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Lamia Berrah, Laurent Foulloy, Vincent Clivillé

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Towards a unified methodological framework for both industrial objectives break-down and performance expression*

Lamia BERRAH, Laurent FOULLOY, Vincent CLIVILLÉ[a]

[a] *LISTIC Université de Savoie*

Abstract

This article deals with the definition of a unified framework for the simultaneous handling of both industrial objectives declaration and performance expressions. Subscribing to continuous improvement process, previous works have been separately focused, on the one hand, on the objective quantification and, on the other hand, on the performance expression mechanism. This mechanism was based on a formal distinction between the elementary performances and the overall one. Overall performance is associated to the overall considered objective while elementary performances correspond to the elementary objectives, namely the objectives which are provided by the overall objective break-down. Looking now to unifying, into a methodological framework, the different steps that are involved in a performance expression process, this study focuses on the objective break-down step. In this sense, it is proposed to consider, according to the industrial practice, that this break-down is no more than the corollary of the associated action plan. Structural break-down, with the variable central point, and temporal break-down are highlighted, and illustrated by industrial examples.

Key words: objective - performance expression - variable - structural break-down - temporal break-down.

1 Introduction

According to the Deming's wheel principle [1], any improvement can be realised if, sequentially, objectives are declared, actions are launched, performances are expressed and decisions are made with regards to what happened during each of these steps. Subscribing to this way of thinking, previous works have particularly dealt

* This paper was not presented in any other revue. Corresponding author V. Clivillé. Tel. +33 450 096 585. Fax +33 450 096 559 *Email addresses:* lamia.berrah@univ-savoie.fr (Lamia Berrah), laurent.foulloy@univ-savoie.fr (Laurent Foulloy). vincent.cliville@univ-savoie.fr (Vincent Clivillé).

with the performance expression mechanism. A formal framework has then been proposed, distinguishing the expression of the “elementary” performance, on the one hand, and the expression of the “aggregated” one, on the other hand. Elementary performance has been defined as the result of the comparison of the objective as the target value, and the measurement as the acquired one [2]. Aggregated performance has been introduced as being the result of the combination of the elementary performances [3]. It is also assumed that the links between aggregated and elementary performances were deduced from some kind of structural links that are inherited from the objectives analysis. These links identify those between one overall objective that corresponds to the aggregated performance and a set of sub-objectives, provided by the break-down of the overall one and corresponding to the elementary performances. Moreover, formal tools have been used, namely the fuzzy subset theory for the handling of imprecision and uncertainty in the elementary expression, and the MAUT – Multi Attribute Utility Theory – [4][5] for the aggregated one.

The aim of this study subscribes to the definition of a unified framework that covers the different aspects of the performance expression. It is proposed here to particularly focus on the specificities of the objective break-down in order to extend the previous works in this sense [6]. In the current open economic world, manufacturing companies look for the continuous improvement of their performance, in terms of productivity results, sustainability, innovation... [7]. Strategies are thus defined; overall objectives are declared, as well as action plans, temporal horizons and milestones. Coherently defining the set of objectives to achieve, on the one hand and the actions to launch on the other hand, requires a necessary common deployment of the decisional entities that will be considered [8]. What is called variable or criterion [9] identifies the decisional concept that is: quantified when it is talked about objectives declaration; acted on when the actions are planned and observed when the reached performance is expressed.

The concept of variable is more or less implicitly handled in Performance Measurement Systems – PMS’s [10]. PMS’s can be seen as “multi-criteria instruments, made of a set of performance expressions (also referred to as “metrics” [11][12], *i.e*. physical measures as well as performance evaluations, to be consistently organized with respect to the objectives of the company” [3][13]. Moreover, the multicriteria aspect of PMS’s has led to consider what it can be introduced as the objectives break-down problem. The *Balanced Scorecard* [14] defines the company performance with regards to four axes, namely the “financial”, the “customer”, the “organizational learning” and the “processes” axes. These axes can be viewed as variables that are considered for deploying strategy. Then objectives, targets (*i.e.* objectives at short horizons), measures and initiatives are defined according to each axe. The *Process Performance Measurement System* PPMS [15] takes up the same principle, adding a fifth variable which is the “innovation”. In the same manner, the *GRAI* methodology [16] defines three main variables, “delay”, “quality” and “cost”. For each entity of the physical system, indicators are built, by associating objectives and measures at these variables. More globally, propositions such as the *Integrated Dynamic Performance Measurement System* IDPMS [17] or the *European Network for Advanced Performance Studies* ENAPS approach [18] propose to retain generic variables. The *Quantitative Model for Performance Measurement System* QMPMS [19] adopts specific variables identified thanks to a cognitive map [20]. The variables and their interactions are then represented through a criteria tree [21].

