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# Evaluation process in end-of-life systems management using BOCR analysis

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## Abstract:

Nowadays, sustainability is an indicator or even a concept that guides many public as well as private decisions or actions. In manufacturing sectors, firms are paying an increasing attention to this concept with regards to their products once they are the end of their life; this attention is not only due to the respect of norms and laws policy makers are continuously editing to protect the environment or the sensitivity of consumers to ecological issues but also because of possibilities of new business this concept offers. Indeed, firms noticed that they can create value with the end-of-life products by dismantling them and recovering parts and/or materials that can be re-introduced into manufacturing process, into maintenance process, etc.; or just by the improvement of their image with regards to public opinion. The process of recuperating end-of-life products, known as reverse logistics, is therefore a sustainable development process which will be triggered by the consumer and consists in a series of activities; one such activity concerns withdrawal problem that consists in responding some questions such as: where the end-of-life product must be dismantled?, how to bring the product from its actual position to the dismantling place?, who is in charge of this activity?, etc. This paper considers the issue of evaluating and optimizing the withdrawal process in the field of aircraft dismantling. The withdrawal plan evaluation is formulated here as multi-criteria / multi-objectives decision making problem and solved using BOCR analysis as the structuring framework for the elicitation process and satisficing game theory as the most suitable mathematical tool for recommendation process.

**Keywords:** end-of-life product, reverse logistics, withdrawal plan, BOCR analysis, satisficing game.

## 1. INTRODUCTION

Firms are increasingly interested in recovering used products due in particular to growing environmental awareness and increasing customer expectations of enterprises to dispose of manufactured products safely (Fleischmann et al. 2000).

Thus, sustainable development notion is becoming pervasive in socio-economic life which is manifested by growing interest of academic and business community to the processes related to that field as reverse logistics. Reverse logistics establishes a planning process to implement and control raw materials flows, current inventory, finished goods from the point of use to the point of recovery or proper disposal site. Reverse logistic services include product returns, recycling, materials substitution, reuse of materials, waste disposal, refurbishing, repair, and remanufacturing (Stock 1998). The existence of legislative pressures in terms of environmental protection and economic benefits (Godichaud et al. 2011),(Gupta 2013),(Ilgin & Gupta 2010),(Ilgin & Gupta

2012) generated by policy of sustainable environment requires to focus on economic, environmental and social aspects. These aspects are very important as they are considered as critical factors in measuring the contribution of a firm to sustainable development. For example, economic benefits for adopting reverse logistics by manufacturers are cost saving or improvement of the corporate image, allowing the company to gain competitive advantage and to increase the environmental performance (Nikolaou et al. 2011).

Consequently, end of life (EOL) systems management is becoming a major concern for systems manufacturers which allows reducing the negative impact of these systems on the environment and increasing benefits of manufacturers thanks to recycling and recovery operations. Indeed, EOL systems management allows the sustainable use of EOL products from activities such as: recycling, destruction, secure storage, valorization, scrapped, etc.,

see for instance (Godichaud et al. 2011).

Today, in aerospace sector, engineers pay a special attention to the scrapped end-of-life aircrafts. In fact, as any product, aircraft depreciates in value with time in reason of increased cost of maintenance, repair and upgrading to comply with legislation; when exceeding a certain threshold these factors become uneconomic and the aircraft is considered out of service. However, recalled aircrafts usually contain valuable components and parts that can be reused and reintroduced in the second hand parts market (Engineering and Physical Sciences Research Council 2007). The recycling has been considered for retired planes and Boeing's research showed that the most effective way to maximize airplane recycling would be to develop solutions in a collaborative fashion with companies that are already effectively engaged in that activity. For example, recycling carbon fiber can be done at approximately 70 percent of the cost with less than 5 percent of the electricity required to make new carbon (William Carberry 2008). Thus, to improve older fleet asset management and promote the best practices in terms of deconstruction, some groups and projects such as PAMELA (Process for Advanced Management of End of Life Aircraft) or AFRA (Aircraft Fleet Recycling Association) have emerged, driven by companies (in that case Airbus and Boeing respectively) to optimize recycling and valorization of aircraft materials for safe and environmentally reuse, and reduce the quantity of waste to be eliminated.

