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***An Integrated Approach For The Construction  
Of Enterprise Change Trajectories***

*D. Crestani, V. Chapurlat, B. Durand*

Ecole Nationale Supérieure Mines Alès -- 6 avenue de Clavière, 30319 Alès cedex  
LGI2P - Laboratoire de Génie Informatique et d'Ingénierie de Production, Parc scientifique Georges  
Besse, F30035 Nîmes

# AN INTEGRATED APPROACH FOR THE CONSTRUCTION OF ENTERPRISE CHANGE TRAJECTORIES

D. Crestani<sup>1</sup>, V. Chapurlat<sup>2</sup>, B. Durand<sup>1</sup>

*1 - Laboratoire d'Informatique, de Robotique et de Microélectronique de Montpellier – LIRMM - 161, Rue Ada, 34 392*

*Montpellier Cedex 5, Université Montpellier 2 – C.N.R.S.*

*Tel. (+33) 467 418 513 - Fax (+33) 467 418 500*

*Email: [crestani@lirmm.fr](mailto:crestani@lirmm.fr), [durand@lirmm.fr](mailto:durand@lirmm.fr)*

*2 - Laboratoire de Génie Informatique et d'Ingénierie de Production - LGI2P - site EERIE de l'Ecole des Mines d'Alès, Parc Scientifique Georges Besse, F30035 Nîmes cedex 5, France – Tel. (+33) 466 387 066 – Fax (+33) 466 387 074*

*Email : [Vincent.Chapurlat@mines-ales.fr](mailto:Vincent.Chapurlat@mines-ales.fr)*

**Abstract:** Managing change projects in manufacturing enterprises remains difficult and often risky. Some existing research works, good practices and available tools are poorly adapted or hard to autonomously use by industrial decision makers themselves. This article presents and illustrates a change management aided decision approach allowing the construction and evaluation of different possible change projects while taking a given enterprise strategy into account. First, the enterprise is described by using a cross reference to systemic and enterprise modelling approaches. Secondly, the current state of the enterprise is characterized and evaluated from different enterprise performance viewpoints. Thirdly, operational methods are modelled to improve reactivity, flexibility, interoperability and so on, while respecting the behavioural constraints and performance indicator impacts, thus facilitating the building, evaluation and comparison of different change project solutions. Fourthly, this approach is implemented using a methodology and supporting tool.

Key words: change management, change trajectory, continuous change, enterprise modelling, performance, decision-making.

## 1. INTRODUCTION

Manufacturing companies must continuously maximize their performances in terms of costs, lead times and quality so as to be able to deal with chaotic market changes, to foresee competition and changes in customers' requirements. Managers and engineers must therefore define and strive to apply different potential change projects focused on improving the company's reactivity, flexibility, interoperability and globally its profitability. A change project aims adapt the organization, means, flows and resources, reducing waste, improving behaviours and functioning modes. This involves taking customers' advice and needs, new potential innovative technologies and organization models, such as virtual enterprise, distributed enterprise, and so on, into account. However, an enterprise is a complex sociotechnical system, which means that it is very hard for stakeholders to understand its structure, behaviour and to determine potential and relevant change projects, i.e. impact of possible changes in the company. Secondly, several studies (European Time Guide project (Time Guide 1996), ADESI research project (ADESI 2004, Boucher and Crestani 2007)) have shown that industrial stakeholders require operational methods and tools, i.e. relevant change approaches and means for decision makers. These studies underline the following points.

- Organizational factors (e.g. organizational inertia) and social factors (e.g. change resistance) are very important for successful change.
- Engineers responsible for change projects have a limited understanding and practical knowledge about production change management methods.
- Engineers' and managers' rationales are rooted in short-term decisions.
- The same engineers need to integrate a multi-dimensional view when considering performance, i.e. not only guided by the conventional costs/lead time/quality trio.

- They want to manage their change projects themselves.
- Moreover, managers still lack sound methods and tools to support complex decision processes and to integrate all dimensions of performance.

This article proposes an industrial oriented change management approach for manufacturing companies striving to evolve continuously while taking care about strategic objectives (Ben Zaida 2008). This approach specifically aims:

- To gain insight into the enterprise system complexity, its real performance indicators and strategic objectives by defining some representation means and tools.
- To choose effective potential and usable change means, i.e. potential known operational approaches for adapting and improving organisation, flows, activities, resources, and so on, in the enterprise to fulfil the needs of the adopted change strategy.

This paper is structured in four parts. The first part presents and discusses the main research and industrial studies that have been carried out on change management in engineering sciences. The second part presents the proposed approach by highlighting and formalising its concepts and their relevance. These are:

- An enterprise and performance modelling framework, including a definition of operational change methods and the characterization of change projects described in the form of change trajectories, to allow the transition from one enterprise state to another while respecting the performance objectives.
- A methodological approach to handle these concepts. This consists of several steps focusing respectively on enterprise description, enterprise current state estimation, determination of the different possible trajectories and, finally, evaluation and comparison of these trajectories.

The third part briefly introduces the GET (Generator of Enterprise Trajectories) software environment used to implement the proposed approach. Lastly, the fourth part illustrates the approach and the application of GET before concluding and presenting some prospects of this approach.

## **2. ENTERPRISE STRATEGY AND CHANGE PROJECTS**

### ***2.1. THE CHANGE ISSUE***

An enterprise is a complex socio technical system geared towards providing products and services required by its customers while maximising its performance, reactivity, agility, flexibility, interoperability, etc for attaining its profitability objectives. It runs in a complex and chaotic changing environment characterized by technical, economical and social dimensions. Thus, any company must define and perform change projects to adapt itself to and foresee changes and as a consequence of a deterministic (Wilson 1992) or deliberate (Mintzberg and Waters 1985) modification in its strategic objectives.

Enterprise change strategies have been largely investigated in management sciences. Any strategy defines a set of long-term objectives often in an abstract manner. These objectives may be then split into more realistic objectives and into actions to be done building the deliberate strategy. An emerging strategy that takes opportunities into account can overlap the deliberate strategy to form the strategy that is to be applied (Mintzberg 1994). Hence, to define a strategy, it is necessary:

- To understand the current organization and behaviour of the enterprise in order to determine the change requirements as well as the enterprise's capacity for change.
- To know the enterprise's current performance state.
- To estimate a relevant, reachable, understandable and accepted performance state to be achieved in order to meet the enterprise's strategic objectives.
- To choose a path, so-called change trajectory, leading from the current state to the target state by applying a set of actions so called the change process (Figure 1).

