Decision aiding in manufacturing improvement approaches

Lamia berrah, Vincent Clivillé, Gilles Mauris
LISTIC Polytech Annecy Chambéry France

1 Introduction

In an increasingly complex environment, faced with an open market and tough competition, the manufacturing company must excel in its production function. In this context, multicriteria objectives are defined coherently with the company's strategy and performance improvements are continuously launched to reach these objectives (Berrah et al., 2000). The improvement approach steps generally implemented use the traditional feedback loop principle, in accordance with the Deming wheel (Plan-Do-Check-Act) (Deming 1986). Namely, improvement actions are first planned knowing the associated expected performance measures, before they are implemented, then checked according to both the fixed targets and the considered performances, and corrected if necessary, and so on as long as some improvements are still achievable.

In this context, the definition of a performance measurement system (PMS) is a key point (Neely 1999; Kaplan and Norton 1992; Mills 2002; Nudrupati 2011). Indeed, according to their definition, the purpose of a such system is, on the one hand, to give pieces of information about the objective's satisfaction and, on the other hand, to link the current measures to the improvement actions to launch (Fortuin 1988; Bitton 1990). In this sense, a PMS is an instrument to support decision-making, either for launching, choosing or diagnosing improvement actions, or redefining objectives (Neely 1999).

From a global point of view, a PMS can be seen as a multicriteria instrument, made of a set of performance expressions (also referred to as "metrics") (Cooke 2001; Melnyk et al., 2004), *i.e.* physical measures as well as performance evaluations, to be consistently organised with respect to the objectives of the company. These expressions are necessary for the identification of the relevant actions to launch, the checking of their efficiency and the diagnosis of the possible causes of inefficiency and then the correction and the adaptation of these actions. According to the various performance criteria of the company, the PMS can be considered as multicriteria decision aiding, knowing that on the one hand the improvement manager is the decision-maker (DM), on the other hand many improvement actions and multiple criteria for the decision have to be taken into account.

In spite of these decision problem characteristics, the main PMS propositions such as the balanced scorecard (Kaplan and Norton 1992), the processed based approach (Neely 1995), the Integrated Dynamic Measurement Performance System (Ghalayini 1997), the ENAPS approaches (Browne, 1999), the ISO 9000 framework (ISO 9000, 2001), do not consider this aspect and aim to give to the improvement manager only a set of performance measures. Theses models are not always available to answer to questions such as: "is the situation at the end of the third semester better than the previous one?", "is the action A better than the action B regarding the whole set of criteria?", "what are the main causes of the bad results of a given business unit?" To avoid this lack, some propositions have been made in order to introduce the MCDA aspect in the PMS definition (Santos et al., 2002). Let us mention in this sense the Performance Criteria System (Globerson 1985), the ECOGRAI method (Bitton 1991) or the Quantitative models for Performance Measurement System (Bititci 2000).

Subscribing with the idea of linking PMS's to a decision-aiding exploitation, this work deals with the use of the MCDA methods in an industrial improvement context, by considering the useful pieces of information that can be provided in addition to those expressed by PMS's. In this sense, Section II focuses on the major requirements in terms of decision-aid along the different steps of an improvement process. Hence, the encountered decision problems are matched with the major

MCDA method categories (namely, the choice, sorting, ranking and description ones). We conclude this description by considering the relevance of the MACBETH method to help the decision making by offering a formal way to transform the available qualitative DM's preferences into quantitative ones. Section III gives a brief description of MACBETH, particularly its adaptation to the Choquet Integral operator which is used in order to take the mutual interactions between criteria into account. Section IV gives an illustration of the method deployment in the case of the definition of a preference model for a set of four regional companies that are involved in sustainable development approaches. Some concluding remarks and perspectives are then proposed.

2 What are the decision problems in an improvement process?

The generic PETRA methodology which is based on the PDCA Cycle involves the following six steps (figure 1): problem statement - corporate strategic analysis - organisation analysis - opportunity evaluation - organisation redesign – implementation - closure. (Berrah et al., 2001a, 2001b).

