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BOCR analysis applied to the management of end-of-life systems

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Abstract. Nowadays, most of the firms are involved in a sustainable development approach aiming to ensure financial, social and environmental performance, in order to satisfy legislation and customers that have become increasingly demanding. Reverse logistics is part of the process of sustainable development. This process triggered by the consumer consists in a series of activities required for recovery and reprocessing of used products. These products can be reused in some cases. In the framework of sustainable development, this paper is concerned by the design and the evaluation process of withdrawal plans in the field of aircraft dismantling. A multi-criteria decision aid support based on BOCR analysis is proposed to select adequate withdrawal plans. Variables used to evaluate a candidate withdrawal plan constitute what we refer to as repatriation trajectory. A repatriation plan is evaluated on a bipolar scale by two measures namely selectability measure and rejectability measure in the framework of satisficing game to highlight positive aspects and negative aspects with regards to decision making main objectives.

Key words: BOCR analysis, bipolarity, decision aid support, scrapped aircraft, reverse logistics.

1. Introduction

Nowadays, sustainable development notion is pervasive in socio-economic life and a growing interest of academic and business community is observed about the processes related to that field. Indeed, the existence of legislative pressures in terms of environmental protection and economic benefits (Godichaud et al., 2011) 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 (Evangelinos, Allan, 2011).

Thus, 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 raison 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 fiber (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 (Cotes, 2006), ensure security, propose economic and environmental management of EOL aircraft and suggest solutions for the reuse of airplane parts and assemblies from older airplanes (Carberry, 2008).

In fact, the older fleet management and aircraft scrapping often involve conflicting economic, environmental, and socio-ecological impacts. For example, locating a new withdrawal plan for the dismantling end of life aircraft requires; optimizing some preference indicators such as, logistic costs, environmental effects…etc.

By considering that the withdrawal plan precises the repatriation plan of the EOL aircraft until its dismantling place (Godichaud, Pérès, 2007), 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 plane 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 location problem. To select the best alternative or the most satisficing one, this paper proposes a multi-criteria decision approach based on BOCR analysis to identify an adequate withdrawal plan.

The remainder of this paper is organized as follow: 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

A system of deconstruction is a sequence of complex processes that begins with the decommissioning of the aircraft until the treatment of its constituents. It aims to deconstruct the end of life systems so as to recover reusable or recyclable parts in compliance with environmental standards.

In the framework of the aircraft dismantling, Gaudichaud et al. (Gaudichaud 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 that have the potential to be reused on the one hand (engine, landing gear, equipment ...) and, in case it is not possible or not economically worthy, to extract the reusable materials (aluminum, alloys, plastics ...).
- Valuation activities have essentially economic objectives, there are four types of recovery:
  - functional recycling (reinstate the products resulting from the deconstruction)
  - material recycling (reusing the material components of the end of life 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

Our issue, that is the selection of the best site of dismantling is formulated as a multicriteria decision problem, where each dismantling potential site is considered as an alternative. It is then evaluated according to a set of indicators presented by the actors of the decision and detailed on quantifiable attributes in order to estimate the degree of achievement of decision objectives by each alternative.

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 on bipolar basis of them (supporting /rejecting attributes).
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. It corresponds to evaluate 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).

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

Table 1. BOCR analysis factors

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.

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 is reached (Tchangani et al., 2012).

The resulting model from the combination of the BOCR analysis and AHP procedure is shown in the Figure 1.

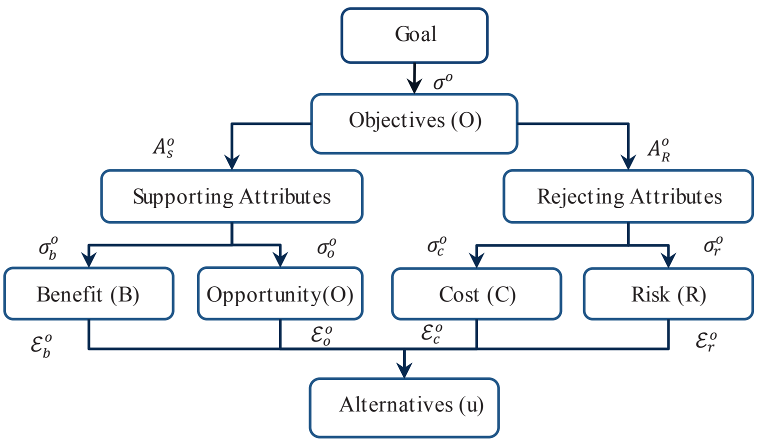


Fig 1.BOCR-AHP model structure

The evaluation of the decision problem by the AHP procedure (Tchangani et al., 2012) starts with the assessment of the importance of the objective weight considering the overall goal. A pairwise comparison of the set of objectives is achieved by answering questions such "how important is objective $'o_k'$ compared to the objective

$'o_l'$ with regard to the overall decision goal?". The AHP scale given in Table 2 is used to obtain a pairwise comparison matrix φ^o where $\varphi^o(k,l)$ is the relative importance of objective $'o_k'$compared to the objective $'o_l'$ with regard to the overall decision goal.