A change process can be from two types. First if the required time has to be as short as possible to achieve a marked performance improvement, the change can be viewed as breaking change. This induces drastic modifications in the enterprise behaviour and organization and impacts notably the resources, especially workers. This usually generates substantial organizational resistance. For example, BPR (Business Process Reengineering) (Mintzberg and Waters 1993) methods can be used to make some radical changes.

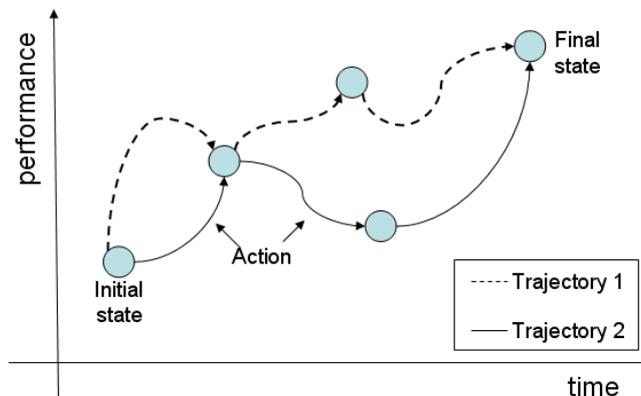


Figure 1: Change trajectory and change process

Second, the change process can be more continuous and is then generally more easily accepted by workers. In this case, the performance improvement is only gradually generated over a longer change process time. Many methods are available to ensure continuous change (Bodek 2004).

So, management science studies have been largely focused on the question "Why must an enterprise change?" but unfortunately they do not answer to the questions "How can an enterprise change?", "What concrete initiatives can enable an enterprise to change?". Conversely, industrial engineering sciences studies focus essentially on industrial point of view "how to control and act on the manufacturing system change?". Even though there is no contradiction between these two communities but there is no real connection between their research to address industrial issues and fulfil engineers' needs in terms of change project definition and management highlighted by both communities. A conventional approach based on Plan-Do-Check-Act principles can be applied to determine these needs:

- **To Plan:** the enterprise has to anticipate changes from environment then to design the most suitable and as continuous as possible relevant change project. Le Moigne (Le Moigne 1977) defines the link between the enterprise mission and the enterprise environment stability (Table 1). Four types of projects are identified Regulation and program adaptation correspond to the nominal behaviour of the enterprise striving to achieve a set of defined and stable objectives without modifying its structure. Structural adaptation and structural change require modifying the structure and/or implementation schemes to handle new enterprise objectives. The proposed work focuses only on these two last kinds of projects.

		Enterprise Mission	
		Constant	Variable
Enterprise Environment	Constant	Regulation	Structural adaptation
	Variable	Program adaptation	Structural change

Table 1: The equilibration framework

This requires first detecting environment movements, requirements and expectations (the Customer Voice concept in 6-Sigma approach). Secondly, the enterprise must analyse the impacted parts of the enterprise (organisation, products or services, customer relationship, human resources knowledge or motivation, etc.). Thirdly, it involves defining a valid change strategy over a more or less long period of time. Lastly,

it is necessary to build, validate, plan and implement a change project aiming to modify and adjust the organisation, behaviour or functioning modes of the enterprise while taking the strategic decisions, events, risks, opportunities, new technologies, etc., into account. Means and tools are required to gain insight into and evaluate the enterprise situation, to define, compare and decide what industrial approaches are to be applied during the project (5S principles, Kanban for minimising stocks and straight flows, SMED for minimising production time, training activities, etc.).

- **To Do / to Check:** the goals are first to manage the change project throughout the proposed period, second evaluating, verifying if the objectives set for the project are reached and detecting the causes of a given disruption. So different sets of indicators are required allowing decision makers and project managers to evaluate, control and, if necessary, reorient the project over its full term.
- **To Act:** the same kind of project can be applied in other parts of the enterprise so managing and reusing the project history is necessary.

## **2.2. PREVIOUS STUDIES AND DISCUSSION**

The main previous studies concerning the definition and management of company change projects highlight the following key limitations upon which the proposed approach focuses. First, some of them concentrate on a single given dimension or viewpoint concerning the company's performance and its business typology (Larsen et al. 2002). Others only concern minor changes that are beyond our field of investigation (Grosz et al. 2000) or they do not outline the rationale of the state change implemented (Mansar et al. 2005). Only (Malhene 2000) defines and provides performance indicators that simultaneously formalise several company dimensions (multi criteria). He proposes to monitor variations in these indicators by comparing and then detecting when a difference arises between the reality of the company and an ideal and abstract change trajectory of the company. However although he assesses change methods that could be deployed throughout a change project (KANBAN, 5S, etc.), the author does not propose any tools to guide engineers in choosing a list of relevant and applicable methods for their project. (Sieberborn 2005) proposes a more interesting analysis of change methods that can be applied during a project. However, there is no real analysis of potential rules (eligibility rules that take into account, the company's typology, expertise and domain of activity, sequence, parallelism and compatibility of rules, constraints, etc.) that have to be respected when these methods are applied during a project in a given enterprise.

Otherwise, no studies propose an open approach to deal with the whole enterprise, i.e. generally centered around an enterprise (global or partial) model. (Zakarian et al. 2001), by modelling processes critical to the company, tried to analyze, identify operational problems and propose solutions. (Girard et al. 2004) models the process to assess the functioning of a company after integration of new production processes. However, these authors consider change only as a logical adaptation of the company's structure and behaviour and that a change project should focus on a regulation issue. Lastly, few studies specify how change projects have to be built (Mansar et al 2005) or only very abstract or high-level analysis are proposed, such as by (Debenham 2003). In the same way, if simulation is proposed to guide change management and the project definition, it is not preceded by a real analysis step that could potentially allow, if needed, generalization of the simulation results to other case studies. Indeed, the studies are either much too specific (Zakarian et al. 2001) (Mansar et al. 2005) or they consider only a single performance criterion, as proposed by (Larsen et al. 2002) and (Debenham et al. 2003).

