Preference and causal fuzzy models for manager's decision aiding in industrial performance improvement

Jacky Montmain, Vincent Clivillé, Lamia Berrah, Gilles Mauris

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Abstract—**The design and use of Performance Measurement Systems (PMS's) for industrial improvement and control have received considerable attention in recent years. Indeed, industrial performances are now defined in terms of numerous and multi-level criteria to be synthesized for overall improvement purposes. This article is a contribution to the decision-maker's information needs for optimizing the improvement of an overall performance versus the allocated resources and for choosing the right actions in order to achieve the required overall performance. The latter is decomposed into elementary performances according to decision-makers' preferences represented by a fuzzy integral aggregation. The causes-effects links between possible actions and performances are represented by a fuzzy ordinal influence model. The proposed fuzzy models are both applied for improvement actions selection on a case study submitted by a company manufacturing kitchens and bathrooms.**

I. Introduction

According to the current industrial context, manufacturing systems are sufficiently complex to require adequate decision support tools. To succeed in continuous improvement, these tools have to include, on the one hand, the multi-criteria performance expressions and the modeling of their preferential relationships, and on the other hand, the modeling of the causal relationships between the possible improvement actions and the performance expressions [1][2]. Thus, the foundations for any performance improvement decision aiding rare:

- the set of the considered objectives to model according to the decision-maker's preferences,
- the set of possible action aimed at achieving the objectives to causally relate to the performance expressions,
- the way the preference and causal models are joined together.

In this view, the so-called Performance Measurement Systems (PMS's), which are instruments to express performance [1]-[5], are aimed at aiding manager's decision making. Indeed, a PMS is made of a set of performance expressions to be consistently organized with respect to the objectives of the company. From a quantitative viewpoint, performance expressions associated with the various heterogeneous criteria are in existing PMSs translated into a common reference (generally cost or satisfaction degree)[3][4[5]. Generally, the overall performance is obtained by simply calculating a weighted mean of all the elementary performances. Many approaches proposed in the literature are based on the AHP method (Analytic Hierarchy Process) [6][7] for expressing elementary performances on the one hand and their weights on the other hand. In our previous studies, the MACBETH method [8] has been applied to transform qualitative decision-maker's preferences into performance expressions and criteria weights and interactions according to measurement theory requirements [9][10]. Further, with this framework, we have considered the optimization of the performance improvements according to costs constraints [11]. But next, to achieve the defined optimized improvements, concrete actions has to be planned according to the physical constraints imposed by the considered manufacturing processes.

Therefore, in this paper a fuzzy causes-effects model relating actions to performance expressions is proposed according to the qualitative engineers' knowledge. It follows the same spirit as the propositions developed by Félix [12][13], but aggregation and action selection are made differently. Finally, to meet the expected overall performance improvements, relevant actions are deduced by an adequate procedure using jointly both the preference and causal fuzzy models.

The paper is organized as follows. Section II recalls the fundamental concepts required for the expression of elementary performances and their bottom-up aggregation. Decision-maker's preferences are modeled by a 2-additive Choquet integral [14]. From this preference model, the determination of the least costly elementary performance improvements able to comply with a required overall performance is deduced. Then, in Section III, a fuzzy model of the relationships between objectives and possible action is introduced in order to represent the engineer's knowledge about the physical manufacturing processes. Then we propose an iterative procedure based on both fuzzy models to achieve the fixed performance improvements by an adequate selection of actions. Finally, in section IV, the propositions are illustrated on a case study that concerns a SME producing kitchens, bathrooms and storing closets.

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II. A FUZZY INTEGRAL MODEL OF DECISION MAKER'S PREFERENCES

This section briefly recalls the fundamental concepts required for the expression of elementary performances and their bottom-up aggregation to obtain an overall performance according to decision-maker's preferences (more details are exposed in [9][10]). Then the problem to achieve a required overall improvement according to cost constraints on elementary performance improvements is considered [11].