Moreover, in addition to this structural aspect considered around the strategy deployment problem, temporal horizons are systematically associated with the objective achievement, according to the duration of the action plans execution, *i.e.* the execution of the associated operational processes. For instance, the *GRAI* method distinguishes several time horizons according to the considered decision levels, while the *Balanced Scorecard* evokes temporal duration for the initiatives without nevertheless defining them. The most advanced proposition is the *IDMPS* one since it deals with the temporal aspect of the PMS by reusing the Value Focus Cycle Time [22] which periodically reconsiders the objectives. Although present in the literature, the temporal aspect is not clearly handled by PMS’s.

This study deals with the objective break-down definition and its use in the performance expression mechanism. In the following section, the objective concept is discussed, its declaration and its links with the action plan concept. The set of attributes that characterise the universe of discourse of the objectives is defined by means of mathematical functions. Then, the objective achievement point of view is adopted, thus emphasising the structural and the temporal break-downs of the objectives. The former concerns the representation of the objectives by means of a tree of variables, while the latter is related to the temporal trajectories of the objectives. In the third section, using the basis of industrial illustrations will explain how the tree of variables of the structural break-down can be used for the performance expression. Some remarks and perspectives conclude this article.

2 Objective break-downs

2.1 The objective attributes

From a general point of view, an objective is identified to a target value that is associated with a variable or criterion and which should be achieved at the end of a given temporal horizon [14][16]. Beyond this value, the objective concept involves other attributes in its definition. This is because two points of view can be adopted with regards to the objective: the quantification one, and the achievement one. The quantification of the target value is the result of what is previously called the objective declaration [2][3][13]. From this point of view, an objective is characterised by the declaration of a target value associated with a variable. Moreover, each objective is related to what is called universe of discourse, which is used for the "precisiation" of its declaration. The universe of discourse contains the necessary parameters to make the objective declaration understandable. It contains at least the variable and the target value that is associated with a set of admissible values, a unit for the values, a temporal horizon to which the objective is defined. Let us note that the term "precisiation" was introduced by Zadeh in his work about "computing with words" [23]. It defines the process which transforms natural language expressions into mathematical expressions and makes the computation possible.

Thus, let $\mathcal{V}$ be the set of all the variables involved in the system under consideration. Let v be a variable of $\mathcal{V}$, associated with an objective. It is assumed that there exits a function u such that $u(v)$ is the unit of the variable v or functions T_i and T_f such that $T_i(v)$ and $T_f(v)$ are respectively the beginning and the end of the action plan. The interval $[T_i(v), T_f(v)]$ is called *the temporal horizon*. The target value which should be achieved at the end of the action plan, *i.e.* at $T_f(v)$, is given by means of a function o such that $o(v)$ is this target value. Although the target value $o(v)$ is only an attribute of the objective, in industrial practice it is very common to say that $o(v)$ is the objective.

Example: Let v be the variable associated with the *Work In Progress Level*. Assume that a temporal horizon is defined from week 1 to week 48 and that the objective target value to achieve is 2 days. This leads to the following notations: $T_i(v) = 1$, $T_f(v) = 48$, $o(v) = 2$, $u(v) = day$.

2.2 Structural break-down

Top level objectives are the strategic objectives. Knowing the complexity of the company organisation, such objectives become overall and are often broken-down into sub-objectives. The break-down operation can be defined as the process that consists of hierarchically identifying and selecting the variables concerned by the considered objective, then declaring the sub-objectives. According to Keeney, objectives at a given level can be seen as the means to achieve objectives at the upper levels [9][24]. In other words, they are sub-objectives of these upper levels. This recursive decomposition process is called *structural break-down*.