Their missions are: to encourage recycling aircrafts by showing that 85-95% of retired planes components can be recycled, reused, or recovered, ensure security, propose economic and environmental management of EOL aircraft and suggest solutions for the reuse of airplane parts and assemblies from older airplanes (William Carberry 2008).

In fact, the older fleet management and aircraft scrapping often involve conflicting economic, environmental, and social impacts. For example, choosing a new withdrawal plan for the dismantling EOL aircraft requires; optimizing some preference indicators such as, logistic costs, environmental effects, job creations, economic enhancement, etc.

By considering that the withdrawal plan begins from the repatriation plan of the EOL aircraft and goes until its dismantling place (Godichaud, et al. 2009), the withdrawal design phase is realized firstly in order to determine the complexity of the transport, the depth of disassembly and the sequencing of operations according to sustainable development (Lobato 2011).

An evaluation phase must then be realized to choose the best alternative among different existing deconstruction places. In fact, several sites can be candidates for the deconstruction operations which lead to many solutions in terms of logistics. In this context, this paper addresses the scrapped aircraft withdrawal plan problem. To select the best alternative or the most satisficing one, this paper proposes a multi-criteria/multi-objectives decision approach based on BOCR analysis to identify an adequate withdrawal plan.

The remainder of this paper is organized as follows: section two introduces the deconstruction processes and the characteristics of a deconstruction trajectory. Section three addresses the method of structured problem based on bipolar nature of variables. Section four presents the basis of the satisficing game theory. Section five provides an example of application. Section six concludes the article and discusses some perspectives and guidelines for future works.

## 2. DECONSTRUCTION PROCESS CHARACTERISTICS

Deconstruction system is a complex system involving requirements for environmental protection and valuation of EOL system components. It allows dismantling an EOL product using a variety of activities from withdrawing product to the service processing components. The objectives of a deconstruction process are the valuation components, regenerative active products, the mastery of operations for ensuring the safety, disassembly and dismantling, as well as the separation of hazardous components to ensure the safety of the environment and traceability of reuse parts from deconstruction.

In the framework of the aircraft dismantling, (Godichaud, et al. 2009) have sequenced the deconstruction process in three stages:

- The logistics of return also called reverse logistics; once the plane is declared out of service, it has to be removed and a quick diagnosis will determine the operations to be carried out before it is able to go on its own or to be transported to the place where it will be dismantled.
- The dismantling process is generally done on premises specialized in decommissioning. The goal is to recover the components (engine, landing gear, equipment, etc.) that have the potential to be reused on one hand and, in case it is not possible or not economically worthy, to extract the reusable materials (aluminum, alloys, plastics, etc.).
- Valuation activities have essentially economic objectives, there are four types of recovery:
  - functional recycling (reinstating the products resulting from the deconstruction)
  - material recycling (reusing the material components of the EOL system)
  - energy recovery (incinerating of non-recyclable products obtained from deconstruction to produce energy)
  - packaging and storage of hazardous products and products that cannot be valued in environmental friendly conditions.

## 3. STRUCTURED FRAMEWORK FOR ANALYSIS

The selection of a dismantling site as described in the previous section is obviously multi-objectives and a multi-criteria decision making problem where each potential dismantling site constitute an alternative. A potential alternative will be evaluated with regards to some objectives decision maker(s) want to achieve. To measure the adequacy between a given objective and an alternative, some attributes or criteria of the alternatives will be used; these attributes may

be organized hierarchically going from very general attributes till quantifiable ones are attained.

The stages of decision making problem under consideration are described as follows:

1. Actors select objectives and indicators to measure achievement of these objectives.
2. Potential alternatives are then identified.
3. For each pair (objective, alternative), actors can determine a set of attributes that permit evaluation of an alternative with regard to an objective.
4. Alternatives are evaluated with regard to the objectives for recommendations.

We propose in this paper a structuring framework based on a BOCR analysis combined with the Analytic Hierarchy Process (AHP) method as assessment tool. The BOCR analysis results from convergence of supportability/rejectability notions and uncertainty, see (Tchangani et al. 2012), (Bouzarour-Amokrane et al. 2012) as resumed in the following table (table 1). It consists in evaluating each alternative based on what it brings (B for benefit), what it allows (O for opportunity), what it costs (C for costs), and what it threatens (R for risk).