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

Table 2. Classical AHP pairwise comparing weights

The pairwise comparison matrix φ^o can be constructed arbitrarily using a straightforward approach based on the selection of a pivot objective to which the other objectives will be compared., in that case a consistent matrix[1] is obtained (for more details see (Tchangani et al., 2011)). The relative importance of attributes considering objectives $\sigma_\times^o$ is also obtained by pairwise comparison of attributes considering objectives for each attribute sub-set on each $\times = b, o, c, r$ factors. Evaluation alternative matrix considering different sub-sets of attributes $\mathcal{E}_\times^o$ $(\times = b, o, c, r)$ factors can be obtained in two ways: for a given attribute, if the evaluation of the alternative is numerical with $ak(u_i)$ the performance of alternative u_i with regard to a_k then the pairwise comparison matrix $\varphi_\times^{a_k}$ is obtained through equation 1

$$\varphi_\times^{a_k}(u_i, u_j) = \frac{\mathrm{a_k\,(u_i)}}{\mathrm{a_k\,(u_j)}} \tag{1}$$

Otherwise, the matrix is obtained 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 ?" and the matrix is obtained by equation 2

$$\mathcal{E}_\times^{o_j}(u_i, a_k) = \frac{1}{n}\sum_j \frac{\varphi_\times^{a_k}(u_i, u_j)}{\sum_l \varphi_\times^{a_k}(u_l, u_j)} \tag{2}$$

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 in the final evaluation. 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. The satisficing game theory is characterized by several sets:

Definition 1. The satisficing set Σq U is the set of alternatives defined by the following equation

[1] A pairwise comparison matrix M is said to be consistent if it verifies $M(j,j) = 1$, $M(j,l) = \frac{1}{M(l,j)}$ and $M(j,l) = M(j,k)M(k,l)$.

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

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 Σq is empty for instance.

However, there are many cases where some alternatives have better selectability and lower rejectability than others, it is clear that in such situation, the decision maker will want to choose these alternatives, the interesting set would be the set where satisficing alternatives are the best (without alternative better than them).

Then, we define the equilibrium set E as a set (alternatives for which there are no strictly better alternatives), which cannot be empty by the following definition (see equation 4)

$$E = \{u \in U : D(u) = \emptyset\} \quad (4)$$

and the satisficing equilibrium set, E_q^S is given by

$$E_q^S = E \cap \Sigma q \quad (5)$$

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

$$\mu_s(u_i) = \frac{\gamma B(u_i) + (1-\gamma)O(u_i)}{\sum_{v \in U}(\gamma B(v) + (1-\gamma)O(v))} \quad (6)$$

$$\mu_s(u_i) = \frac{\gamma B(u_i) + (1-\gamma)O(u_i)}{\sum_{v \in U}(\gamma B(v) + (1-\gamma)O(v))} \quad (7)$$

with;

$$X(u) = \sum_{o_j \in O}\left(\sigma^o(o_j)\left(\sum_{o_k \in A_\times(o_j)} \sigma_\times^{o_j} \mathcal{E}_\times^o(u_i, a_k)\right)\right) \quad (8)$$

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

γ : stands for the index of risk aversion and is used to take into account the behavior of decision makers towards risk. When the aversion risk 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 γ tends towards 1 (a risk aversion 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.

a. 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 end of life 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 following table. There are 7 potential repatriation plans.