A. Elementary performance expressions

Broadly speaking, a performance expression is associated with a given objective and can be defined as a satisfaction degree. In practice, elementary performances are returned by the so-called performance indicators [2]. They result from the straightforward comparison between the objectives (obtained by the break-down of the overall considered objective) and the observed measurements (describing the actual process or activity taking place). Hence, the performance expressions can be formalized by the following mapping [2]:

$$\mathrm{P} : O \times M \rightarrow E$$
$$(o,m) \rightarrow \mathrm{P}(o,m) = p$$

O, *M* and *E* are respectively the universes of discourse of the set of objectives *o*, the set of measures *m* and p the performance. The key point in differentiating this kind of performance expression from conventional measurements is the comparison of the measurements acquired with an objective defined according to the control strategy considered. Thus, the mapping P is usually a ratio, a relative difference, or a normalized distance [2].

B. Aggregated performance expressions

1) Generalities

The aggregation of the performances can be expressed as an operation that synthesizes the elementary performances into an overall expression. Hence, the performance aggregation can be formalized by the following mapping:

$$Ag : E^1 \times E^2 \times ... \times E^n \rightarrow E$$
$$(p_1, p_2, ..., p_n) \rightarrow p_{overall} = Ag(p_1, p_2, ..., p_n)$$

E^i is the universe of discourse of the elementary performances $\vec{p} = (p_1, p_2, ..., p_n)$ and E is the universe of discourse of the overall performance $p_{Overall}$.

2) The Choquet integral aggregation operator:

The performance criteria are supposed to be characterized by subordination as well as preferential interacting relations. In order to take both these relations among criteria into account, our aggregation model is based on a fuzzy Choquet integral [16]. It allows to consider the relative importance of a criterion and the mutual interactions between the criteria.

In our framework, we use a particular case of Choquet integrals, based on the so-called 2-additive measure [15]: in this simplified model, only interactions by pairs of criteria are considered. The 2-additive Choquet Integral (*CI*) can then be expressed in the interpretable form as follows:

$$CI(p_1, p_2, ..., p_n) = \sum_{i=1}^{n} p_i.v_i - \frac{1}{2}.\sum_{i>j} I_{ij}.\left|p_i - p_j\right| \qquad (1)$$

with the property that $(v_i - \frac{1}{2}\sum_{i \neq j}\left|I_{ij}\right|) \geq 0$.

The v_i's are the Shapley indices, representing the importance of each criterion relative to all the others, with $\sum_{i=1}^{n} v_i = 1$; I_{ij} represents the interactions between pairs of the criteria (*i*, *j*) with values contained in the interval *[-1;1]*. A value *1* means a full positive synergy between the two criteria (they are expected to be simultaneously satisfied), a value of *–1* indicates a full negative synergy, and a null value means that the criteria are independent [16].

C. From overall to elementary performance improvements

Once an improved overall value $p^* > p_{Overall}$ has been fixed, the manager is faced with different ways of achieving p^* due to the fact that there exist many elementary improving vectors $\vec{\delta} = (\delta_1, \delta_2, ..., \delta_n)$ such that:

$$CI(\vec{p} + \vec{\delta}) = p^*$$

where $\vec{p} = (p_1, p_2, ..., p_n)$ is the initial elementary performance vector such that $p_{Overall} = CI(\vec{p})$

To aid the manager, we propose to introduce cost information $c_i(p_i, \delta_i)$ for each elementary performance improvement. Then, we consider the least costly improvement, i.e. the one which minimizes $c(\vec{p}, \vec{\delta}) = \sum_{i=1}^{n} c_i(p_i, \delta_i)$.

The optimization problem (denoted $\mathbf{P_1}$) can then be formulated as follows:

Objective function

$\min c(\vec{p}, \vec{\delta})$

Constraints

$C_\mu(\vec{p} + \vec{\delta}) = p^*$ —(Behavioral constraint)

$\forall i, \quad 0 \leq \delta_i \leq 1 - p_i$ — (Bound constraints)

The piecewise linearity of *CI* enables to tackle the problem as a linear programming problem. Indeed, *CI* behaves as a weighted mean on each simplex:

$$H_{()} = \left\{ \vec{p} \in [0,1]^n \,/\, 0 \leq p_{(1)} \leq \cdots \leq p_{(n)} \leq 1 \right\}.$$

This remark enables to break down the initial problem into $n!$ linear programming sub problems [11].