Table 1. BOCR analysis factors

	Certain	Uncertain
Support	Benefit (B)	Opportunity (O)
Reject	Cost (C)	Risk (R)

Elicitation of supporting/rejecting attributes can be done by answering questions like "what are certain/uncertain characteristics that represent a benefit / opportunity (cost / risk) in using the alternative 'x' to achieve objective 'y' ". Two distinct groups are identified;  $A_s^o$  that represents the set of attributes that support the achievement of the objective 'o' (includes attributes of benefits and opportunity) and the set of attributes that reject the achievement of the objective 'o' (the attributes of cost and risk)  $A_R^o$ . Once these attributes are identified, one may consider evaluating the strength of their relationships with the considered objectives; any evaluation methods can be used. But here we choose to use AHP procedure because of its structuring power. The AHP procedure allows structuring a decision problem by following a linear hierarchy that goes from general to more particular until a level of operational criteria against which the decision alternatives can be evaluated (Tchangani et al. 2012). The resulting model from the combination of the BOCR analysis and AHP procedure is shown in the Figure 1.

The evaluation of the decision problem by the AHP procedure starts with the assessment of the importance of the objective weight considering the overall goal (Tchangani et al. 2012). A pairwise comparison of the set of objectives is achieved by answering questions such "how important is objective 'o<sub>k</sub>' compared to the objective 'o<sub>i</sub>' with regard to the overall decision goal." The AHP scale given in Table 2 is used to obtain a pairwise comparison matrix from which the relative comparison vector  $\sigma^o$  is obtained with regard to the overall decision goal.

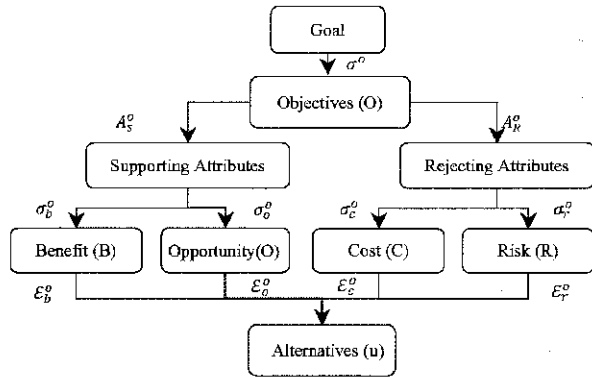


Fig 1. BOCR-AHP model structure.

Table 2. Classical AHP pairwise comparing weights

Qualitative scale	Numerical values
Equally important	1
Moderately more important	3
Strongly more important	5
Very strongly more important	7
Extremely more important	9
Intermediate scales (compromise)	2, 4, 6, 8

The pairwise comparison matrix can be constructed using a straightforward approach based on the selection of a pivot objective to which the other objectives will be compared (Tchangani et al. 2012). The relative importance degree of attributes considering objectives  $\sigma_x$  is also obtained by pairwise comparison of attributes considering objectives for each attributes sub-set  $A_x^o$  on each  $x = b, o, c, r$  factors. Evaluation alternative matrix considering different sub-sets of attributes  $\mathcal{E}_x^o$  ( $x = b, o, c, r$ ) factors can be obtained in two ways: for a given attribute, if the evaluation of the alternative is numerical with  $a_k(u_i)$  the performance of alternative  $u_i$  with regard to  $a_k$  then the pairwise comparison matrix  $\phi_x^{a_k}$  is obtained through (1).

$$\phi_x^{a_k}(u_i, u_j) = \frac{a_k(u_i)}{a_k(u_j)} \quad \forall a_k \in A_x^o \quad (1)$$

Otherwise, the matrix is obtained for  $n$  alternatives using the AHP procedure by answering a question of the form "how well does perform alternative  $u_i$  compared to alternative  $u_j$  with regard to attribute  $a_k$ ?" for each attributes sub-set  $A_x^o$  and the matrix is obtained by (2).

$$\mathcal{E}_x^{o_j}(u_i, a_k) = \frac{1}{n} \sum_j \frac{\phi_x^{a_k}(u_i, u_j)}{\sum_i \phi_x^{a_k}(u_i, u_j)} \quad (2)$$

Once the AHP procedure has been carried out by taking into account the bipolar nature of the attributes, the final evaluation consists in aggregating data in order to represent each alternative with a unique supporting measure (represented by benefit and opportunity) and unique rejecting measure (represented by cost and risks). Given the bipolar

nature of the attributes, we propose the use of satisficing game theory as the suitable mathematical tool for final evaluation process. In the following, a brief descriptive of the satisficing game theory is presented before addressing the application example.