Lastly, some other authors using BPR approaches (Mansar and Reijers 2005) do not address continuous change. Overall, there is a lack of a global framework to combine enterprise trajectory building and a decisional process to manage enterprise change (Boucher and Crestani 2006).

In summary, methods are required for modelling and analysing models used within a decision process. The proposed work focuses essentially on the Plan step, even though the proposed concepts can also be used during the other steps. This work starts from a fixed strategy decision definition and ends when the project definition and validation is over. Modelling is required to gain insight into and share advice about the enterprise system, to evaluate its current and target situation, and to determine impacts of possible

industrial approaches that could be applied during the project in order to guide decision makers when defining and comparing different project solutions. The proposed approach aims to help decision makers in enterprise manufacturing domain build, evaluate and compare change projects. Hypothetically, the enterprise strategy is first defined and the approach focuses on continuous change which minimizes change resistance. Second, the approach aims to evaluate the potential impact of different operational change methods derived from the industrial domain (6-sigma, 5S, JIT, etc) on the enterprise performance. The next parts present different modelling and analysis concepts, and a global methodology is defined and illustrated.

### **3. THE PROPOSED APPROACH**

This approach aims to fulfil the following industrial needs:

- To draw up a modelling enterprise framework relevant for understanding and characterizing enterprise change issues.
- To deduce, from a predefined strategy, the relevant performance objectives to reach.
- To be able to consider multidimensional performance viewpoints.
- To be able to identify different potential change trajectories by associating various operational change methods.
- To be able to propose criteria to assist managers in the decision making process.
- To dispose of an operating toolbox that could facilitate managers' autonomy.

The following approach is proposed to fulfil the above needs. It can be divided into the following six main steps:

- Step 1 describes the structural, functional and behavioural views of the enterprise using adapted modelling languages.
- Step 2 characterizes the initial state of the enterprise by estimating the performance indicators.
- Step 3 identifies the methods that can be used in the current state to help achieve the performance objectives.
- Step 4 estimates the impact of the different applicable methods and the corresponding new future potential states.
- Step 5 constructs the corresponding trajectories of the change process.
- Step 6 evaluates possible change processes once the process construction is finished.

These steps are detailed and illustrated Figure 2.

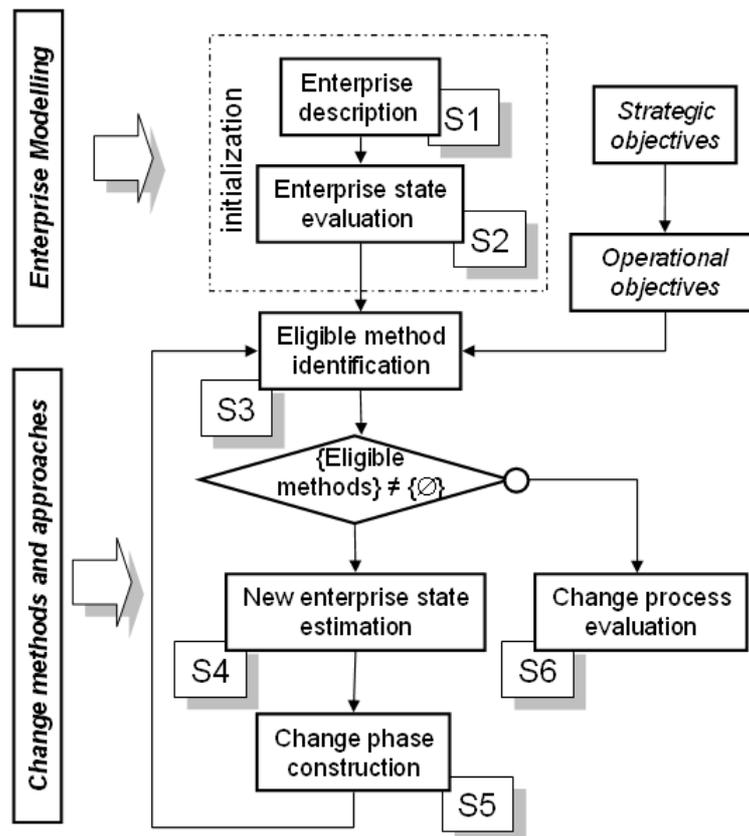


Figure 2: The proposed approach

### 3.1. ENTERPRISE MODELLING FRAMEWORK

Enterprise Modelling (Vernadat 1996) concern a set of methods, modelling languages (Petit and Doumeings 2002), ontologies (Ushold and Gruninger 1996) and architecture frameworks (GERAM 1999) in order to represent knowledge related to enterprise. This knowledge is share by stakeholders and applications for analysing and improving the enterprise performance. The proposed approach requires a modelling framework which integrates existing languages. This framework is based on theSAGACE method (Penalva 1997) proposed in 1989 to guide and improve the description of complex systems. The proposed modelling framework is inspired by the modelling grid of SAGACE composed of 9 complementary viewpoints focusing each on functional, structural and behavioural aspects of a given system.

Most relevant modelling languages for each viewpoint have been selected and integrated by defining a common metamodel (Ben Zaïda 2008). The resulting framework is named SAGACE-CE:

- Functional aspect: KAOS (Knowledge Acquisition in autOmedated Specification) modelling language (Lamsweerde 2001) allows describing strategic objectives and their breakdown.
- Behavioural aspect: eFFBD (enhanced Function Flow Block Diagram) (Long 2002) are used for describing processes and UML state diagrams (Jacobson et al. 1998) are used for describing configurations.

Structural aspect; resources, roles and global organisation of the enterprise are represented with UML Class diagrams (Jacobson et al. 1998). The links between the Strutral and behavioural aspects are specified with UML collaboration diagrams (Jacobson et al. 1998).

Considering the enterprise model which emerge, its performance and the potential impact of any operational method is then modelled as follows.

### 3.2. PERFORMANCE MODELLING FRAMEWORK

To construct enterprise change trajectories it is essential to evaluate the enterprise performance. This complex task must answer a set of fundamental questions:

- What relevant performance indicators should be adopted to reflect the different enterprise viewpoints and to guide change trajectory choices?
- How can an open system of enterprise performance indicators be built to cover all parts of the enterprise?
- Among the huge variety of performance indicators and according to the performance objectives, what relevant performance indicators can be chosen to be able to characterize the enterprise performance?
- How can current and expected states of enterprise performance be evaluated?