Such a break-down is strongly linked to the action plan that is defined for the achievement of the considered overall objective. In this sense the variable selection is generally based on the cause-effect analysis principle [25][26]. For instance, the Forrester diagram [27] or the cognitive map [20] are highlighted in the literature for this purpose. Namely, the variable associated to the overall objective, *i.e.* the Key Success Factor, as well as the set of variables hierarchically linking strategic objectives to the operative system, *i.e.* the Key Performance Factors are identified at the tactical level. These links are detailed as necessary, until the actions become operational. The considerations of hierarchical links, on the one hand, and the recursive aspect of the approach, on the other hand, lead to the representation of the structural break-down as a tree where:

- the root is a strategic objective,
- the height (depth) identifies the number of considered levels,
- the nodes identify the different sub-objectives,

- the arcs carry the contribution link between the sub-objectives at a given level to its parent objective; these links support the action or set of actions launched to achieve the parent objective.
- the leaves identify the elementary objectives which are no longer broken-down anymore.

Let us remark that the elementary or overall character of the objectives is relative, being strongly linked to the visibility area of the decision-maker on the one hand, and the operative system on the other hand. These notions subscribe to the *CIMOSA*, *GRAI*, or *GIM* [28] enterprise modelling principles with regards to the processes, activities or functions and decision centers. The company can moreover be considered according to several points of view. V. Popova et A. Sharpanskykh [29] propose the “organisation”, “process”, “agents” and “performance” aspects. In other words in addition to the physical system, authors emphasize on aspects such as human resources or organisation.

Strictly speaking, the break-down structure is an acyclic oriented graph. The strategic objectives (the root of the tree) are the summits with an input degree of 0. For the sake of simplicity, but also because it corresponds to most of the industrial case studies [30][31][32], the tree notion is generally kept. As an illustration, Fig. 1 gives an example of the structural break-down of two strategic objectives of a business unit of the Bosch Rexroth Company. The resulting graph expresses the decision-maker expertise as it has been given.

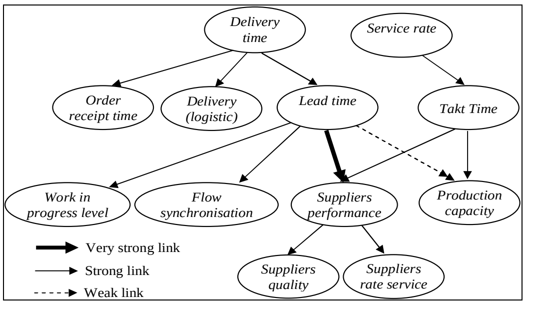

Fig. 1: Examples of structural break-down in the Bosch Rexroth Company

At the decision levels other than the operational one, decision-makers can simultaneously consider several objectives. The achievement of these objectives requires action plan implementation which share common variables. It explains the possible pooling of the sub-objectives for several parent objectives, such as the *Suppliers performance* objective in Fig. 1. To simplify the representation, it is recommended to associate one tree with each strategic objective as shown in Fig. 2 for the *Delivery time*.

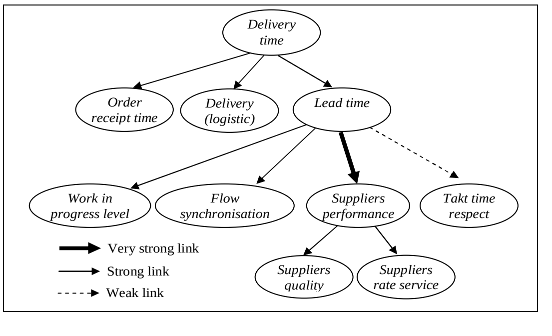

Fig. 2: Structural break-down of the *Delivery time* in the Bosch Rexroth Company.

The number of levels depends on the implemented action complexity. The break-down is carried out until simple actions are identified, *i.e.* actions which can be implemented without any ambiguity. It results, in the final step, in the elementary objectives, which are the leaves of the tree. Thus the action impact on the objective can be quantified and a performance directly expressed.