III. A FUZZY CAUSAL MODEL OF ACTIONS/PERFORMANCES LINKS

The above model only captures preferences of the company managers without further considerations regarding the physical constraints behind the improvement execution. However, these constraints cannot be ignored to design the implementation of the improvement project. In this section we introduce a fuzzy relationships model between actions and performances, inspired from Felix [12][13], to aid to the selection of actions. Indeed, industrial improvement is now considered in terms of concrete actions to be carried out to achieve as well as possible the elementary performances $\vec{p}* = (p_1^*...p_i^*...p_n^*)$ which have been specified by the preceding optimized improvement (section II.C).

A. Performances and actions relationships

The relationships between possible actions and performances' improvements are generally quite complex while related to the manufacturing physical processes. Therefore available engineer's knowledge can often be expressed only under the form of the qualitative influences of elementary improvement actions. Let A be the set of potential actions and let us consider for each elementary performance p_i , as proposed by Félix [12], both the set S_{p_i} of actions a_j that support an improvement of p_i with a degree δ_{ij}^s and the set D_{p_i} of actions $\bar{a}_j$ that distract from p_i with a degree δ_{ij}^d .

Thus, relationships between actions and performance can be represented through a digraph (see figure 1), such that:

$$\begin{aligned} &\forall\ action\ a_j, \forall\ p_i, \\ &arc_{ij} = +\delta_{ij}^s\ when\ a_j \in S_{p_i} \\ &arc_{ij} = -\delta_{ij}^d\ when\ a_j \in D_{p_i} \end{aligned}$$

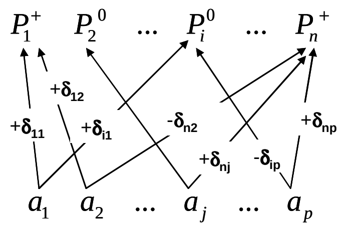

Figure 1: Actions/performances relationships model

Let us remark that in most industrial practical cases the $\delta_{ij}^{s,d}$'s cannot generally be defined on a cardinal scale, and therefore they cannot be added to the performances. Indeed, they are only considered as ordinal information. The higher the influence δ_{ij}^s (resp. δ_{ij}^d), the higher the improvement (resp. damage) with regards to p_i .

Therefore we propose to represent S_{p_i} *and* D_{p_i} by fuzzy sets defined on the universe of actions by normalizing the degrees $\delta_{ij}^{s,d}$ between 0 and 1.

1) Support membership function of performance p_i :

$s_{p_i}(a_j) = \delta_{ij}^s \Leftrightarrow$ action a influences p_i positively (supports p_i) with degree δ_{ij}^s, else 0.

2) Distraction membership function of performance p_i :

$d_{p_i}(a_j) = \delta_{ij}^d \Leftrightarrow$ action a_j influences p_i negatively (distracts from p_i), with degree δ_{ij}^d , else 0.

B. Influence of a set of actions

Les us note p^+ the set of elementary performances to be improved that results from solving (**P$_1$**) ($\forall i \in p^+, p_i^* > p_i^I$) and p^0 the set of criteria for which no improvement is required ($\forall i \in p^0, p_i^* = p_i^I$).

Hereafter, we present a procedure for selecting a set of actions SAP_J aimed at achieving the performances in p^+. The set J refers to the subset of indices for performance in SAP_J , J_i^+ the subset of indices for actions in $SAP_J \cap S_{p_i}$, and J_i^- the subset of indices for actions in $SAP_J \cap D_{p_i}$.