Economic objective			**Alternatives**							**Units**
Factors	**Indicators**	**Attributes**	**u1**	**u2**	**u3**	**u4**	**u5**	**u6**	**u7**	
Benefit	Recycled products	% of materials to be recycled	0,55	0,4	0,63	0,68	0,65	0,08	0,25	%
		price or value of materials to recycle	50	30	45	25	60	35	35	EURO/KG
	Reused products	% of parts of systems to reuse	0,35	0,4	0,3	0,2	0,25	0,15	0,6	%
		resale value of material	150	100	300	500	200	150	100	EURO/UN
	Energy value	% of wastes	0,08	0,25	0,05	0,1	0,08	0,03	0,13	%
		Energy value	15	10	15	13	1	12	10	EURO/KG
	Ressources	% of use of resources used	0,85	0,65	0,9	0,825	0,75	0,6	0,66	%
		distance traveled with 1Ton of freight with 1l of fuel	50	45	80	200	250	70	50	KM T/L
		volume of the material	10000	120000	150000	17000	13000	70000	10000	UNITES
		% of skilled labor	0,3	0,6	0,85	0,75	0,6	0,9	0,5	%
Opportunity	Forecast orders	forecast quantity of parts and systems components	10000	10000	10000	15000	12000	70000	80000	UNITES
		frequency of orders	40	30	60	50	40	55	50	1/AN
		volume of the material	10000	120000	150000	17000	13000	70000	10000	UNITES
	Possible profits	taxes	2000	1000	3000000	2000	15000	5000000	150000	EUROS
		Credits	45000	10000	400	100	150000	50	50	EUROS
Cost	Transportation cost	distance instead of deconstruction	1500	300	2000	8000	1000	500	1000	KM
		cost/km	15	40	25	10	60	45	20	EURO.KM
		travel time	16	7	15	30	10	13	12	JRS
		location cost	25000	30000	75000	5000	50000	15000	5000	EURO
	Packaging cost	cost of ownership (depreciation)	1000		15	25	35	40	45	EUROS
		working hours	3	15	5	20	7	10	15	days
		hourly cost	120	300	45	100	90	75	50	EUROS
		parking time prior to the construction	200	100	50	90	130	250	200	days
	Cost of production	service life	260	150	100	90	150	300	350	days
		cost of service	2000000	3500000	1500000	4000000	2000000	1500000	3000000	EUROS
	Administration cost	management costs (doc, training etc.)	10000	150000	70000	5000	10000	15000	120000	EUROS
Risk	Evaluation	% of skilled labor	0,3	0,6	0,85	0,75	0,6	0,9	0,5	%
		resources	2500000	3000000	3000000	3000000	3000000	3000000	3000000	EUROS
		volume of the material	10000	120000	150000	17000	13000	70000	10000	UNITES

Table 3. Performance matrix for attributes of economic objective

b. Results

The evaluation of alternatives by the AHP procedure in the BOCR analysis framework was achieved by applying the equations (2) and (8). The results obtained are summarized in Table (4). Then selectability measure is calculated by combining the benefit and opportunity contribution for each alternative (equation6) and measuring rejectability by aggregating the cost and risk contribution of each alternative (equation 7). Table (5) summarizes the results obtained. For easier reading of these results, the graphical representation of these terms in(μ_s,μ_r) plane is done. We obtained 3 graphs by varying risk aversion indices (γ=0.5, γ=0.2, γ=0.8) (Figure 2). We can observe easily the satisficing equilibrium set for each case at the caution index q=1.

Objectives	$\mathcal{E}_{\times}^{o}$	U1	U2	U3	U4	U5	U6	U7
Economic objectives	$\times = b$	0,1312	0,1468	0,1735	0,1774	0,1501	0,1028	0,1182
	$\times = o$	0,0764	0,1206	0,2406	0,036	0,1998	0,2647	0,062
	$\times = c$	0,1467	0,2135	0,1393	0,103	0,1103	0,1096	0,1775
	$\times = r$	0,098	0,1445	0,1682	0,1523	0,1388	0,1683	0,1298
Environnemental objective	$\times = b$	0,1298	0,1413	0,1629	0,1604	0,1463	0,1251	0,1242
	$\times = o$	0,092	0,1828	0,1883	0,1629	0,1499	0,1437	0,0805
	$\times = c$	0,0341	0,1934	0,1131	0,3619	0,0726	0,0639	0,151
	$\times = r$	0,086	0,1328	0,1509	0,1562	0,125	0,211	0,1382
Social objective	$\times = b$	0,1598	0,1438	0,1328	0,1794	0,1098	0,1383	0,1261
	$\times = o$	0,1281	0,1642	0,149	0,1313	0,1408	0,1377	0,1488
	$\times = c$	0,0938	0,0365	0,0886	0,5157	0,1005	0,0771	0,0878
	$\times = r$	0,0616	0,0909	0,1035	0,5194	0,0636	0,0803	0,0807

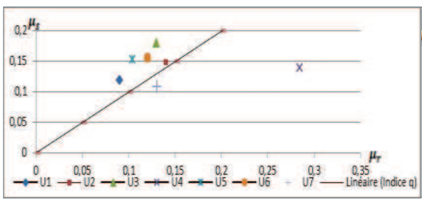
Table 4. AHP Evaluation matrix for b, o, c, r factors