2.3 Temporal break-down

An objective is declared for a given temporal horizon. With regards to the control requirements and the uncertainties due to the long term duration of the handled improvements, it is often useful to define *intermediate objectives*, *i.e.* targets which should be achieved at given milestones of the considered horizon. This process is called *temporal break-down*.

For a given variable *v*, let us denote $t_i(v)$ with $i \in \aleph$ the milestone of the i^{th} intermediate objective and $o_i(v)$ the target value to achieve. The temporal break-down consists of providing a set of couples $(o_i(v), t_i(v))$ such that $0 \le o_i(v) \le o(v)$ and $T_i(v) \le t_i(v) \le T_f(v)$. The set of couples is called the *intermediate objectives temporal trajectory*. Defining the intermediate objectives is not a simple task and depends on the industrial context. According to industrial practice, two main cases can generally be considered and are detailed hereafter.

In the first case, a continuous trajectory is *a priori* defined because there are no constraints with regards to the objective achievement, neither on the allocated means nor on the synchronisation with other company activities. For instance, in the field of continuous manufacturing processes the production can generally be linearly spread over. If intermediate objectives at given milestones are useful to control the objective achievement, the corresponding target values can be deduced from the *a priori* trajectory. Thus, for an objective of monthly quantity, milestones can be defined for each week, possibly each day, and the temporal weekly or daily quantity objectives can be directly obtained by reading the trajectory y-axis for the given week or day . This concept can be generalised to any time $t \le T_f(v)$. Let (v,t) be a couple such that $v \in \mathcal{V}$ and $t \le T_f(v)$. The value that should be achieved at time *t* for the variable *v* is called the *quantification* and is denoted $q(v,t)$. Let us remark that, according to these notations, the target value, given by the function *o*, is such that $o(v) = q(v, T_f(v))$ and the intermediate ones $o_i(v)$ are such that $o_i(v) = q(v, t_i(v))$.

In the case of additive variables like cost, quantity, defects, and so on, the overall objective can be described as the accumulation of the intermediary ones that are issued from the temporal break-down. Thus, given the intermediate target value $o_i(v)$ for the milestone $t_i(v)$, it is possible to define an incremental target $\Delta_i(v)$ such that $o_{i+1}(v) = o_i(v) + \Delta_i(v)$. In the industrial practice, linear trajectories are frequently used and the duration between two consecutive milestones is often the same, *e.g.* one day or one week. In this case, declaring the incremental objective $\Delta(v)$ between two successive milestones is possible: $o_{i+1}(v) = o_i(v) + \Delta(v) = (i+1)\Delta(v)$.

Fig. 3 illustrates such a case where a linear trajectory links the initial state to the objective on the horizon. For instance, the weekly objective of the A3P pump is $o_f(v) = 10$ units and the considered milestone is the day with an incremental objective $\Delta(v) = 2$ units. The broken line represents the ideal trajectory without any waste of quality or time, while the continuous one represents the objective trajectory which leads, at the end of the week, to satisfy all the orders. At each time, a target can be deduced from the continuous line. The measure of the truly manufactured production is plotted by the operator as a red cross when it is below the target. If the cumulated production overtakes the target, which is possible in theory, a green cross is used. In the lower part of the board, dedicated frames can be used for the diagnosis and analysis of the difference between the target and the measure in order to correct further production and to achieve the weekly objective.

Fig. 3: Temporal break-down for a *Vacuum Pump Quantity* objective Adixen Pfeiffer Group

The second case is close to the project management break-down approaches [33], where the *a priori* trajectory knowledge is rarely well-known. It concerns action plans with uncertainties about their impact. For instance a given activity which requires about three weeks before launching the following one, or for the project, for instance the production engineering that cannot begin before the end of the design. It means that, for a given variable *v*, the set of milestones $\{t_i(v)\}_{i\in\aleph}$ depends on the project or the operation management and cannot *a priori* be defined, independently of the industrial context (available resources, projects portfolio in progress, etc.). However, in such cases, the set of target values to achieve is generally known. Each time $t_i(v)$, a target value $o_i(v)$ is reached, it becomes possible to set the next target value $o_{i+1}(v)$ as the objective to achieve. This type of break-down is called *target-oriented temporal break-down*. It differs from the previous case where the milestones and the temporal objective trajectory are *a priori* known, making it possible for the decision-makers to deduce the corresponding target values. In this second case, the target values are *a priori* known and the milestones become the consequences of the way of achieving the objective.