#### 4. SATISFICING GAME THEORY

The satisficing game theory is based on the fact that decision makers in solving real problems do not necessarily seek to achieve the optimum but most of the time settle for alternatives that are just "good enough" because their cognitive capacities are limited and the information in their possession is almost always imperfect. The concept of being good enough is suitable for our approach, where good enough for an alternative can simply signify that the supporting contribution exceeds the rejecting one in some sense. To this end, each alternative  $u$  will be characterized by a selectability measure  $\mu_S(u)$  that measures the extent to which  $u$  works towards the achievement of overall goal and rejectability measure  $\mu_R(u)$  that represents the cost associated with alternative  $u$ . The satisficing game theory is characterized by several sets:

Definition 1. The satisficing set  $\Sigma_q \subseteq U$  is the set of alternatives defined by the following (3).

$$\Sigma_q = \{u \in U : \mu_S(u) \geq q\mu_R(u)\} \quad (3)$$

The caution index  $q$  can be used to adjust the aspiration level: increase  $q$  if too many alternatives are declared satisficing or, on the contrary, decrease  $q$  if  $\Sigma_q$  is empty for instance.

But for a satisficing alternative  $u$  there can exist other satisficing alternatives that are better (having more selectability and at most the same rejectability or having less rejectability and at least the same selectability) than  $u$ ; it is obvious that in this case any rational decision maker will prefer the later alternatives. So the interesting set is that containing satisficing alternatives for which there are no better alternatives: this is the satisficing equilibrium set  $E_q^S$ . To define this set, let us define first, for any alternative  $u$ , the set  $D(u)$  of alternatives that are strictly better than  $u$ ;  $D(u)$  is given by (4).

$$D(u) = D_S(u) \cup D_R(u) \quad (4)$$

where  $D_S(u)$  and  $D_R(u)$  are defined by below

$$D_S(u) = \{v \in U : \mu_R(v) < \mu_R(u) \text{ and } \mu_S(v) \geq \mu_S(u)\} \quad (5)$$

$$D_R(u) = \{v \in U : \mu_{SR}(v) \leq \mu_R(u) \text{ and } \mu_S(v) > \mu_S(u)\} \quad (6)$$

The equilibrium set  $E$  (alternatives for which there are no strictly better alternatives), which cannot be empty by construction, is defined by following equation

$$E = \{u \in U : D(u) = \emptyset\} \quad (7)$$

and the satisficing equilibrium set, the set  $E_q^S$  is therefore given as shown below

$$E_q^S = E \cap \Sigma_q \quad (8)$$

Notice that the set  $E_q^S$  constitutes a Pareto-equilibria set so that there is incomparability between a pair of alternatives in this set, so that a trade-off process is necessary for final choice purpose for instance that mean possible indecision; these alternatives are those laying on the portion of green curve (above which there is no alternatives meaning the Pareto equilibrium) that is above the red line (separating satisficing and non-satisficing alternatives) of the following Figure.

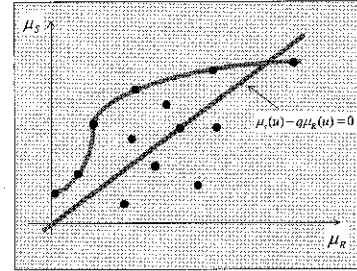


Fig 2. Positions of alternatives in the plan  $(\mu_R, \mu_S)$

Table 3. Performance matrix for attributes of economic objective

Economic objective		
Factors	Indicators	Attributes
Benefit	Recycled products	% of materials to be recycled
		price or value of materials to recycle
	Reused products	% of parts of systems to reuse
		resale value of material
	Energy value	% of wastes
	Resources	Energy value
		% of use of resources used
distance traveled with 1Ton of freight with 1l of fuel		
volume of the material		
Opportunity	Forecast orders	% of skilled labor
		forecast quantity of parts and systems components
		frequency of orders
	Possible profits	volume of the material
Taxes		
Cost	Transportation cost	Credits
		distance instead of deconstruction
		cost/km
	Packaging cost	travel time
		location cost
		cost of ownership (depreciation)
		working hours
		hourly cost
		parking time prior to the construction
Cost of production	service life	
	cost of service	
Administration cost	management costs (doc, training etc.)	
Risk	Evaluation	% of skilled labor
		Resources