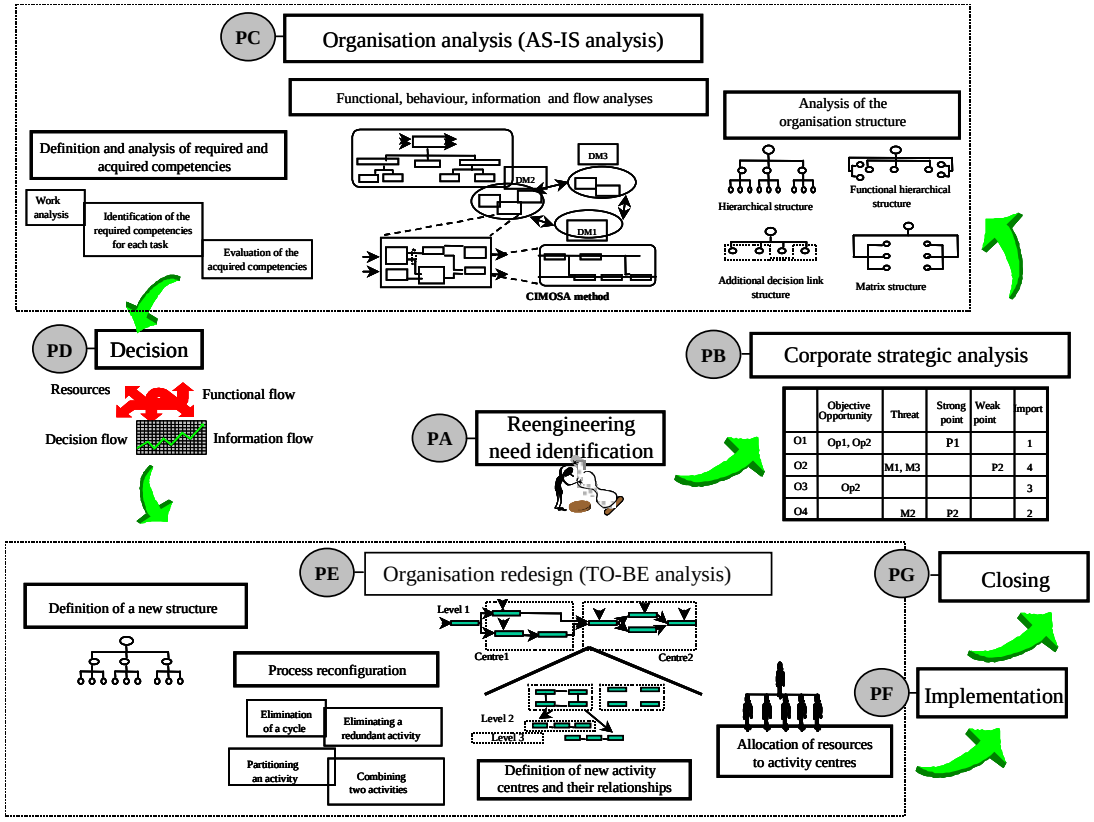


Figure 1: Company reengineering cycle according the PETRA methodology

This cycle is reiterated as long as the considered objectives are not satisfied and as long as improvement opportunities can be considered. So in such approaches several decision problems can be identified. Before going further in the analysis of these problems and in order to get a meaningful description of them, let us recall first the four reference problematics in the decision area (Roy 1985; Jacquet-Lagreze 2001). By considering a set of actions and a set of criteria, are distinguished:

- the choice problematic α. which consists of choosing an action *a* from the set of potential actions,

- the sorting problematic β, which allows the DM to sort the potential actions in well-defined categories,
- the ranking problematic γ, which ranks the potential actions from the worst one to the best one(s),
- the description problematic δ, which describes the action in term of their performance with regard to the set of criteria.

Note that these problematics can be separately or conjointly encountered in real-life situations. Let us now identify hereafter, step by step according to the PETRA framework, the decision problems that characterise an improvement process.