This case which is described in Fig. 4 shows one possible evolution of both temporal objective trajectory and its achievement way. The target value $o_2(v)$ is reached at time $t_2(v)$. The achievement of the next target value $o_3(v)$ without knowing when it will be reached: $t_3(v)$ remains unkown until the full $o_3(v)$ achievement. This case is very frequent in the food-process industry when milestones depend on the season or in a case of the *engineer to order* or *design to order* production..

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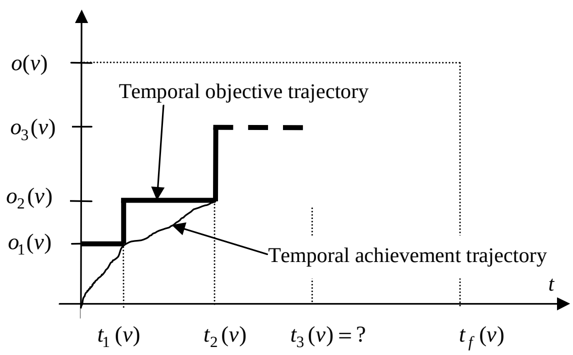

Fig. 4: Example of target-oriented temporal break-down.

As a summary, let us mention once again that the temporal objective trajectory notion is strongly linked to the company context. Indeed, the milestones definition can be quite freely made when the temporal objective trajectory is *a priori* known, while this definition is constrained when this trajectory depends on the decisions made when the temporal achievement trajectory cannot be *a priori* known (cf. Fig. 3). Moreover the objectives value can be deduced from the trajectory in the first case while they are deduced thanks to the decision-maker expertise and the temporal objective achievement in the second case.

It has been shown in this section that strategic objectives can be broken down and represented by means of a tree laying on the concept of variables. It has also been shown that the temporal break-down of the objectives led to introduce time in the objective quantification. In the next section, these two concepts are unified to make the performance expression a temporal one so that, at any time, decision-makers can use the performance expression to react.

3 Performance expression

In the structural breaking-down process, objectives which are not broken down are called *elementary objectives*. Since structural break-downs lead to trees, elementary objectives are the leaves of these trees. It means that the decision-makers have sufficient pieces of information. Especially, a measurement of the variables associated with the objective can be performed. In such cases, let us recall that the performance can be directly obtained by comparing the value of the objective to the measurement by means of a comparison function f. Let v be the variable associated with an elementary objective. It is proposed to unify the structural and temporal break-downs by writing the performance expression for this elementary objective as $p(v, t) = f(q(v, t), m(v, t))$ where $q(v, t)$ is the quantified target value at time t and $m(v, t)$ the measurement at time t.

Now, when objectives are not elementary ones, it can be difficult to directly obtain the performance expressions. In such cases, the use aggregation operators has been proposed which take into account the dependencies between the expressions to aggregate. Unifying the structural and temporal break-downs leads to consider that each expression to aggregate is associated with its variable and has a value at any time. Therefore, the aggregated performance expression is given by $p(v,t) = Ag(p_1(v_1,t),\ldots, p_n(v_n,t))$ where v_i is the variable associated with the i^{th} child of the variable v and $p_i(v_i,t)$ is the performance expression of this child. As long as performance expressions are commensurable, the aggregation process can be recursively applied to a tree starting from its root, which is the strategic variable, by a traversing tree algorithm. Since elementary objectives must be visited first; the conventional recursive post-order depth first algorithm has been used in this framework.

In order to illustrate this approach, let us consider the Bosch Rexroth *Delivery time* break-down described in Fig. 2 and let us consider, for the sake of the simplicity, the *Lead time* sub-tree. Let us assume that the company wants to reduce its *Lead time* from 7 days to 4 days within a year of 48 working weeks. Due to the structural break-down and the links between the variables, let us also assume that the decision-makers provided realistic target values to be reached by each variable within a year. Current values and target ones used in this illustration are given in Table 1.