The proposed idea is based on the question: how influential any set of action SAP_J for p^+ is?. Our answer consists to define first the influence degree of SAP_J with regard to each elementary performance p_i^+ by:

$$\forall i, s_{p_i}(SAP_J) = \min_{j \in J_i^+} \delta_{ij}^s, \text{when} \min_{j \in J_i^+} \delta_{ij}^s > \max_{j \in J_i^-} \delta_{ij}^d, \text{else } 0 \quad (2)$$

This formula means that the influence degree relative to p_i^+ is the minimum above all the influence degrees of all the actions composing SAP_J , but under the restriction that the minimum positive influence is higher than the maximum negative influence. Note that averages on the degrees cannot be considered because this operation, unlike min and max, is not meaningful for ordinal values Then, the influence degree of the set of actions SAP_J, i.e. relative to all the elementary performances of p^+, is defined by:

$$s_{p^+}(SAP_J) = \min_{i \in p^+} s_{p_i}(SAP_J)$$
$$\text{when } \forall i \in p^0, s_{p_i}(SAP_J) > 0, \text{ else } 0 \quad (3)$$

The choice of the "min" operation in formula (3) leads to a form of veto upon any performance criterion. Thus, it models a cautious viewpoint in the lack of knowledge about the importance of each elementary performance on the overall one. By considering the contribution of any criterion to the overall performance improvement $CI(\vec{p}^*) - CI(\vec{p}^I)$, which is related to the latter and to the weights ν_i and interactions I_{ij}, a w_i weights distribution can be assign to the performance criteria (the details of the w_i definition are described in [17]). Therefore, formula (3) can be adapted as follows:

$$s_{p^+}(SAP_J, (w)_i) = \min_{i \in p^+} \max(1 - w_i, s_{p_i}(SAP_J))$$

$$\text{when } \forall i \in p^0, s_{p_i}(SAP_J) > 0 \text{, else } 0 \qquad (4)$$

Finally, all the subsets of the sets of all actions (there are $\tilde{2}^k$ with k the number of possible actions) are represented with the fuzzy membership functions $s_{p^+}(SAP_J, (w)_i)$. These fuzzy sets which reflect the ordinal influence of the actions can then be used to aid the decision makers' to select the actions to carry out. One aiding procedure is proposed hereafter.

C. Procedure of action set selection

To select a relevant set of actions, we propose to consider the α-cuts of $s_{p^+}(SAP_J, (w)_i)$ denoted $SA\Pi_\alpha$. The latter correspond to the sets of action that influence the performances in p^+ at least with a degree α:

$SA\Pi_\alpha = \{SAP_J \,/\, s_{p^+}(SAP_J, (w)_i) \geq \alpha\}$.

The higher α is, the higher the positive influence is. Note, that it is possible, especially for high value of α, that $SA\Pi_\alpha = \varnothing$. Therefore we consider $\alpha_{\max}$ such that: $\forall \alpha \leq \alpha_{\max}, SA\Pi_\alpha \neq \varnothing$; $SA\Pi_{\alpha\max}$ is the set of actions that leads to the highest minimal influence on the performances defined by p^+ according to the available ordinal causes-effects information. In some cases, $\alpha_{\max}$ can be very small, and the expected small effect will be insignificant with regards to the required one. Therefore, we introduce a *min_influence_threshold* under which it is recommended to lower the performance p^* by a value ε to be defined by the decision maker. The complete proposed algorithm is described hereafter.

Define the objective p^*
<u>Step 1</u> Compute the most efficient elementary improvements $\vec{\delta}^* = (\delta_1^*, \delta_2^*, ..., \delta_n^*)$ and the associated elementary performances $(p_1^*, .., p_i^*, .., p_n^*)$ with $(\mathbf{P}_1)$
<u>Step 2</u> Compute the criteria in p^+ to be improved first
Establish the weights distribution $(w_i)_{i=1..n}$
Compute $A\Pi_{\alpha_{\max}}$
 If $\alpha <$ *min_influence_threshold*
  Change $p^* := p^* - \varepsilon$ then return to step 1
 End if
Apply the set of action $SA\Pi_{\alpha_{\max}}$
Measure the achieved elementary performances $\vec{p} = (p_1, p_2, ..., p_n)$
If $p_{overall} = CI(p_1, p_2, ..., p_n) < p^*$ then
 If $\vec{p} = (p_1, p_2, ..., p_n)$ is in the uppercube $[\vec{p}^I; \vec{p}^*]$
  then return to step 2
  Else return to step 1
 End if
End if
End

To deal with the large combinatory (related to the numbers of actions and of elementary performances) a branch and bound solving method can be used. Note finally, that this procedure provides only an aid to the decision maker. Due to the approximate aspect of the actions-performances model, the applied set of actions will often in practice not provide exactly p^*, but only a close value.

