Fuzzy Symbolic Handling of Industrial Instantaneous and Trend Performance Expressions

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Abstract
This study subscribes to the performance expression and the control of the achievement of an industrial objective. Temporal trajectory is considered for describing such an achievement, which links the initial instant of the corresponding action plan to the final one. At each milestone, instantaneous and trend performances are expressed. The purpose is thus to simultaneously handle the previous kinds of expression in order to define a meaningful piece of information that takes into account the obtained results along the considered temporal horizon. A rule-based aggregation is retained in this sense. Moreover, according to the visual management principles, symbolic fuzzification and deffuzzification are used, and colored emoticons are proposed in this sense.

Keywords Industrial objectives, Instantaneous performance expressions, Trend performance expressions, Visual management, Fuzzy logic.

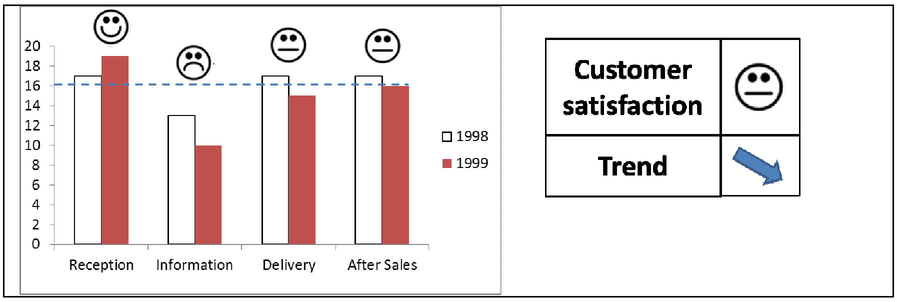
1 INTRODUCTION

This study deals with the simultaneous handling of "instantaneous" performance expressions and "trend" ones, with regards to the achievement of tactical industrial objectives. This achievement can be described by a temporal trajectory. Such a trajectory is defined in coherence with the duration of the execution of the associated action plan. At the initial instant, the objective achievement is planned as being null, while at the final one, it is supposed to be totally achieved, in accordance with the expected value.

In order to control the objective temporal trajectory, milestones are introduced. These milestones generally correspond to the end of sets of actions of the considered action plan, being thus a kind of check point for the decision-maker for reacting with regards to the expressed performances. Rightly, performance expressions are provided by Performance Indicators – PI's – and Performance Measurement Systems – PMS's – [6], [7]. These expressions are the result of comparison mechanisms of the expected objectives with the acquired measures [2], [1], [5]. They are conventionally computed under numeric formats, at each milestone. That is what we can call "instantaneous" expressions. In this work, we look for the definition of a kind of enriched performance expression that not only handles the instantaneous result but also the trend one, according to the obtained performances until the considered milestone. According to us, such an expression allows the decision-maker to have a more meaningful piece of information about the given objective achievement.

Subscribing to some principles of the visual management [4], [9], [11], we choose to describe this enriched performance expression under a symbolic form, namely coloured emoticons. Fuzzy inference mechanisms are used in this sense. Indeed, for the sake of simplicity, graphical representation has been progressively introduced in manufacturing companies during the two last decades. Providing visual pieces of information has been highlighted with the Toyota Production System, namely the Kanban flow control or the 5S management [8], [4]. For instance, the last version of the ISO 9000 standard explains how to formalise PI's through ten parameters, and gather them into visual scorecards. The visual representation is based on values, colours, curves, graphics or icons, by also considering trend data (see Fig. 1).

Fig. 1. Example of PI visual representation inspired by the French version of ISO 9000.



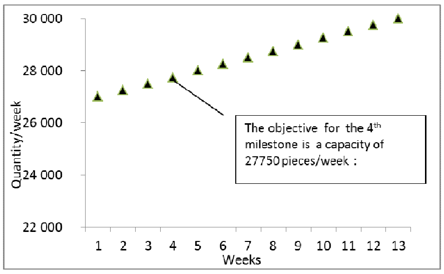
Besides, the industrial practice shows that many visual formats are used for expressing performances, such as the emoticons, the traffic lights or the weather symbols. Nevertheless, the association between performance expressions and symbols generally remains implicit, while a systematic formal processing would ensure a commensurate handling. Dealing with this drawback, this article is organised as follows. In Section 2, we present the proposed fuzzy formalism. The developed ideas are illustrated by examples extracted from the case study, which is submitted by a bearings manufacturing company, around the "manufacturing Capacity" action plan. Finally, we conclude by some remarks and prospective investigations.