Table 1: Expected evolution of the *Lead time* sub-tree variables within a year

Objective variables	**Current values**	**Target values**		
		Week 15	**Week 30**	**Week 48**
Work in progress level	*4 days*	*3.5 days*	*2.8 days*	*2 days*
Flow synchronisation	*2 days*	*1.5 days*	*1.2 days*	*1 day*
Supplier quality	*3000 ppm*	*2500 ppm*	*1500 ppm*	*1000 ppm*
Supplier rate service	*88%*	*90%*	*93%*	*95%*
Takt time respect	*0.15h*	*0.13h*	*0.11h*	*0.1h*

Let us assume that the decision-maker decides that the temporal break-down for each variable is simple linear interpolation between the milestones. Fig. 5 illustrates, in simulation, the temporal break-down of the objective and the measurement and the temporal performance expression associated with each elementary objective involved in the *Suppliers performance* structural break-down.

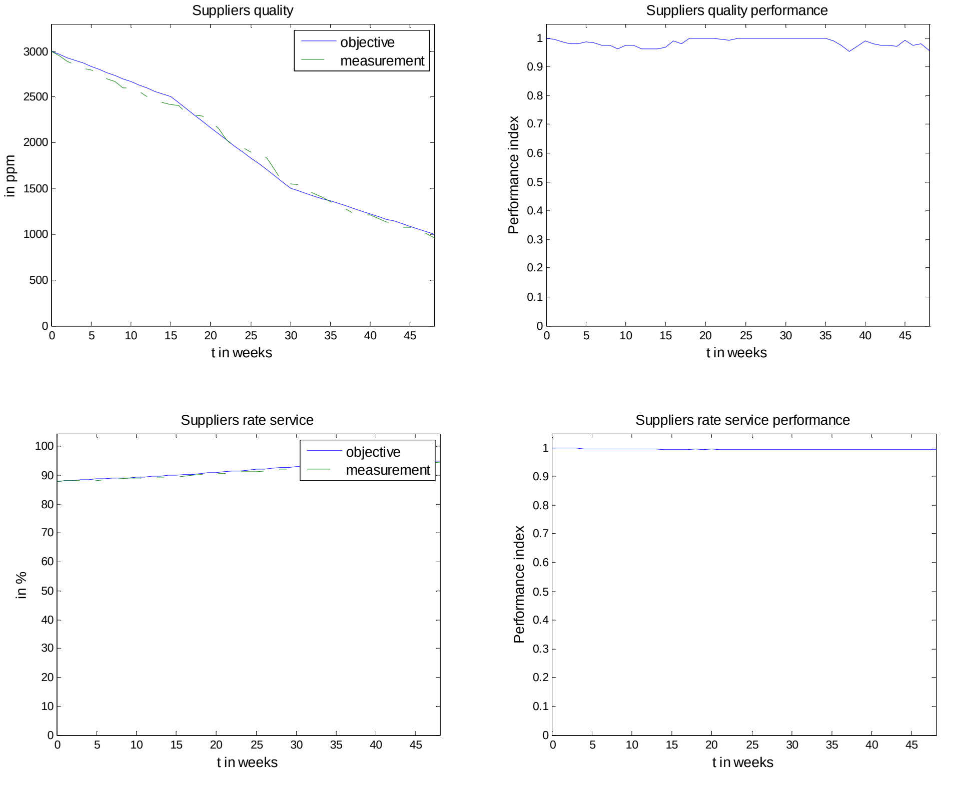

Fig. 5: Temporal break-down and performance expression associated with the *Supplier performance*.

