud and al, 2014]. For the real purpose and the experience of the maintenance department this study was not required.

5 CONCLUSION

This study was intended to explore the contribution of decision support methods for the issue of maintenance policy selection. The bibliographical research shows that some applications using the MCDA methods to resolve the issue of maintenance policy selection have been all converged on the applications of a single method, which is none other than the AHP. While the latter was criticized by several researchers. The analysis conducted in this document is a proof that the possibility of using multi-criteria decision support methods may not be reduced to a single method. Interesting results were obtained by using the outranking method such as ELECTRE II in the case study. Indeed, it is shown that the simplicity of the decision process of the ELECTRE II allows a full participation of the stakeholders. This is shows the opportunity of using methods of outranking approach for maintenance policy decision making problem. Finally, we underline also that the synthetic structure of decision criteria established in this paper should strongly facilitate the process of decision making for maintenance policy selection. The future work will focus on developing this structure of decision criteria and to determine their consistencies in the different type of industry.

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Appendix A. Literature review: Synthesis of the decision

Reference and Typical application	***Criteria***	***Reference and Typical application***	***Critteria***
[Alnajar, 2003]: Chemical industry (ex: Paper mills)	Mode of operation (continuous or intermittent)	**Van Horenbeek [2010]:** Wide approach	Maintenance costs (discounted)
	Load (high or low)		Maintenance quality
	Speed (high or low)		Personnel management
	Operating temperature		Inventory of spare parts
	Humidity		Overall equipment effectiveness
	Radiation		Number of maintenance interventions
	Ambient temperature		Capital replacement decisions
	Dirt in the surrounding		Life-cycle optimization
	Lubricant quality (specifications)		Availability
	Lubricant temperature		Reliability
	Service quality, e.g. mechanical looseness		Maintainability
	Consistency of component quality		Environmental impact
	Availability of product quality data		Safety/risk
			Logistics
			Output quantity
			Output quality
[Triantaphyllou et al. ,1996]: Wide appraoch	Cost	**[Bertolini et Bevilacqua, 2006]:** (Set of critical pump in an oil refinery)	Detectability
	Reparabilty		Severity
	Reliabilty		Occurence
	Availability		
[Coetzee, 1996]: (Wide approach)	Availability	**[Jardine et Banjevic, 2006]**	Capital replacement modelling
	Reliability	**[Bucher et al, 2006]**	Safety
	Operability	**[Ilgin et al, 2007]**	Spare parts inventory
	Safety	**[Quan et al,2007]**	Maintenance personnel management
	Acceptable Cost		

Reference and Typical application	***Criteria***	***Sub-criteria***	
Bevilacqua et Braglia, 2000]: Power plant industry	Damage	product damage	
		people damage	
		image damage	
		plant damage	
		environmental damage	
		production loss	
	Applicability	Investment required	Hardware
			Software
			Personnel
		Technique Reliability	Failure identification
			As Good as New
	Added-value	Product quality	
		Know-How	
		Intrinsec safety	
	Cost	MTBF	
		MTTR	
		Spare parts stocks	
		Assurance cost	
[Sadeghi et al, 2012]: Manufacturing steel company	Quality	Reduction in defective products	
		Customer satisfaction	
	Safety	corporal damages	
		material damages	
		environmental damges	
	Cost	Hardware	
		Software	
		Personnel	
	Delivery	Reduction in lead time	
		Reduction in late deliveries	
	feasibility	Acceptance by labors	
		Technique reliability	

Appendix A. Literature review: synthesis of the decision criteria (continued)

[Mishra et al, 2007]: Wide approach	Required data		
	Staffing		
	Ease and time to implement the policy		
	Technicals requirement		
	Industrial typologie		
	Financial implication	Hardware	
		Software	
		Manpower	
	Cost	Breakdown cost	
		Maintenance cost	
[Dekker, 1996]	Ensuring systme function	Availability	
		efficiency	
		Product quality	
	Ensuring system life	Asset management	
	Safety		
	Human well-being		
[Parida, 2006]: Various industries (chemical, Nuclear, process, service, etc)	Equipment and process related	Production rate	
		Quality	
		Number of stops	
		Down time, etc	
	Cost and finance related	Maintenance cost per ton	
	Maintenance task related	Change over time	
		planned maintenance task	
		unplanned maintenance task, etc	
	Learning growth and inovation	Skill improvement training	
		Generation of number of new ideas, etc	
	Customer satisfaction related	Quality complaint numbers	
		Quality return	
		Customer satisfaction, etc	
	Health safety and Enviroment (HSE)	Number of accident	
		HSE complaints, etc	
	Employee satisfaction	Employee complaints, etc	
[Goosssens et Basten, 2014]: Maritime and Naval industy	Maintenance Goals	KPIs (Key Performance Indicators): mesurable reasons for doing maintenance	Avalibality
			Crew Safety
			Mission Readiness
			Planability of maintenance
			Relaibility
		Desirables: not measurable reasons for doing maintenance	Drive for innovation
			Compliance with existing policies and prescriptions
			Passion for maintenance
	Fit to the maintenance process to the company	Fit to Crew	Crew size
			Crew educational level
		Fit to knowledge	Amount of outsourcing
			Experience with maintenance
			Insight in system
			Knowledge
		Fit to mission	Age (of vessel)
			Mission location
			Mission profile
		Fit to relations	Already existing prescriptions
			Good relations with other companies
			Maintenance feedback
			Requirements of 2nd parts
		Fit to the Spare Parts	Commonality Presence
			Spare parts amount
			Spare parts availabilty
		Fit to tasks	Consequences of bad maintenance
			Criticality of parts
			Maintenance location
			Reachability of parts
			Redundancy presence