2 FUZZY PROCESSING

2.1 Case study and background

The bearings manufacturing company being considered works for automotive and aeronautics companies, spatial and several other high-tech activities. One of the most important Original Equipment Manufacturers in Europe, its market shares have continuously grown over the last ten years. The different bearing families are produced in specific plants and the production of a given type of bearing is made in a dedicated line which ensures the whole customer demand. Due to the success of innovative products, the submitted problem has concerned the increase of the capacity of one production line, leading thus the plant manager, who is the tactical decision-maker, to the declaration of an objective of a *capacity of 30 000 pieces par week at the end of 2013's last trimester*; knowing that the capacity at the beginning of the trimester was 27 000 pieces. Fig. 2 gives the objective trajectory planned in this sense.

Fig. 2. Objective trajectory for the production line capacity



For the control of the objective trajectory, the plant manager has defined weekly milestones. The purpose is based on the idea of providing, at each milestone, meaningful pieces of information with regards to the obtained performance. Moreover, knowing the numerous people involved in this action plan, a visual performance representation is retained. To be more precise, let k be the milestone corresponding to the k^{th} week, $k = 1$ to 13. And let $o(k)$, $m(k)$, $p(k)$ and $p'(k)$ respectively be the objective, the measure, the instantaneous and the trend performance expressions, with regards to the production capacity. The idea developed here is to take advantage of the instantaneous performance behaviour to introduce some kind of weighting by the performance trend. The following processing is proposed.

1 $p(k)$ and $p'(k)$ are fuzzified, into linguistic fuzzy subsets.

2 $p(k)$ and $p'(k)$ are aggregated in $C(k)$ by means of a fuzzy rule base.

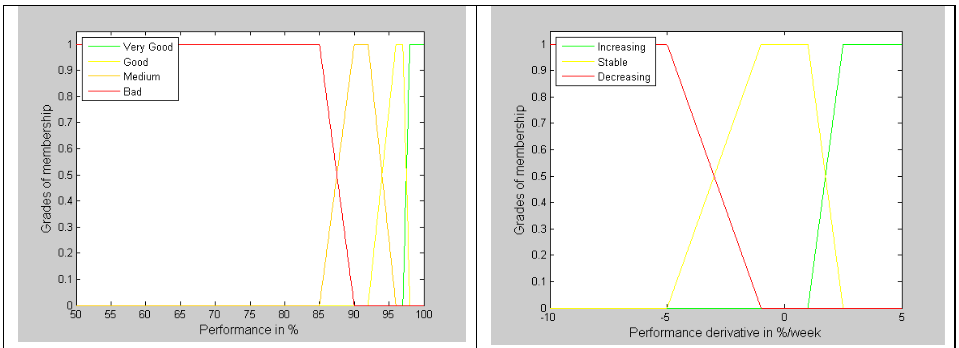
3 $C(k)$ is defuzzified into a coloured emoticon $e(k)$.

2.2 Instantaneous and trend performance expression fuzzification

We choose to express the instantaneous performance expression $p(k)$ by the ratio $p(k) = \dfrac{m(k)}{o(k)}$. The performance expression trend is obtained from the backward approximation of the first derivate with a first order accuracy and a period of 4 weeks is used: $\forall k > 0,\ p'(k) = \dfrac{p(k) - p(k - \min(k,4))}{\min(k,4)}$. (1)