### 3.2.1. PERFORMANCE: BUILDING A GLOBAL SYSTEM OF PERFORMANCE INDICATORS

It is essential to build a general system of performance indicators in order to be able to deal with any strategic objectives that will impact some performance criteria in some parts of the target enterprise. This system must reflect all relevant identified performance axes and criteria, while also handling all the parts of the enterprise and their potential interactions. Finally, it must provide mechanisms to enable evaluation of the enterprise performance state. Moreover, from an operational standpoint, it is important that the user is provided a methodological guide to facilitate the construction of the considered performance indicator system.

Many building methods for performance indicator systems have already been proposed. Most of them offer a formalised or structured approach to guide users in the building task. Some, like The Balanced ScoreCards (Kaplan and Norton 2000) and ABC/ABM (Lorino 1991) approaches, are widely used in the industry or are well known, e.g. Ecograi (Doumeingts et al. 1995) and the Process Based Approach (PBA) (Neely 1995).

Generally they do not focus on specific indicator classes, but they also do not propose to users a set of relevant indicator classes tailored to the studied problem. The Balanced ScoreCards and the Process Performance Measurement System (PPMS) (Kueng et al. 2001) consider that the financial and customer aspects are two important dimensions with respect to the enterprise performance. This limited choice should be more open to deal with change issues. Few building methods, like the Quantitative Model for Performance Measurement System (QMPMS) (Bitici et al. 2000) or PBA, consider the enterprise system globally. Generally, e.g. Ecograi or ABC/ABM, a top down process guides the user from high level objectives through decisional levels to the corresponding performance indicators. This limits the amount of handled information, but only a small part of the indicator system is built. Unfortunately, QMPMS does not propose a methodological guide to construct the indicator system. PBA does not guide the choice of performance axes and does not propose an efficient performance indicator aggregation mechanism. Hence, it seems that a dedicated and adapted approach must be proposed for building an efficient performance indicator system having the above defined properties.

Firstly, relevant performance viewpoints must be identified before building a performance indicator system. Historically, enterprise performance was first focused on financial/cost aspects. In the 1990s, timeframe and quality were identified as new relevant indicators. Now, according to industrial needs (Adesi 2004, Time Guides 1996), it is widely accepted that enterprise performance must integrate a large panel of paradigms like flexibility, reactivity, and innovation, etc.

In the present study, as proposed within the Sagace systemic framework, the enterprise performance is broken down into three main performance axes, with each integrating several performance criteria (Figure 3). However, the list of the proposed performance criteria remains open and can be adapted to the specific technical or economical environment of an enterprise.

- The control axis describes the most classical performance dimension. It is defined as the ability of the enterprise to fulfil its mission within a given timeframe. It gathers the usual cost, quality and timeframe criteria.
- The adaptation axis corresponds to the ability of the enterprise to remain stable, i.e. to become successful whatever its current state and its functioning mode and despite some environmental disturbances. Proactivity and reactivity seem to be two relevant criteria for characterizing the adaptation axis.
- The anticipation axis describes the ability of the enterprise to avoid loss of performance in case of organisational breakdown or behavioural problems. Flexibility, standardization, resources redundancy and innovation were chosen to be the most relevant criteria associated with this performance axis.

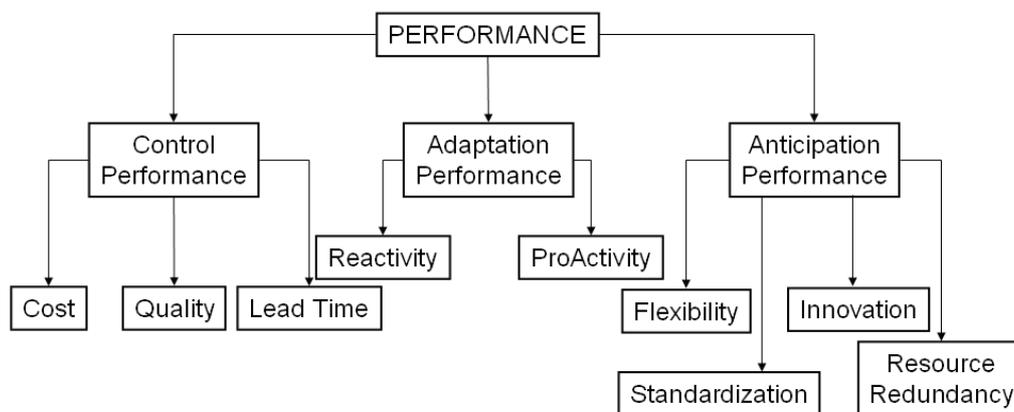


Figure 3: Performance axes and criteria

Control performance is usually the only axis used to control enterprise performance. It is essential but it is not sufficient from a change standpoint. It is thus important to have other sensitive criteria to enable a more in-depth evaluation of the impact of a change process and to provide some decision-making arguments to compare different change trajectories.

Now the key point is: How to build an indicator system that will include all sides and performance dimensions of the enterprise? A methodological guide divided into three main phases is proposed to answer to this fundamental question (Figure 4):

- Firstly, the Program view of Sagace-CE permits users to identify all Management, Supporting and Core Business Processes.
- For each process, and within a process for each performance axis, a performance indicator tree is built for each corresponding performance criterion.
- Within a performance indicator tree, indicators are identified using a causal analysis that connect performance inductors and indicators. The Ishikawa approach (Ishikawa 1985) is used to assess all potential causes of performance alterations where materials, machines, methods, environment and workforce issues are considered. This analysis is recursively performed until the operational indicators are found.

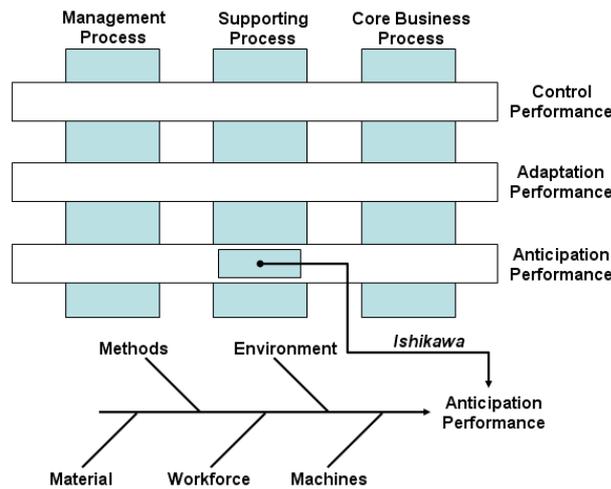


Figure 4: A performance indicator tree building method.