IV. Case study

The case study concerns a SME producing kitchens, bathrooms and storing closets [18]. The goal of the company is to continuously increase its productivity and the customer satisfaction. At this aim, managers have to identify and select actions able to improve the company performance in these areas. In this view, a top-management strategic objective related to the productivity rate is the *lead time* which is a key success factor to be improved. Due to a new manufacturing line, the *lead time* performance is currently not satisfactory and the plant manager is looking for improvement actions.

First, our modeling approach consists in breaking down the *Lead time* to the various levels of the hierarchical decisional structure of the company. Figure 2 provides a first level break-down into 4 basic criteria to be used to assess the operational objectives: *Work-in-progress*, *Bottleneck productivity*, *Internal logistics*, *Missing products* [18].

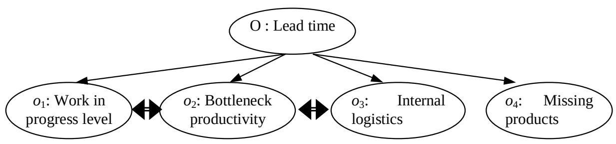

Figure23: *Lead time* breakdown

The elementary and overall performances as well as the CI aggregation parameters have been determined thanks to the expertise of managers gathered according to the Macbeth methodology [18]. The obtained CI parameters are:

$$\nu_1 = 0.2 \;\; \nu_2 = 0.25 \;\; \nu_3 = 0.35 \;\; \nu_4 = 0.2$$

$$I_{12} = -0.15 \;\; I_{13} = +0.25 \;\; I_{14} = I_{23} = I_{24} = I_{34} = 0$$

The current performance state is characterized by the following set of performance expressions denoted $p^I = (0.50, 0.27, 0.37, 0.53)$ leading by applying equation (1) to an overall performance: $p_{Ag} = 0.41$. This current state of the company is not satisfactory as shown figure 3.

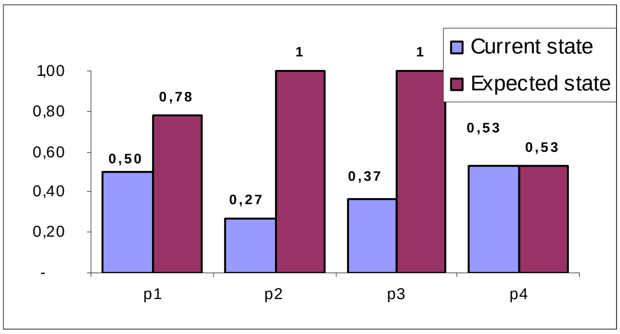

Figure 3: The current and expected performances

The plant manager expects an overall performance of $p_{Overall} = 0.85$ for July 2010 and he is looking for the ways to achieve this overall performance. By solving the optimization problem $\mathbf{P_1}$ with the following elementary cost improvements[1]: $cp_1 = 2;\ cp_2 = 1;\ cp_3 = 1.25;\ cp_4 = 3$, the least costly improvement vector is: $p^* = (0.76, 1, 1, 0.53)$.

This result is quite intuitive though it is clear that p_2 and p_3 improvements are less costly than the p_1 and particularly p_3 ones. Thus, it is recommended to improve p_2 and p_3 to *1*, while p_4 is not modified, p_1 being improved to *0.76*.

Then, the plant manager has to look for actions able to achieve this set of elementary performances p^*. In the considered manufacturing context, well known actions are at disposal to improve the *lead time* performance. The difficulty is to identify the most relevant ones and to select the best ones in order to achieve or at least to come near p^*.

After a discussion between the plant manager and the production lines executives the proposed possible actions are:

- To carry out kanban in the upstream flow noted (a_1),
- To develop the Total Productive Maintenance (a_2),
- To generalize the "Andon" display system (a_3),
- To localize the furniture parts thanks a RFID ship (a_4),
- To carry out a one piece flow for the downstream flow (a_5).
- To carry out a milk-run picking system for the assembly posts (a_6).