The symbolic fuzzification goes the same way for the two expressions. The symbolic fuzzification of $p(k)$ denoted φ, relies on the fuzzy meaning of the linguistic terms, *i.e.* the membership function associated with each term [12]. Let $p(k)$ be characterised by the set of linguistic terms L_1 = = {Very Good, Good, Medium, Bad}, for short L_1= = {VG, G, M, B}. Let the membership functions of these terms, *i.e.* their fuzzy meaning, be represented in Fig. 3. Using Zadeh's writing for discrete fuzzy subsets [13], and considering $k = 2$ as an example, the symbolic fuzzification of $p(2) = 97.85\%$ is $\varphi(p(2)) = A = 0.85/VG + 0.15/G + 0/M + 0/B$. It means that $p(2)$ is described by the term *Very Good* with a degree of 0.85 and by the term *Good* with a degree of 0.15. The symbolic fuzzification of the trend is a linguistic fuzzy subset of L_2 = {*Decreasing*, *Stable*, *Increasing*}, for short L_2 = {*D*, *S*, *I*}. The membership functions associated with these linguistic terms are given in Fig. 3. For example, the performance trend is $p'(2) = 1.41$, and its symbolic fuzzification is $\varphi(p'(2)) = B = 0.27/I + 0.73/S + 0/D$, *i.e.* the trend is stable with a small increase.

Fig. 3. Fuzzy meanings of the linguistic terms describing the performance expressions.



Fuzzy meaning for instantaneous expression | Fuzzy meaning for trend expression

2.3 Aggregation of the instantaneous and trend performance expressions

In order to aggregate the two linguistic fuzzy subsets representing respectively the instantaneous and trend performances, we choose to use a rule based aggregation. Such a mechanism captures, more easily, various cases. The rule base used in the case study presented here is given in Table 1. The typical cases are expressed as couples of linguistic values, for example (*VG*, *D*), where the instantaneous performance is *Very Good* but its trend is *Decreasing*. Each typical case is associated with a fuzzy evaluation defined on a set of emoticons L_3 = {☺, 😐, ☹}. Using a fuzzy set of emoticons instead of a unique crisp emoticon provides a more precise way to code the aggregation. For example, assume that for (*VG*, *D*), we consider that aggregated evaluation can be characterised as a happy one, *i.e.* ☺, but may be also a neutral one, *i.e.* 😐, and certainly more happy than a neutral. This type of smooth natural language description can be captured by expressing that the fuzzy subset 0.7/☺ + 0.3/😐 is associated with (*VG*, *D*), according to Zadeh's conventional description one for discrete fuzzy subsets.

Table 1. Fuzzy rule base for the typical cases related to the Capacity action plan

	D	***S***	***I***
VG	0.7/☺ + 0.3/😐	1/☺	1/☺
G	0.4/☺ + 0.5/😐 + 0.1/☹	0.6/☺ + 0.4/😐	0.8/☺ + 0.2/😐
M	0.5/😐 + 0.5/☹	1/😐	0.5/☺ + 0.5/😐
B	1/☹	0.3/😐 + 0.7/☹	0.1/☺ + 0.3/😐 + 0.6/☹

This table is the graph of a fuzzy relation R defined on the Cartesian product $L_1 \times L_2 \times L_3$. Let X be a fuzzy subset of L and $l \in L$. $X(l)$ denotes the grade of membership of l in X. Let A be a fuzzy subset of L_1 and B be a fuzzy subset of L_2. Thanks to Zadeh's compositional rule of inference [13], the aggregation process is represented by a function g such that $C = g(A, B)$ with C being a fuzzy subset of L_3 and: $\forall l_3 \in L_3, C(l_3) = \perp_{(l_1,l_2)\in L_1\times L_2} \mathrm{T}(A(l_1), B(l_2), R(l_1, l_2, l_3))$ with $\perp$ a t-conorm and T a t-norm. Most often max-min operators are used as t-conorm and t-norm. It was shown in [3] that other couples of operators can be used. In particular, $\forall x, y \in [0,1]\times[0,1], \perp(x, y) = \min(x + y, 1)$ and $\mathrm{T}(x, y) = x.y$ preserve Ruspini's fuzzy partitions [10] and lead to:

$$\forall l_3 \in L_3, C(l_3) = \sum_{(l_1,l_2)\in L_1\times L_2} A(l_1).B(l_2).R(l_1, l_2, l_3)\,. \qquad (2)$$