	U1	U2	U3	U4	U5	U6	U7
$\mu_s(u)$	0,1199	0,1504	0,1751	0,1417	0,1499	0,1526	0,1103
$\mu_r(u)$	0,0869	0,1355	0,1275	0,3019	0,102	0,1186	0,1277

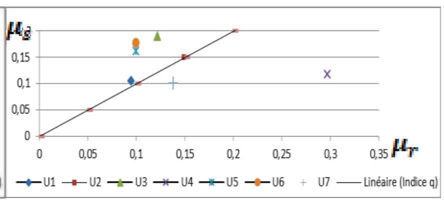
Table 5. Selectability and rejectability measures for the considered application (γ=0.5)

The first case (γ = 0.5) in Figure 2 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 (γ = 0.2) which considers that decision makers have a low risk aversion 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 γ = 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 better than those presented by the alternative 6, however the opportunity offered by the alternative 6 is greater than alternative 2.

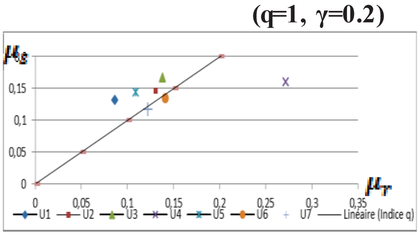
To choose the most satisficing alternative the following selection criteria have been used: the sensitivity analysis of the risk aversion index that varies between 0 and 1 and the difference between selectability and rejectability measures in the case of q=1, γ=0.5. The ranking of alternatives is shown in table 6.



(q=1, γ=0.5)



(q=1, γ=0.2)



(q=1, γ=0.8)

Fig 2. Alternative representation in (rejectability, selectability) plane

Alternatives	U1	U2	U3	U4	U5	U6	U7
Ranking	3	4	2	7	1	5	6

Table 6. Ranking of considered alternatives

6. Conclusion

This paper addresses the problem of selecting a site for dismantling end of life aircraft. After a brief descriptive characterization of the deconstruction process, the proposed method has been described; considering the problem as a multi-criteria multi-objectives decision, the AHP procedure combined with BOCR analysis have been proposed to solve the problem. Taking into account the bipolar nature of attributes, the satisficing games theory have been proposed as the final aggregation process. The risk aversion index that decision makers may be presented is also taken into account in the model. A graphical representation allows the decision maker to identifiy clearly the degree of support and reject of each alternative to achieve the objectives. The proposed model is intended to structure and render flexible the overall decision process in order to tend towards a robust decision.

References

Tchangani, A.P, Bouzarour, Y. and Pérès, F (2012). Evaluation Model in Decision Analysis: Bipolar Approach INFORMATICA, International Journal xx: yy. zz.

Tchangani. A.P, Bouzarour Y, Pérès, F (2011). Bipolar Evaluation Model in Decision Analysis. Dans 12ème Congrès annuel de la société française de recherché opérationnelle et d'aide à la décision, ROADEF 2011. Saint Etienne.

Bruno COSTES, PAMELA (2006) - Process for Advanced Management of End of Life of Aircraft.

Engineering and Physical Sciences Research Council (2007). The Aircraft at End of Life Sector a Preliminary Study.

Godichaud, M. Tchangani, A.P, Pérès.F and Iung B (2011). Sustainable management of end-of-life systems. *Production Planning & Control*, p.1–21.

Godichaud, M. and Pérès, F (2007). Optimisation économique des dates de fin de vie des systèmes industriels et détermination des stratégies de revalorisation des produits issus de leur déconstruction. EDSYS PhD Students Congres.

Evangelinos, K. and Allan, S (2011). A Reverse Logistics Social Responsibility Evaluation Framework based on the Triple Bottom Line Approach. *Journal of Cleaner Production*..

Lobato, M.A. (2011). Gestion des risques dans la logistique de démantèlement, Master Thesis, ENIT.

Godichaud, M, Pérès, F and Tchangani,A.P (2009). Disassembly process planning using Bayesian networks. Dans Proceedings of Fourh World Congres on Engineering Asset Management (WCEAM), pp.280-287, ISBN: 978-1-84996-002-1: Springer.

Carberry,W (2008). Airplane Recycling Efforts Benefit Boeing Operators. *Boeing AERO Magazine QRT*, (130.76.96.105).

Bouzarour-Amokrane, Y, Tchangani, A.P and Pérès.F (2012). Definition And Measure Of Risk And Opportunity In The Bocr Analysis. In Proceedings of 10th International Conference of Modeling and Simulation - MOSIM'12. « Performance, interoperability and safety for sustainable development. » (forthcoming). Bordeaux- France.