In a same manner, the performance expressions can be computed, at each time, for all elementary objectives and then propagated in the tree resulting from the structural break-down using the aggregation operators previously mentioned. Let us assume that the decision-maker decides, for each elementary objective, to use a bounded ratio, *i.e.* $p(v, t) = min(m(v, t) / q(v, t), 1)$. The most common aggregation operator is the weighted mean [5][19][21] but other operators like the Choquet integral can also be used [3], dealing with the commensurability condition on the one hand and with the interactions between criteria on the other hand. This paper focussing on the objective break-down, the conventional Arithmetic Means were used for the sake of simplicity, that is $WAM_w(x) = \sum_i x_i w_i$ with $\sum_i w_i = 1$. Let $x = (x_1,..., x_4)$ be the vector of the values to aggregate which are respectively related to the *Work in progress level*, the *Flow synchronisation*, the *Suppliers performance* and the *Takt time respect*. According to the links between the variables shown in Fig. 2, the weight vector $w = [0.15\ 0.15\ 0.6\ 0.1]$ was provided by the DM. Let $x = (x_1, x_2)$ be the vector of values respectively associated with the *Suppliers quality* and the *Suppliers service* rate. As the *Suppliers service rate* performance is considered as more important than the *Suppliers quality* one, the weight vector $w = [0.35\ \ 0.65]$ is used. Fig. 6 illustrates the temporal performance expressions of the elementary objectives involved in the *Supplier performance*, *i.e.* the *Supplier quality* and the *Supplier rate service*, and the resulting aggregated performance expressions for the *Supplier performance* objective and the *Lead time* (or *throughput time*) strategic objective.

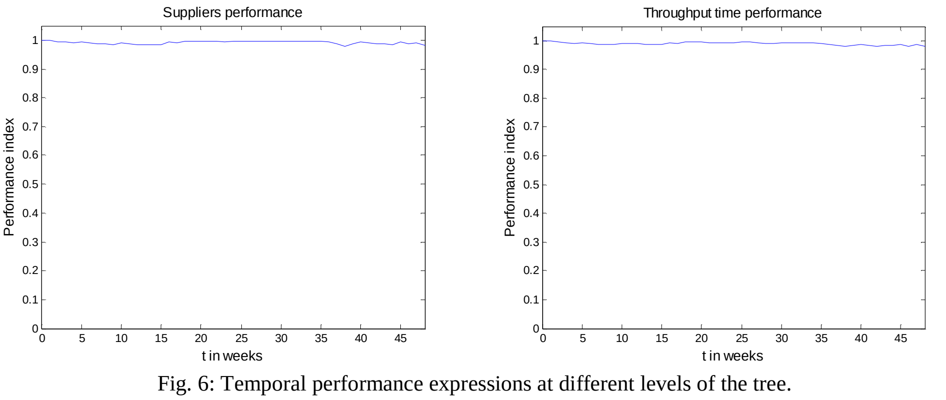

Fig. 6: Temporal performance expressions at different levels of the tree.

Thanks to the performance expressions shown in Fig. 6, it clearly appears that the improvement is well controlled. Indeed the elementary temporal objectives are always reached (cf. Fig 5) and consequently the elementary and aggregated performances are close to 1.

4 Conclusion

In this paper the concept of objective has been considered from the industrial point of view, especially its connection with the action plan. This approach has led to present two complementary types of break-down, the temporal one and the structural one. The former concerns strategic objectives that can be broken-down into trees of objectives. The leaves of the trees are elementary objectives for which decision-makers know which actions can be undertaken and how to measure their effects. The latter is related to the trajectory which elementary objectives are supposed to achieve. Finally, it was shown how the two break-downs can be unified to compute the performance expression at any time. It makes it possible for the decision-makers to follow the behaviour of all or a part of the company during the action plan implementation and possibly react, before the end of the action plan, based on the trends of the performance trajectories. The unification is based on a recursive post-order depth first algorithm which computes the elementary performances, *i.e.* the leaves of the tree, by means of comparison functions while aggregation functions are used for nodes. Several examples have been provided either from real industrial cases or from simulations based on industrial applications.

Some perspectives can be proposed with regards to this study. Among them the one which concerns the coupling between the performance expression issued from the objective break-down and the launched action plan. Indeed the structural break-down is closely linked to the action possibilities and the temporal break-down with the task execution duration. In this sense a deployment methodology should be proposed that respects the unified framework helped by a Decision Support System that assumed the procedural and computational aspects of this methodology. Finally some case study applications are necessary to experiment and improve the proposition.

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