[1] For sake of confidentiality the costs are defined on a relative ratio scale instead of monetary amounts.

They agree with the following actions/performances relationships ordinal information (see the $\delta_{ij}^{s,d}$ in table 1).

Table 1: Influence of actions on elementary performances

	p^i	a_1	a_2	a_3	a_4	a_5	a_6
p_1	0.25	0.4		0.2		0.8	0.6
p_2	0.27		0.6	0.4		0.4	-0.2
p_3	0.37	-0.2	0.8		0.4	-0.6	0.8
p_4	0.49	-0.2			1	-0.2	-0.2

Knowing the current state $p^I = (0.50; 0.27; 0.37; 0.53)$, the expected overall performance, $p_{Overall} = 0.85$, the expected elementary performances $p^* = (0.39, 1, 1, 0.49)$, the fuzzy sets $s_{p^+}(SAP_J, (w)_i)$ can be computed by applying formulae (2), (3), and (4), and the solving of the action selection algorithm (section III. C) gives:

- the set of the elementary performances to improve equal to $p^+ = (p_1, p_2, p_3)$,
- the set of unchanged elementary performances equal to $p^0 = (p_4)$.

In order to avoid carrying out too less influencing actions, a $min\text{-}influence\_threshold = 0.2$ is set and in a first simulation all the weights w_i are set to *1*.

According to this information, the algorithm of actions selection provides the following result:
$SA\Pi_{\alpha_{\max}} = \{a_2, a_4, a_6\}$ with $\alpha_{\max} = 0.4$.

This result is interpreted in the following way: a_2 is selected because it improves both p_2 and p_3, and a_6 because it improves p_1. Unfortunately, a_6 distracts from p_4, thus it entails a_4 to be carried out to compensate the negative influence of a_6 on p_4. Nevertheless, the minimal influential degree of $SA\Pi_{\alpha_{\max}} = \{a_2, a_4, a_6\}$ is higher than the threshold value of 0.2, thus the subset of actions $SA\Pi_{\alpha\,max} = \{a_2, a_4, a_6\}$ can be launched.

By making different simulations, it appears clearly that the $min\_influence\_threshold$ is a key parameter in the selection procedure. Indeed, the plant manager can be more demanding by increasing the threshold. Therefore, the subset $SA\Pi_{\alpha\,max}$ is reduced, i.e. only the very influencing actions are kept. The manager can also keep the same threshold and reduce the subset p^+ thanks to a lowering of the overall expected performance.

To illustrate this aspect, let us consider a higher value of 0.4 for the $min\_influence\_threshold$. In this case $SA\Pi_{\alpha\,max} = \varnothing$, and the plant manager revises the overall expected performance p^* to a lower value $p_{Overall} = 0.75$ (return to step 1). The corresponding revised set of elementary performances is: $p = (0.5, 1, 0.87, 0.53)$. So $p^+ = (p_2, p_3)$ and the actions selection algorithm provides: $A\Pi_{\alpha_{\max}} = \{a_2\}$ with $\alpha_{\max} = 0.6$, a value greater than the *min_influence_threshold* .

In fact, in order to have a good view of the possibilities for improvements, the plant manager has to simulate different values of the parameters *min_influence_threshold* and ε. In addition, sensitivities to Choquet integral parameters, costs, and influence degrees may be of great interest for the final decision. At this aim, a user-friendly software is under development.

V. CONCLUSION

This paper proposes decision aiding functionalities for action selection in industrial performance improvement when decision-makers are faced with interacting multi-criteria and multi-level objectives. Our approach clearly separates the strategic manager's preference model from the operational causes–effects model. Indeed, a 2-additive Choquet integral represents the manager's preferences under an analytic form that facilitates the search of optimized improvements in terms of minimal cost. It thus provides a powerful artefact to capture the overall performance of the company and to reason about it from a managerial decision viewpoint. To integrate the physical operational constraints, a fuzzy ordinal influence model representing causes-effects links between possible actions and performances has been established according to engineers' knowledge. An iterative procedure has been proposed that conciliates both fuzzy models to identify relevant actions that comply with the initially assigned overall performance improvement. The approach has been illustrated on a case of productivity improvement of a SME.