- Step 1*: problem statement*. The decision problem concerns the global diagnostic of the current state of the company which can be expressed by: is the overall performance of the company satisfactory? In the case of a positive answer, no more improvement action is needed; otherwise, the diagnostic must be deepened in order to identify the causes of the overall dissatisfaction. According to us, no multicriteria decision problem can be identified at this step.
- Step 2 and 3: *strategic and detailed analysis*. The decision problem consists of the preference criteria definition and the corresponding expected satisfaction levels. Here, the DMs are looking for a more precise diagnostic that is based on the identification of the strengths and the weaknesses of the considered system. The decision problem is viewed as a problematic δ, related to the description of the company's current state.
- Step 4: *opportunity evaluation*. Supposing that a set of relevant opportunities can be retained by the DMs from the previous diagnostic, the decision problem concerns the choice of the improvement opportunity among the potential ones. This problem can be viewed as a problematic α of an opportunity choice from several ones.
- Step 5: *organisation redesign*. The selected opportunity is deployed on the considered system. Operational actions must thus be chosen and planned from the potential ones. The considered problem is similar to those of the previous 2, 3, 4 steps, however at a more detailed level.
- Step 6*: implementation*. Knowing that the effect of the action cannot be certain, it is useful to regularly check the reached performances, generally at the different milestones of the operational actions planning. The decision problem is viewed as a problematic δ related to the description of the reached states (at each milestone) possibly combined with the problematic α of choice when the actions must be revised.
- Step 7: *closure*. Even if no action can be launched after the closure of the improvement project, the company must know the reached level of satisfaction at the end of the opportunity implementation and possibly diagnose the strengths and the weaknesses corresponding to this final reached state. This decision problem can be viewed as a combination of a description problematic δ of the final reached state, with a choice problematic α concerning the opportunity/action selection.

As a summary, from a decisional point of view, DMs build a preference model (steps 2 and 3), then apply it from the strategic level (diagnosis of step 3 and choice of step 4), to the operational one (step 5). They apply it again at each milestone of the opportunity planning (choice of step 5 and diagnosis and choice of step 6), and finally apply it one last time at the end of the opportunity planning (diagnosis of step 7).

However, some additional considerations have to be taken into account before the selection of a MCDA method in this context, namely:

- the adoption of the same preference model along the whole improvement approach.
- the comprehensive aspect of the defined model.

In previous works, in order to deal with all these constraints, an aggregation method has been considered allowing the DMs to both diagnose and make choices during the whole improvement approach. More precisely, the MACBETH methodology has been considered, for the description and the ranking of the alternatives actions, according to a set of criteria and the associated DM's preferences.

The proposed model has been applied in many industrial cases such as the improvement of the *service rate* of a SME that manufactures kitchens, bathrooms and storing spaces (Clivillé et al., 2007), the optimisation of the *Lean Manufacturing policy* in an automation components producer (Berrah et al., 2011), the sustainable development in a panel of manufacturing companies (Berrah and Clivillé 2010), the supply chain management in the bearings industry (Clivillé and Berrah 2011)… Our proposition is briefly presented hereafter, illustrated through the definition of a part of a preference model, the determination of the aggregation operator parameters, for a sustainable development problem.

3 The MACBETH preference model for the performance improvement

3.1 The MACBETH methodology

MACBETH (Bana e Costa *et al*., 1997) is a synthesising criterion method which supplies a quantitative overall utility function $u(a)$ for each potential action (a). The relation between the unique synthesising criterion utility value $u(a)$ and the marginal utility values denoted $u_j(a)$ is given by the Weighted Arithmetic Mean (WAM) operator. Both marginal and overall utility functions are defined according to interval scales. The interval scales are built from an information process based on the concept of strengths of preference (Vansnick 1984) provided by the DM.

The definition of the marginal utility functions is issued from the pair-wise comparison judgments. So an action a is compared to an action b according to a criteria c_j under the form "a is preferred to b with a strength of preference h", h being able to take one of the 6 following semantic categories: *very weak, weak, moderate, strong, very strong, extreme.* For each criterion, two reference levels, "Neutral" and "Good" are defined, corresponding to the boundaries of the marginal utility. All the comparisons are then expressed under the form of constraints which are solved by linear programming, in order to give numerical values for the marginal utilities.