So finally, for an enterprise process, a performance indicator tree is hierarchically structured into many levels (Figure 5). From the performance root, the first level corresponds to the performance axis, the second one to the performance criteria. From the third level to the tree leaves, the Ishikawa approach is used to identify the performance indicators. Within all trees representing the global enterprise performance system, a given performance indicator is unique but it can be shared between several trees to highlight process interactions.

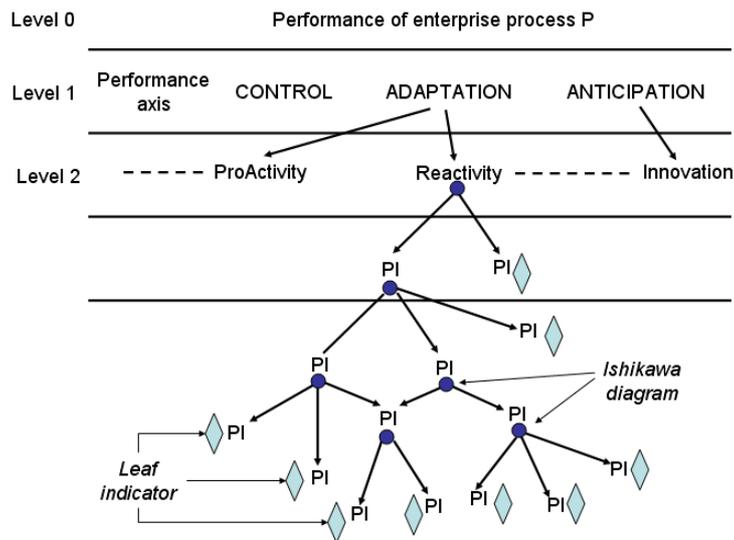


Figure 5: Generic structure of a performance indicator tree

### 3.2.2. FROM STRATEGIC OBJECTIVES TO FORMALISATION OF THE ENTERPRISE STATE

The state concept is a key point of the proposed approach because it permits assessment of current and future enterprise performance levels. This concept is widely used in many scientific domains but how can the enterprise state be defined to construct enterprise change trajectories?

Some works (Malhene, 2000) consider that the enterprise state must be defined, over time, as the value of each performance indicator of the enterprise. This definition is certainly correct but it cannot be used in practice due to the large number of performance indicators that apply to an enterprise. Hence, to reduce the number of concerned indicators, the enterprise state may only include the most relevant indicators for the target change. The chosen enterprise state must therefore include the operational performance indicators linked with the defined strategic objectives.

Many studies, such as the Balanced ScoreCards (Kaplan and Norton 2000) or Ecograi (Doumeingts et al. 1995), propose top-down approaches to differentiate operational indicators from strategic ones. BSC is used in the industry but it is a locked method where the studied performance dimensions differ from the

performance axis of the proposed approach. Using the GRAI grid, Ecograi enables the construction of indicator systems by identifying, through the different decisional levels, the performance indicators derived from the strategic ones.

In this study, an Ecograi-like top-down decomposition technique is used. Firstly, enterprise processes impacted by the strategic objectives are identified in paired sets (Objective, Process). For each pair, the corresponding process performance indicator tree is recursively explored to identify the impacted performance indicators. The process is stopped when a performance indicator is considered to have an acceptable granularity (see part 3.3).

Decomposition thus enables identification of sets of relevant operational indicators that will ensure the success of the strategic objectives and provide basic indicators required for evaluating the enterprise state. Indeed, this must only include relevant performance indicators concerned by a change process, i.e. the following indicator classes:

- Performance indicators derived from the decomposition of strategic objectives.
- High level performance indicators (corresponding to the nine performance axes) of each impacted enterprise process. These indicators can verify that the change will not have a bad impact on the global process performance even if the change permits to achieve the fixed strategic objectives.
- User indicators if the user wants to monitor some particular aspects.

The enterprise state has the following formulation (Equation 1):

$$\text{State (Entreprise, } t) = \left\{ [(PI_{11}, \dots, PI_{im})] \{[(Qua, Cos_1, LT_1) (Rea_1, Pro_1) (Stan_1, RR_1, Inn_1, Fle_1)]; \dots; [\dots (Stan_n, RR_n, Inn_n, Fle_n)]\}, [(PI_1, \dots, PI_k)_{user PI}], t \right\} \quad \text{Equation 1: Enterprise state formulation}$$

Where:

- $[(PI_{11}, \dots, PI_{im})]$ : Performance Indicators corresponding to the strategic objectives with  $PI_{ij}$  : Performance Indicator  $i$  for objective  $j$ .
- $(Qua_i$  : Quality ;  $Cos_i$ : Cost;  $LT_i$  : Lead Time of enterprise Process  $i$ .
- $(Rea_i$  : Reactivity;  $Pro_i$  : Pro-activity) of enterprise Process  $i$ .
- $(Stan_i$  : Standardization;  $RR_i$  : Resource Redundancy ;  $Inn_i$  : Innovation ;  $Fle_i$  : Flexibility) of enterprise Process  $i$ .
- $t$ : time corresponding to the state evaluation time.

### 3.2.3. ENTERPRISE STATE EVALUATION

Once the enterprise state is formalised, it is important to be able to correctly evaluate each performance indicator. This is based on the previously built performance indicator trees and needs to be able:

- To evaluate the leaf performance indicators.
- To propagate the performance evaluation from the leaves to the roots of the performance trees.

The leaf indicators are first qualitatively evaluated, by an expert if necessary, within a qualitative scale having five levels ranging from very bad (--) to excellent (++) . Then this evaluation is translated quantitatively into a normalised interval between 0 and 1, where each qualitative level corresponds to an interval having 0.2 width.