The case study has highlighted the need of a software tool to simulate different values for the different parameters involved. In other respects, the combination of influence degrees has to be further studied in relation with the more or less cautious behavior of the manager.

REFERENCES

[1] Bititci U.S, "Modelling of performance measurement systems in manufacturing enterprises", *International Journal of Production Economics* 1995; 42: 137-147.

[2] Berrah L.., Mauris G., Foulloy L., Haurat A., "Global vision and performance indicators for an industrial improvement approach.",*Computers in Industry* 2000; 43: 211-225.

[3] Kueng P., Krahn A.J. Building a Process Performance Measurement System: Some Early Experiences. *Journal of Scientific,Scientific & Industrial Research* 1999; 58: 149-159.

[4] Ghalayini A.M., Noble J.S., Crowe T.J. An integrated dynamic performance measurement system for improving manufacturing competitiveness. *International Journal of Operations & Production Management* 1997; 15: 80-116.

[5] Neely A. The performance measurement revolution: why now and what next? *International Journal of Operations and Production Management* 1999; 19 (2): 205-228.

[6] Rangone A. An analytical hierarchy process framework for comparing the overall performance of manufacturing departments. *Int. Journal of Operations and Production Management* 1996; 16 (8): 104-119.

[7] Saaty T. The analytic hierarchy and the analytic network processes for the measurement of intangible criteria and for decision-making. *in MCDA. Multiple Criteria Decision Analysis. Figueira J., Greco S., Ehrgott M.(eds). Kluwer Academic Publishers* 2004: 345-407.

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

[9] Berrah L., Mauris G., Vernadat F. Information aggregation in industrial performance measurement :measurement: rationales, issues and definitions. *International Journal of Production Research 2004; Vol 42 (20):* 4271-4293.

[10] Cliville V., Berrah L., Mauris G. , "A Quantified Industrial Performance Measurement System Based on a Choquet Integral", *World Congress on computational Intelligence* (WCCI 2006 FUZZ IEEE), CD-ROM , Vancouver, Canada, July 2006, 8 pages.

[11] Sahraoui S.., Montmain J., Berrah L., Mauris G., "User-friendly optimal improvement of an overall industrial performance based on a fuzzy Choquet integral aggregation", *IEEE International Conference on Fuzzy Systems FUZZ-IEEE 2007*, CD-ROM , London, UK, July 2007, 6 pages.

[12] Felix, R. Relationships between goals in multiple attribute decision making. *Fuzzy Sets and Systems,* 1994, 67, pp. 47-52.

[13] Felix, R., "Multicriteria Decision Making (MCDM): Management of Aggregation Complexity Through Fuzzy Interactions Between Goals or Criteria", *12th Int. Conference IPMU*, 2008, Malaga, Spain.

[14] Grabisch M., Roubens M. The application of fuzzy integrals in multicriteria decision making. *European Journal of Operational Research* 1996; 89: pp. 445-456.

[15] Cliville V., Berrah L., Mauris G. A Quantified Industrial Performance Measurement System Based on a Choquet Integral, *World Congress on computational Intelligence* (WCCI 2006 FUZZ IEEE), CD-ROM , Vancouver, Canada, July 2006, 8 pages.

[16] Grabisch M., Labreuche C. Fuzzy measures and integrals. *In MCDA. Multiple Criteria Decision Analysis. Figueira J., Greco S. Ehrgott M. (eds). Kluwer Academic Publishers* 2004: 563-608.

[17] Montmain, J., Sahraoui, S. (2008). How to improve the overall industrial performance in a multi-criteria context. 12th Int. Conference IPMU, 2008, Malaga, Spain.

[18] Cliville V., Berrah L., Mauris G., Quantitative expression and aggregation of performance measurements based on the MACBETH multi-criteria method, *International Journal of Production Economics*, 2007, Vol. 105, issue 1, pp. 171-189.