The same processing is made for the criteria weight determination using reference actions corresponding to the following marginal utility vector (0…1…0) where all the marginal utilities correspond to the "Neutral" level, except the one which corresponds to the "Good" level. The reader can find more information in (Bana e costa et al,. 2003; Clivillé et al., 2007; Mayag 2010).

However, concerning the WAM operator, it is well known that this type of compromise operator is well-adapted in the case of criteria preferential independence. Knowing that this assumption is not always verified, it is possible to deal with the criteria interaction thanks to the family of the Choquet Integral (CI) operators (Grabbisch and Roubens 1996). In our framework, we consider a particular case of Choquet integrals, based on the so-called 2-additive measure: in this simplified model, only interactions by pairs of criteria are considered (Grabbisch 1997).

3.2 The 2-additive CI operator

The 2-additive CI involves the following 2 parameters:

1. the weight of each marginal utility in relation to all the other contributions to the global utility evaluation by the so-called Shapley parameters $\nu_j's$, that satisfy the condition $\sum_{j=1}^{n}\nu_j = 1$, which is a natural condition for the DMs,
2. the interaction parameters I_{jk} of any pair of criteria, that range within [-1,1]:

For a given action a_i the vector of performance expressions noted $(u_1 ..., u_j ..., u_n) \in \mathbb{R}^n$, the aggregation formula by the 2-additive CI is given by:

$$u(a_i) = \sum_{j=1}^{n}\nu_j u_j - \frac{1}{2}\sum_{\{j,k\}\subseteq N} I_{jk}\left|u_j - u_k\right| \qquad (1)$$

with the property:

$$\left(\nu_j - \frac{1}{2}\sum_{k=1}^{n}\left|I_{jk}\right|\right) \geq 0, \forall j \in [1,n],\ j \neq k \qquad (2)$$

The proposed preference model is now illustrated through a case study submitted by some industrial companies (established in Savoie), involved in sustainable development approaches.

4 Case study

The sustainable development concerns numerous aspects of the company such as external logistics points, material recycling, water process, energy production and consumption, etc. In a sustainable development context, it is well established that industrial companies performance lies on three main pillars which can viewed as criteria: the *Economic* performance, the *Environmental* performance and the *Social Responsibility* performance (Sidkar 2003). In this context companies are looking for tools able to reflect these multicriteria aspects of the performance to help them to choose the relevant improvement actions in the long term. Concretely, they need to identify the preference model corresponding to the PETRA PC step. Then this preference model can be exploited to diagnose the current state (phase PC) and to choose the opportunity (phase PD). It could also be refined during the PE step for the control of the implementation during the PF step. The following section highlights the preference model identification.

In order to reinforce or revise this proposition some investigations have been made with four companies in the Savoie area, namely:

- PFEIFFER ADIXEN which produces vacuum technology (600 employees),
- FOURNIER which produces kitchen and bathroom furniture (1000 employees),
- NTN-SNR which produces automotive and special bearings (4000 employees),
- the Office National des Forêts (ONF) which handles public forests (300 employees).

For each company, one DM is asked about his perception of the relative importance of the 3 pillars of the sustainable development. The interview is structured by 6 steps.

1. The hypothesis concerning the relevance of the pillars is proposed and discussed, presenting the main indicators of each pillar.
2. The mechanism of elementary performance expression (marginal utilities) is presented using graphic representation of the satisfaction level.
3. The DM is facing particular situations where the elementary performances can be, totally satisfactory, moderately satisfactory, or totally unsatisfactory.
4. The DM is asked about this preferences and strengths of preference.

5. The DM expertise is processed according to the MACBETH method and the corresponding CI parameters are computed and presented through some example situations.
6. The DM can modify these judgments if he does not agree with the results.

These steps correspond to the MACBETH standard procedure, except step 3 which is adapted because the aggregation operator differs from the MACBETH one (§3.2).