Hence, aggregating information for $k = 2$, $(p(2), p'(2)) = (97.85, 1.41)$, leads to:

$$\begin{aligned} A &= \varphi(p(2)) = 0.85/VG + 0.15/G + 0/M + 0/B \\ B &= \varphi(p'(2)) = 0.27/I + 0.73/S + 0/D \\ C &= g(A, B) = 0.95/☺ + 0.05/😐 + 0/☹ \end{aligned} \qquad (3)$$

Even if at this step, the plant manager can characterise every week his performances by an expression on the basis of $\varphi(p)$ and $\varphi(p')$, a final processing is necessary to propose a visual handling of this expression.

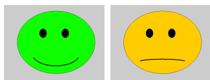
2.4 The emoticon-based scorecard

The idea is now to defuzzify the fuzzy subset defined on the set of emoticons into a unique colored emoticon whose smile, makes it easily understandable. Indeed, conventionally, two parameters characterise such an emoticon: its smile, on the one hand, and its colour one the other hand, knowing that there is a kind of equivalence between them . Let C be a fuzzy subset of L_3, α_i the grade of membership and $y_i \in Y$ a value, respectively associated with each emoticon. The symbolic defuzzification δ is defined by:

$$y = \delta(C) = \frac{\sum_i \alpha_i . y_i}{\sum_i \alpha_i}\,. \qquad (4)$$

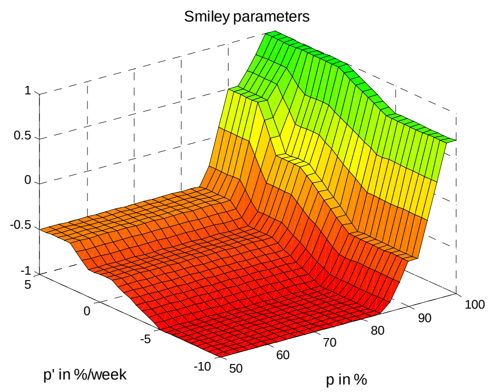
Two symbolic defuzzifications are used at the same time. The first one refers to the intensity of the smile and the second one with the colour of the emoticon. The smile is drawn as part of an ellipsis which is associated with a parameter $s \in [-1, 1]$. When $s = 1$, the emoticon means full happiness. It means that the value 1 is associated with ☺. In the same way, -1 and 0 are respectively associated with ☹ and 😐. Moreover, a "happy" emoticon means a satisfactory situation and the green colour is the conventional one for this type of case. If the colour is defined in the RGB space and each color component is defined in [0, 1], then the vector $c = [0\,1\,0]$, representing the green colour, is associated with ☺. In the same way, red and yellow colours, *i.e*. vectors [1 0 0] and [1 1 0] are respectively associated with ☹ and 😐. For example, given C = 0.95/☺ + 0.05/😐 + 0/☹, we have $s = 0.95$ and $c = [0.05\,1\,0]$ which lead to the left hand side emoticon in Fig. 4. In the same way C = 0/☺ + 0.8/😐 + 0.2/☹ produces the right hand side one.

Fig. 4. Examples of generated emoticons.



It is interesting to note that the fuzzy approach makes it quite simple to capture human expertise for the aggregation of the performance and it trend. Nevertheless, the generated information is not trivial and would have been quite complex had it been represented by mathematical equations. Fig. 5 shows this point. It represents the surface of the emoticon parameter *s*, *i.e*. the smile intensity, in function with the performance and its trend. The colours of the surface are the emoticon colours.

Fig. 5. : The smiley parameter surface



2.5 Illustrations

Figure 6 summarises the instantaneous and trend performance expressions that correspond to the six first weeks of the Capacity action plan. Note that the same scorecard could be refreshed every week until the 13th week of the year 2013. Then expressions are thus fuzzified thanks to the previous φ functions. Results for $\varphi(p')$ are given in Table 2. For instance $\varphi(p'(6)) = 0/I + 0.41/S + 0.59/D$.