A performance indicator tree can be seen as a multicriterion system where each indicator node is the result of the aggregation of several "sub"-indicators (Figure 6). The impact of each sub-indicator can be modulated using weighted coefficients. A classical method, i.e. the Analytic Hierarchy Process (A.H.P.) (Saaty 1980), has been used to rigorously estimate these weights. It is simple, widely used and permits detection of inconsistencies during the evaluation process. It can be expended using expert questionings. The end each performance tree branch is evaluated to estimate (in percentage) the bottom-up influence of a performance indicator. Low level indicators are directly evaluated from the real situation. Then, for each performance indicator tree, indicator values are aggregated from the leaf indicators to the top level performance indicators according to their related weighted influence. Finally, since all the performance

indicators are evaluated, it is then possible to estimate the enterprise state for any enterprise state definition.

Since it is possible to identify, for a change method, the impact performance indicators and their corresponding magnitude, the new enterprise state may be estimated and a change trajectory can gradually be built.

However, evaluation of the final enterprise state from the expected strategic objectives remains a difficult task that was not tackled in the present work. Here it is assumed that the final performance level is set by experts. This final state will only be better, into the proposed quantitative scale, than the initial state.

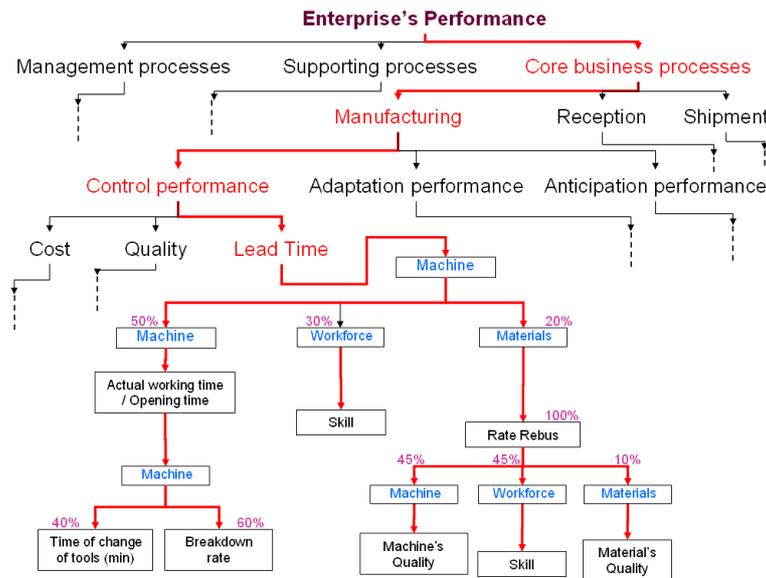


Figure 6: An example of a performance indicator tree

### 3.3. OPERATIONAL METHOD MODELLING FRAMEWORK

An operational method is defined here as a method allowing simultaneous improvement of one or several enterprise performance indicators, i.e. enabling the company to change from a given state to another one in which the global performance will be better according to the final target state.

This mainly concerns production management, resource management and training approaches, as summarized in Table 2.

6 Sigma	Business Process Reengineering	Training
Human resource management	SMED	Customer Relationship Management
KAIZEN	KANBAN	Reducing waste of products and services, costs and timeframes
Lean Manufacturing	PDCA	Poka Yoke
Integrate ERP	5S	JIT
MRP	TQM	Improve internal communication
Toyota Production System	JIT	Total Predictive Maintenance

Table 2: Examples of operational methods

About 30 change methods were studied in the manufacturing enterprise context. Handling and computing their impact on global performance, along with constraints under which they can be applied are dealt with via the model presented in the next section.

A method can be defined according to a reference model highlighting the three dimensions summarised in Figure 7:

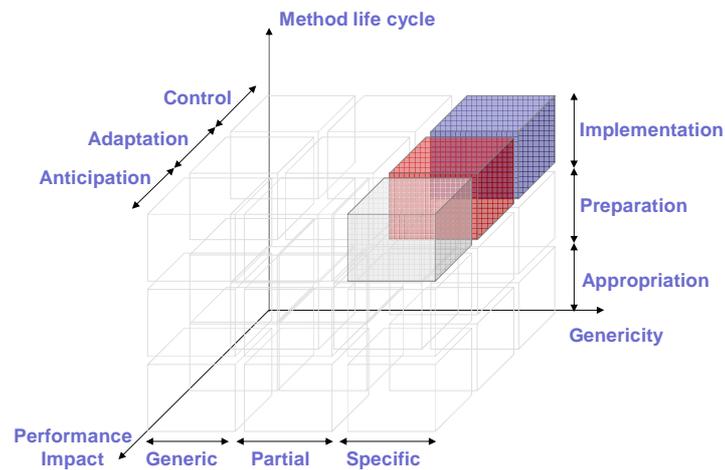


Figure 7: Reference model for change method modelling

- Genericity dimension:** this defines the advantages and uses of the approach according to the type of enterprise and its production management system. This dimension is split into three classes of operational methods. The generic class indicates the approach can be applied without any specialisation in the company. On the contrary, the levels partially and specifically indicate that the use of the given operational method may respect some constraints regarding the company profile, organisation, functioning modes, and so on. For example, some operational methods such as Just In Time or Lean Manufacturing can be considered as production philosophies and thus as generic. However, Kanban or SMED may be considered as specific due to their relevance when applied only to improve flows and machines in manufacturing processes.
- Life cycle dimension:** this allows us to determine the different phases to be respected for each operational method when a stakeholder deploys it in the company. This dimension is split up into three phases. Appropriation allows stakeholders in the company to apply the method autonomously. Indeed, this can require training periods and awareness of stakeholders and teams or pilot projects to test before implementing the method. The preparation phase allows us to determine what is necessary to plan, check and manage before the implementation phase, which concerns the application (corresponding to the do phase) of the method in the industrial setting. This dimension allows us to structure the different operational methods and reveals eventual links or dependencies between different methods. For example, applying the JIT production philosophy leads to the implementation of other approaches such as training and awareness, FMEA and SMED and finally a Kanban system as proposed in Figure 8.