If we consider that the sustainability performance is the result of the aggregation of the Economic performance $p_{Ec.}$, the Environmental performance $p_{En.}$ and the Social Responsibility performance $p_{SR.}$, by the use of the 2-additive CI operator (§ 3.2), the sustainability performance can be written as (Berrah and Clivillé 2010):

$$p_{Overall} = v_{Ec.}p_{Ec.} + v_{En.}p_{En.} + v_{SR.}p_{SR.} - \frac{1}{2}\left[I_{Ec-En}\left|p_{Ec.} - p_{En.}\right| + I_{Ec-SR}\left|p_{Ec.} - p_{SR.}\right| + I_{En-SR}\left|p_{En.} - p_{SR.}\right|\right] \quad (3)$$

where $v_{Ec.}, v_{En.}, v_{SR.}$ are Shapley's coefficients according to, respectively, the Economic criterion, the Environmental criterion and the Social Responsibility criterion, and $I_{Ec.-En.}, I_{Ec.-SR.}, I_{En.-SR.}$ the corresponding interactions.

Let us now see how the CI parameters can be identified. For the sake of conciseness, only Fournier's interview is detailed hereafter. The global results are summarised at the end of the section. Precisely 3 particular performance values are presented (figure 2a), theses values having to represent the same semantic of degree of satisfaction whatever the criteria (figure 2b.).

Figure 2. Performance expression

The idea is to identify the parameters of the aggregation operator using enough comparisons of pair wise situations identified by their elementary performances. The situations described in table 1 are retained. The corresponding quantified elementary performances are provided in the three lowest lines.

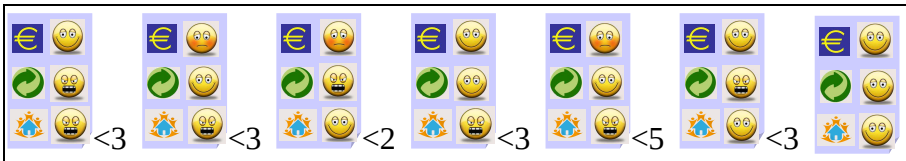
Table 1: The considered situations

							
$p_{Ec.}$	1	0.5	0.5	0.5	1	1	1
$p_{En.}$	0	0	1	1	0	1	1
$P_{SR.}$	0	1	0	0	1	0	1

DM is asked about, respectively, his preferences and strength of preferences between the previous situations. So he ranks them from the worst (on the left of table 3) to the best (on the right). For example a *moderate* strength of preference should be lower than a *strong* one and higher than a

weak one. The results are summarised in table 2. The strength of preference is noted by a value from 0 (no preference) to 6 (extreme preference).

Table 2: situations comparison thanks to strengths of preference


- Level of satisfaction +

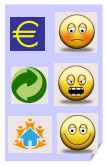
MACBETH thus allows the DM to determine the aggregation operator parameters thanks to the previous judgements. In this case the parameters are:

$$\nu_1 = 0.62,\ \nu_2 = 0.15,\ \nu_3 = 0.23,\ I_{12} = -0.10,\ I_{13} = 0,\ I_{23} = -0.05.$$

Now it is possible to compute the overall satisfaction as shown in table 3:

$$CI(p_1, p_2, p_3) = 0.62.p_1 + 0.15.p_2 + 0.23.p_3 - \frac{1}{2}\left[-0.1|p_1 - p_2| - 0.05|p_2 - p_3|\right] \quad (5)$$

Table 3: The situation overall performance

							
$p_{Ec.}$	1	0.5	0.5	1	0.5	1	1
$p_{Ec.}$	0	1	0	1	1	0	1
$p_{Ec.}$	0	0	1	0	0	1	1
$P_{Overall.}$	0.37	0.51	0.58	0.67	0.74	0.86	1

Results and discussion

The main results are the CI parameter values given in table 4.

Table 4: CI parameters

	FOURNIER	ONF	SNR	ALCATEL
$\nu_{Ec.}$	0.62	0.33	0.56	0.34
$\nu_{En.}$	0.15	0.30	0.18	0.36
ν_{SR}	0.23	0.37	0.27	0.30
$I_{Ec\text{-}En}$	-0.10	-0.05	-0.19	-0.11
$I_{Ec\text{-}SR}$	-	-0.05	-0.26	-0.11
$I_{En\text{-}SR}$	-0.05	-0.05	-0.09	-0.14

It appears that there is not only one CI that can model the sustainable performance. Nevertheless one can see some trends such as:

- the economic pillar is not always the most important weight,

- the societal pillar is often ranked in second place,
- the interactions can be more or less important and implies especially tolerant DM behaviours.