Fig. 6. Instantaneous and trend performance expression for the first six weeks

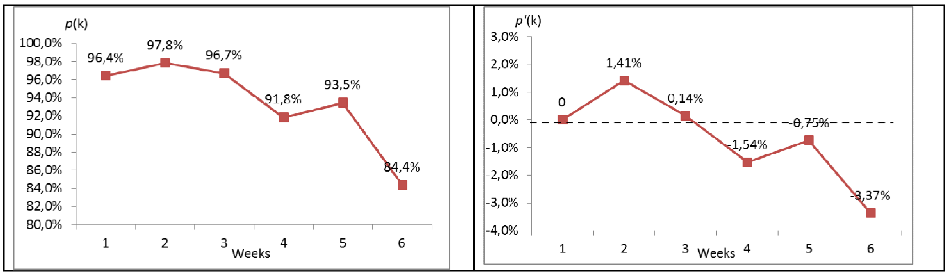


Table 2: fuzzification of the trend performance expression

	1	2	3	4	5	6
p'(k)		1,41%	0,14%	-1,54%	-0,75%	-3,37%
I (Increasing)	-	0,27	-	-	-	-
S (Stable)	1,00	- 0,73	1,00	0,87	1,00	0,41
D (Decreasing)	-	-	-	0,13	-	0,59

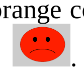
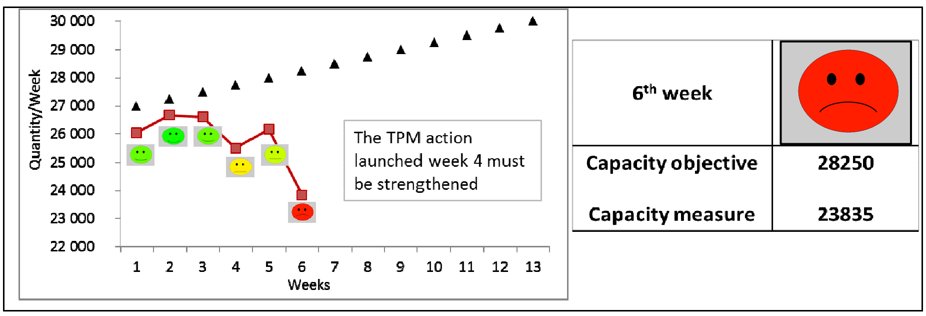
The next step consists in aggregating the fuzzification of $p(6)$, which is $\varphi(p(6)) = 0/VG + 0/G + 0/M + 1/B$, with the fuzzification of $p'(6)$. Using Table 1, we obtain $C(6) = 0/$☺ $+ 0.12/$😐 $+ 0.83/$☹. C is now defuzzified to give a coloured emoticon. For instance, the smile parameter for the 6th week is $s(6) = -0.88$, which characterises an unsmiling mouth, while the RGB vector is $c(6) = [1\,0.12\,0]$, which is an orange colour very close to the red one. It produces the following unhappy emoticon, . Thus the plant manager builds a scorecard (Fig. 7) which respectively gathers, for a considered week, the objective and measure $(o(k), m(k))$. On the left hand side of the scorecard, the performance and emoticon trajectories are displayed from the beginning of the action plan. As it can be seen, a strong and quick corrective action must be undertaken to improve the performance.

Fig. 7. Scorecard for the Capacity action plan at the 6th week



3 Conclusion

Taking trend performance expression into account can be seen as an enrichment of the traditional way of instantaneously expressing performances. Moreover, visual management is useful, in industrial improvement processes, to facilitate the decision. In this sense an information processing has been proposed which aggregates the instantaneous and the trend expressions based on fuzzification mechanisms and inference rules. This aggregated piece of information is displayed in the form of emoticons which ensure an easy and common understanding for most people involved in the improvement action plans. The case study is in progress and should give feedback about the interest and the practical difficulties to deploy this visual management in industrial company. Further development of this work concerns the generalisation of this type of visual temporal approach particularly when many objectives have to be simultaneously reached. An extension of this model is also envisaged for the performance analysis of the temporal trajectories being considered as a whole.

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