	volume of the material
--	------------------------

By using satisficing game theory as final aggregation process, selectability and rejectability measures are obtained as following for an alternative  $u_i$

$$\mu_S(u_i) = \frac{\gamma B(u_i) + (1 - \gamma)O(u_i)}{\sum_{v \in U} (\gamma B(v) + (1 - \gamma)O(v))} \quad (9)$$

$$\mu_R(u_i) = \frac{(1 - \gamma)C(u_i) + \gamma R(u_i)}{\sum_{v \in U} ((1 - \gamma)C(v) + \gamma R(v))} \quad (10)$$

with;

$$X(u) = \sum_{o_j \in O} \left( \sigma^o(o_j) \left( \sum_{o_k \in A_x(o_j)} \sigma_x^{o_j} \varepsilon_x^o(u_i, a_k) \right) \right) \quad (11)$$

where  $X = B, O, C, R$ ; represent aggregation measures for  $x = b, o, c, r$  factors for each alternative  $u_i$  respectively.

$\gamma$ : stands for risk averse index and is used to take into account the behavior of decision makers towards risk. When risk averse index goes to 0 (highly risky decision maker), positive uncertain factor namely opportunity and negative certain factor in terms of cost are favored (potential gain versus immediate cost whatever the potential threat) whereas when  $\gamma$  tends towards 1 (a risk averse decision maker), positive certain factor (benefit) is compared to negative uncertain factor (risk), actual gain versus potential threat whatever the cost to pay.

## 5. APPLICATION EXAMPLE

In this section, we show how to use our approach to resolve the scrapped aircraft withdrawal plan location problem. AHP procedure combined to BOCR analysis is used to select the most satisficing aircraft dismantling site.

### 5.1 Data

The data used in this problem are taken from the work of Lobato (Lobato, 2011). They have been treated and standardized for our needs. The overall goal is to repatriate an EOL aircraft to a dismantling platform. Economic, environmental and social objectives have been fixed by the group of decision makers. The indicators used to calculate the degree of achievement of objectives are elicited by decision makers for each objective and detailed in quantifiable attributes characterizing the alternatives in BOCR analysis framework. To meet the required number of pages, only data on the economic objectives are summarized in the table 3. There are 7 potential repatriation plans.

### 5.2 Results

The evaluation of alternatives by the AHP procedure in the BOCR analysis framework was achieved by applying (2) and (11). The results obtained are summarized in Table (4). Then selectability measure is calculated by combining the benefit and opportunity contribution for each alternative using (9) and measuring rejectability by aggregating the cost and risk contribution of each alternative using (7). Table (5)

summarizes the results obtained. For easier reading of these results, the graphical representation of these terms in  $(\mu_S, \mu_R)$  plane is done. We obtained 3 graphs by varying risk averse index ( $\gamma=0.5, \gamma=0.2, \gamma=0.8$ ) (Figure 3). We can observe easily the satisficing equilibrium set for each case at the caution index  $q=1$ .

Table 4. AHP Evaluation matrix for b, o, c, r factors

Objectives	$\varepsilon_x^o$	U1	U2	U3	U4	U5	U6	U7
Economic objectives	x	0,13	0,15	0,17	0,18	0,15	0,10	0,12
	= b							
	x	0,08	0,12	0,24	0,04	0,20	0,26	0,06
	= o							
	x	0,15	0,21	0,14	0,10	0,11	0,11	0,18
Environne mental objective	= c							
	x=r	0,10	0,14	0,17	0,15	0,14	0,17	0,13
	x	0,13	0,14	0,16	0,16	0,15	0,13	0,12
	= b							
	x	0,09	0,18	0,19	0,16	0,15	0,14	0,08
Social objective	= o							
	x	0,03	0,19	0,11	0,36	0,07	0,06	0,15
	= c							
	x=r	0,09	0,13	0,15	0,16	0,13	0,21	0,14
	x	0,16	0,14	0,13	0,18	0,11	0,14	0,13
Social objective	= b							
	x	0,13	0,16	0,15	0,13	0,14	0,14	0,15
	= o							
	x	0,09	0,04	0,09	0,52	0,10	0,08	0,09
	= c							
x=r	0,06	0,09	0,10	0,52	0,06	0,08	0,08	