The biggest surprise concerns the weight of the economic pillar. The DMs explain that the economic pillar is very important, but it is not possible to have a durable economic performance without ensuring the satisfying social climate. In this way, the negative value IEc.-SR could mean that a good societal responsibility performance guarantees that the economic one will become satisfactory for the long term.

At this time, the industrial DMs involved in sustainable development approaches lay out a preference model corresponding to the company context in order to diagnose the current state and choose the further improvement actions.

5 Conclusion and perspectives

To remain competitive, companies have to continuously improve their performance according to various criteria. In this sense the PETRA methodology structures the improvement approach using seven main steps from the problem identification to the closure of the improvement actions. In this context, decision-making is a central point which requires the identification of a DMs preference model for the approach deployment.

Among the numerous available methods in the MCDA area, the retained preference model must deal with the main decision problems, the choice and the description problematics, during the seven steps of PETRA. The aggregation method MACBETH has been considered, given the ability to give decision aiding in both the previous cases. It is extended to the 2-additive CI operator able into take account the pair-wise interactions between criteria.

However, MCDA practice in the industrial context is not obvious as shown by the proposed case study. The main questions concern the understandability of the preference model, particularly the CI parameter meaning, the comprehension of the definition process of the preference model, and the interest of the supplied information for better decision making during the different steps of the approach.

In this sense, works on the preference model definition are in progress concerning on the one hand complementary works to better use the increasing DMs knowledge during the improvement approach in the MACBETH method, and on the other hand to consider other alternative methods such as ELECTRE III or UTA which are able to use different expressions of the DMs knowledge. Moreover, notions such as the improvement optimisation and criteria contribution can be deepened to enrich the supplied information by the preference model. One other track concerns the decision aiding in supply chain management when several DMs coming from different companies are involved in common improvement approaches.

References

Bana e Costa C.A. and J.C. Vansnick, 1997, Applications of the MACBETH approach in the framework of an additive aggregation model, Journal of Multi-Criteria Decision Analysis, 6 (2), 107-114.

Bana e Costa C.A., J.M. De Corte and J.C. Vansnick, 2003, MACBETH, London School of Economics, Dpt of Operational Research, Working paper 03-56.

Berrah L., G. Mauris , L. Foulloy and A. Haurat, 2000, Global vision and performance indicators for an industrial improvement approach. Computers in Industry, 43, 211-225.

Berrah, L., Clivillé, V., Harzallah, M., Haurat, A., and Vernadat, F., 2001, PETRA un Guide méthodologique pour la démarche de réorganisation industrielle, Internal Report of the LGIPM, 102 p., in French.

Berrah L. Clivillé V., Harzallah M., Haurat A., Vernadat F., 2001, A cyclic enterprise reengineering method, International Conference On Engineering Design and Automation (EDA'01), Las Vegas, NV, USA, actes sur CD-ROM 6 p.

Berrah, L., Clivillé, 2010, IS IT RELEVANT TO EVALUATE"SUSTAINALITY" By USING AGGREGATION OPERATORS LIKE CHOQUET INTEGRALS?, APMS 2010, International Conference in Advances in Production Management Systems, Como, Italia, 11-13 October 2010.

Berrah, L., Montmain, J., Mauris G. and Clivillé, V., (2011), Optimising industrial making improvement within a quantitative multi-criteria aggregation framework, International Journal of Data Analysis Techniques and Strategies, Vol. 3(1), pp. 42-65.

Bititci U., 2001, Strategy management through quantitative modelling of performance measurement systems, International Journal of Production Economics, 69, 15-22.

Bitton M., 1990, ECOGRAI : Méthode de conception et d'implantation de systèmes de mesure de performances pour organisations industrielles », Ph. D. in Control, Université de Bordeaux I, 220 p.