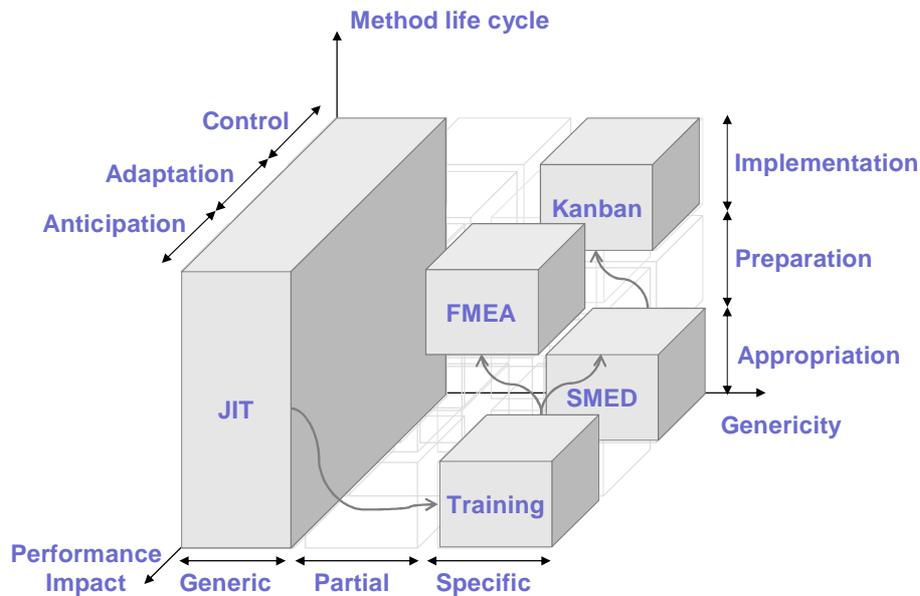


Figure 8: Example of a method life cycle

- Performance impact dimension:** this describes the potential impact of the operational method on the performance indicators. An operational method impacts only tree leaf indicators. As proposed by the performance indicator tree model presented earlier, this dimension is split up into control, adaptation and anticipation. Specific operational methods are the only ones that can impact performance indicators. Moreover, they only impact the indicator leaves of the performance indicator trees. If a specific operational method was considered to impact high level performance indicators, it would consequently impact the following sub-indicators (performance indicator sub-trees) down to the leaves. So, the choice to only impact performance indicator tree leaves avoid the decomposition of its influence through the performance tree. Then, close to the tree leaves, few change methods will impact an indicator but there will be a controlled impact on the performance level. Conversely, far from the leaves, many change methods will certainly impact it, thus generating many possible change projects for the enterprise. Consequently, the choice between controlling the impact of performance indicators and the number of usable change methods can guide users in determining the granularity of the lowest performance indicator level concluding the decomposition process of strategic objectives.

This reference model has to be updated and eventually enhanced by an expert for each company in order to adapt the proposed life cycle of a method to a given company. However, trajectories of the change process are based on the use of several operational methods that can then be implemented in parallel or sequentially. A set of rules, called eligibility constraints, thus had to be defined.

### 3.4. HOW TO BUILD A CHANGE TRAJECTORY?

At this point, on the one hand, a formulation of the state of the enterprise is proposed. It defines the current performance of the enterprise, and evaluates the final performance (potentially corresponding to several final states) the enterprise has to achieve to meet the strategic objectives. On the other hand, a generic framework is proposed to model and characterize an operational change method that outlines its associated life cycle and performance impact. How can these aspects be connected to build change trajectories?

#### 3.4.1. CHANGE TRAJECTORY DEFINITION AND MODEL

The enterprise trajectory concept, or more generally organisational trajectory concept, can be described as a set of event-based transitions between various stabilised situations or configurations (Mintzberg et al. 1999) of a company. Usually enterprise change management is based on the change scenario concept. It is adopted to implement a comparative study between several change alternatives, from an initial starting

situation towards a set of targeted and expected configurations. The modelling scenarios can consider a model of transition between configurations (Mintzberg et al. 1999), different change crisis classes (Grenier 1972) and change factors for enterprise networks (Burlat et al. 2002). In engineering sciences, the scenario concept has been used to manage information system changes (Carvalho 2002) (Chapron 2006). (Malhene 2000) uses the GIM-GRAI approach (Roboam 1993) to develop action plans (change scenario) to build enterprise trajectories consisting of operational change methods.

In the current work, an enterprise trajectory is characterized by its initial state (the current enterprise performance) and its final state (one of the expected enterprise performances deduced from the strategic objectives). A state corresponds to a stable enterprise configuration and has an occurrence date. An enterprise trajectory has a corresponding estimated time and cost. Inside a trajectory, the enterprise evolves from state to state following the application of operational change methods. The switch between two states is called a change phase. The problem is now to identify relevant change methods that can be consistently applied (considering previous changes, resource availability and enterprise characteristics) from a given state.

### 3.4.2. ELIGIBILITY RULES FOR OPERATIONAL METHODS

An eligibility rule qualifies the use of an operational method. It has to be checked to determine whether an operational method can be applied at a given time (from a given change trajectory state) in the enterprise. An eligibility rule thus has to take different characteristics into account concerning the timeframe, resource availability and skills, the nature and strategy of the company, etc.

Two types of rules have thus been defined. Static rules are not time dependent and they have to be checked at the beginning of the proposed project. They depend essentially on the company's objectives, organisation and production typology, as presented in the following paragraphs.

- **Static rule:** a method is eligible if it positively impacts one or several of the company's performance objectives corresponding to an improvement.
- **Static rule:** the company's organisation, as described by (Mintzberg 1982), implies that numerous methods cannot be applied for a given company's organisation class (simple structure, machine bureaucracy, professional bureaucracy, divisionalized form, adhocracy). For example, in the case of a service provider, it would be difficult to use a method such as Kanban without adapting and globally rethinking the method.
- **Static rule:** in the same way, following the manufacturing typology proposed by (Woodward, 65) (mass production lines, production unit, etc.), several methods are not relevant (Sieberborn 2005). For example, in an automotive production line, it would be hard to apply a SMED approach without a performance loss during the SMED implementation.

In contrast, dynamic rules depend on the project change pattern and on the time. They have to be checked throughout the project.

- **Dynamic rules:** they essentially concern the method implementation phase in the company and then the impact of constraints induced by each method on other ones in terms of:
  - Life cycle: in a change trajectory the cycle appropriation, preparation and implementation, and their corresponding methods must be followed,
  - Sequence: a method cannot be reused in a change trajectory,
  - Behaviour: consequently to the previous rule, a generic method cannot be unfolded if one of its internal method has been used before,
  - Parallelism: a method cannot be implemented in same time with itself.
  - Resources allocation: methods using the same resources cannot be parallelised.