Table 5. Selectability and rejectability measures for the considered application ( $\gamma=0.5$ )

	U1	U2	U3	U4	U5	U6	U7
$\mu_S(u)$	0,118	0,149	0,178	0,138	0,152	0,156	0,108
$\mu_R(u)$	0,090	0,140	0,130	0,285	0,104	0,121	0,130

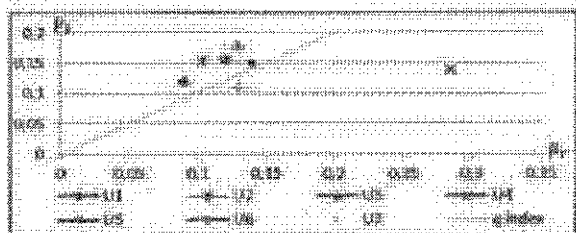
The first case ( $\gamma = 0.5$ ) in Figure 3 considers that decision makers give equal importance to certain elements (benefits and cost) and uncertain one's (opportunity and risk), the satisficing equilibrium set obtained contains the following alternatives  $E_q^S(\gamma = 0.5) = \{U3, U6, U5, U1\}$ , and the second case ( $\gamma = 0.2$ ) which considers that decision makers have a low risk averse contains the same set of satisficing equilibrium  $E_q^S(\gamma = 0.2) = \{U3, U6, U5, U1\}$ . Finally, when decision makers focus on positive certain element (benefit) and negative uncertain element (risk) that is  $\gamma = 0.8$ , the set of satisficing equilibrium contains the following alternatives  $E_q^S(\gamma = 0.8) = \{U3, U2, U5, U1\}$ . Note that the alternative U6 is replaced in this case by alternative U2 in satisficing equilibrium set. This is explained by the fact that the benefit and risk provided by the alternative 2 are more important than those presented by the alternative 6, however the opportunity offered by the alternative 6 is greater than alternative 2.

To choose the most satisficing alternative the following selection criteria have been used: the sensitivity analysis on the risk averse index that varies between 0 and 1 and the difference between selectability and rejectability measures in

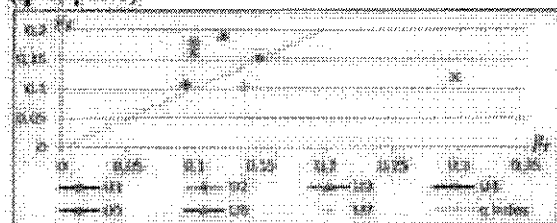
the case of  $q=1, \gamma=0.5$ . The ranking of alternatives is shown in table 6.

## 6. CONCLUSIONS

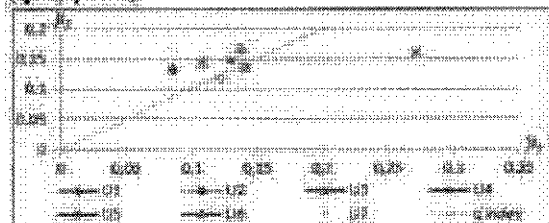
This paper addresses the problem of selecting a site for disassembling ECR aircraft after a brief descriptive characterization of the disassembling process. The proposed method has been described, considering the problem as a multi-criteria/multi-objectives decision. The AHP procedure combined with ECRM analysis have been proposed to structure and assess different components of this problem as well as the strength of their relation. Given the bipolar nature of attributes, the satisfying game theory has been proposed as the analysis tool for the final recommendation process. The risk aversion attitude that the latest makers may present is also taken into account in the model through the risk aversion index. The main contribution of this work is related to the structuring framework to assess the objectives of different alternatives, necessary to adapt the evaluation of different alternatives. Future works must address the application of this approach in a real industrial case study for which concrete practical aspects and engineering refer way for aggregations such as Choquet integral gives the heterogeneity obtained by clustering different elements using bipolar index for hierarchical aspects.



( $q=1, \gamma=0.5$ )



( $q=1, \gamma=0.2$ )



( $q=1, \gamma=0.8$ )

Fig. 3. Alternative representation in (rejectability, selectability) plan

Table 6. Ranking of considered alternatives

Alternatives	A1	A2	A3	A4	A5	A6	A7
Ranking	8	4	2	7	1	5	3

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