Browne J., Devlin J., Rolstadas A., Andersen B., « Performance Measurement The ENAPS Approach », available on :http://www.ipk.ntnu.no/Personal/Privat/bjorna/Publications/PDF%20Files/PM%20The%20ENAPS%20Way.pdf.

Clivillé V., 2004, Approche systémique et méthode multicritère pour la définition d'un système d'indicateurs de performance, Ph. D. in Industrial Engineering, Université de Savoie, 216 p.

Clivillé, V. Berrah, L. Mauris, G., 2007, Quantitative expression and aggregation of performance measurements based on the MACBETH multi-criteria method, International Journal of Production Economics, Vol. 105 (1), p. 171-189.

Clivillé, V., Berrah, L. 2011, Overall performance measurement in a supply chain: towards a supplier-prime manufacturer based model, Journal of Intelligent Manufacturing, Vol. 22, 11 p.

Cooke J.A., 2001, Metrics systems, Logistics Management and Distribution Report 40 (10), 45–49.

Deming E., 1982, Quality, Productivity and Competitive Position, (The MIT Press).

Fortuin, L., 1988, Performance indicators - why, where and how?, European Journal of Operational Research, 34, 1-9.

Ghalayini A. M., Noble J.S., Crowe T.J., 1997, « An integrated dynamic performance measurement system for improving manufacturing competiveness », International Journal of Operations & Production Management, Vol. 15, pp. 80-116,.

Globerson, S., 1985, Issues in developing a performance criteria system for an organisation, International Journal of Production Research, 23 (4), 639-646Neely A., 1999, The performance measurement revolution: why now and what next?, International Journal of Operations & Production Management, 19 (2), 205-228.

Grabisch, M. and M. Roubens, 1996, The application of fuzzy integrals in multicriteria decision making. European Journal of Operational Research, 89, 445-456.

Grabisch, M., 1997, k-ordered discrete fuzzy measures and their representation, Fuzzy sets and Systems, 92, 167-189.

Jacquet-Lagreze, E. and Siskos, Y, (2001), Preference disaggregation: 20 years of MCDA experience, European Journal of Operational Research, Vol. 130, pp. 233-245.

Kaplan, R.S. Norton, D.P. 1992, The Balanced Scorecard: Measures that drives performance, Harvard Business Review, January-February.

Mayag Brice, 2010, Élaboration d'une démarche constructive prenant en compte les interactions entre critères en aide multicritère à la décision, Ph. D. in Informatique, Université de Paris I, 234 p.

Melnyk S, D. Stewart and M. Swin, 2004, Metrics and performance measurement in operations management: dealing with the metrics maze, Journal of Operations Management, 22 (3), 209-218.

Mills, J.F., Platts, K.W., Neely, A.D., Richards, A.H., Gregory, M.J., Bourne, M.C.S., 2002. Creating a Winning Business Formula. Cambridge University Press, Cambridge.

Sikdar S.K.: 2003, Office of Research and Development, United States Environmental Protection Agency (EPA), Cincinnati, OH 45268 Perspective 1928 AIChE Journal, Vol. 49 (8).

Neely, A. Gregory, M. Platts, K. 1995, Performance measurement system design A literature review and research agenda, International Journal of Production Economics, Vol. 48, p. 23-37.

Nudurupati, S. Bititci, U.S. Kumar, V.. Chan., F.T.S, State of the art literature review on performance measurement, Computers & Industrial Engineering, 60, (2): 279-290, 2011.

Iso 9000, 2001, Qualité et systèmes de management ISO 9000, éditions AFNOR, 581 p.

Roy 1985, Méthodologie d'aide à la décision multicritère, Economica, Paris.

Santos S. P., Belton V., Howick S., (2002) "Adding value to performance measurement by using system dynamics and multicriteria analysis", International Journal of Operations & Production Management, Vol. 22 Iss: 11, pp.1246 – 1272

Vansnick J. C., 1984, Strength of preference: theorical and practical aspects, in J.P Brans, eds, Operational Research, IFORS 84, North Holland, Amsterdam, 367-381.