## 4. THE APPROACH SUPPORT TOOL TO PROVIDE ASSISTANCE FOR TRAJECTORY BUILDING AND ANALYSIS

All steps of the proposed approach have been implemented in a software environment. This part presents its main components and functionalities.

#### 4.1. FUNCTIONAL ARCHITECTURE OF THE APPROACH SUPPORT SOFTWARE

The software environment is presented in Figure 9. It can be divided into two main parts.

The first one consists of a set of tools for building the different databases used to construct the change trajectories. The manager must describe the enterprise, whereas the experts must describe and analyze the change methods. Finally, experts and enterprise workers must collaborate to construct the enterprise performance indicator systems.

The second one concerns the change trajectory building process. It allows the manager to convert his strategic objectives into operational ones and then to define the expected final state. Using this latter information and the previous databases, possible change trajectories can be built using the Generator of Enterprise Trajectories (GET) software.

Communications between these two parts are achieved using neutral XML format data files.

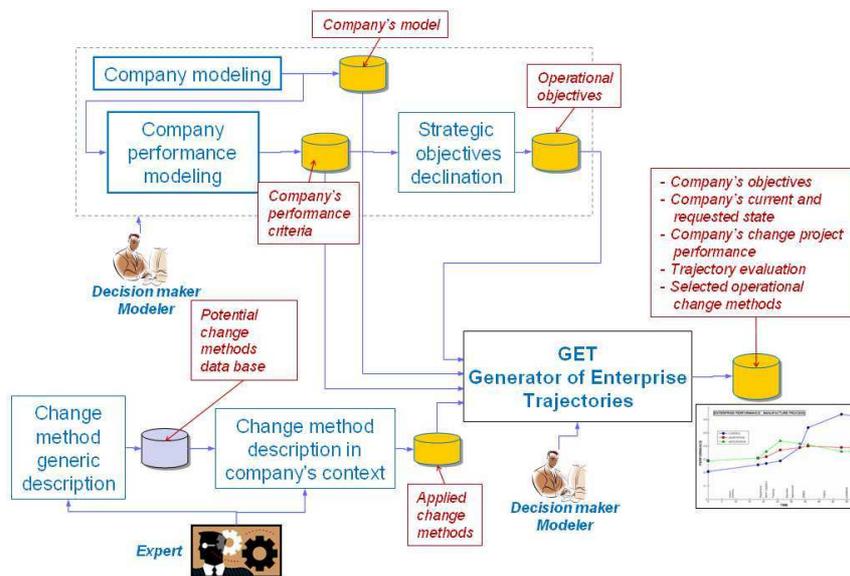


Figure 9: Software functional architecture

#### 4.2. DEVELOPED MODELLING TOOLS

Prior to the development of the different modelling tools, all of the concepts and relations needed for the proposed approach have been described using meta-modelling with GME (Generic Modelling Environment) software. This tool is a reusable framework for creating domain-specific design environments. A meta-model specifies a domain modelling language which, in turn, is used to specify models in the particular domain. It enables users to verify the consistency of the concepts and constraints. Furthermore, it facilitates the creation of the user interface for the different models.

A unified meta-model in UML has been defined upon which the proposed approach is based (Benzaid 2007). This meta-model describes a company as a system and integrates different enterprise modelling languages, i.e. some already existing and some created via the study. Different parts of this unified meta-model have been described and refined to obtain the following modelling tool interfaces that facilitate the user's modelling work:

- Enterprise description via mission, program (enterprise processes), scenario, resources, organization and configuration views editors.
- Generic change method description editor. The generated database describes all the modelled change methods but the name of the impacted performance indicator remains generic and is not evaluated.

- The change method evaluation tools automatically identify the relevant change methods for an enterprise using static rules. It also allows the expert to specify the real name and impacted value of performance indicators.
- Enterprise process performance tree editor.
- Editor for strategic objective decomposition.

These different tools generate databases to supporting the construction of change trajectories using the Generator of Enterprise Trajectories.

### ***4.3. GET: THE GENERATOR OF ENTERPRISE TRAJECTORIES***

This part of the software environment has been implemented using Matlab<sup>®</sup> code. With this choice, a C-like programming language can be used, and it facilitates the development of users' interfaces with graphics. The development of users' interfaces and of an engine to enable the construction of change trajectories represents about 70 000 lines of C-like code.

Presently 33 of the 72 proposed generic change methods have been described. This concerns well known methods like 5S, SMED, FMEA, KANBAN, JIT, etc., but also includes more basic methods concerning worker motivation, personal training, personal recruitment, machine changes, etc..

Moreover, several useful functionalities have been implemented in GET software to control change trajectory construction and facilitate the user decision making process:

- Final performance state definition. The expected value of all relevant indicators can be easily defined. User chosen indicators must also be monitored along change trajectories.
- A flexible user control interface enables users to set the trajectory generation halt conditions (performance conditions must be fulfilled) and to monitor the trajectory construction mechanisms (present state, change method currently used, etc.).
- Change trajectory visualization for all monitored indicators.
- Change trajectory sorting facilities (solution, no solution, cost or time oriented) to facilitate decision-making.

Once the enterprise description is concluded (enterprise processes, performance indicator definition and evaluation and performance tree construction). Based on the definition of a considered enterprise state, the GET software explores the different possible change trajectories to reach an expected final state within the time and cost constraints. The construction task uses the available operational change method database and, in each intermediate state, respects the dynamic eligibility rules.

An example of change trajectory generation is detailed hereafter for a medium-scale enterprise.

## **5. ILLUSTRATION: APPROACH AND TOOL APPLICATION**

### ***5.1. ENTERPRISE PRESENTATION AND PERFORMANCE OBJECTIVES***

The studied enterprise is inspired from a ball bearing and roller production company named SCR (Société Cévenole de Roulements). It produces ball bearings and rollers using average batch production. It has a staff of about 200 people. The firm is organised at three industrial sites. A headquarters site where the top management, human resource management and research and development service are located. This site plans the production of the two other sites remotely located more than 50 km from each other. Production site A is in charge of producing standardised products. Production site B is in charge of producing special products. The global enterprise organisation can be decomposed into nine main enterprise processes:

- **Management processes:** "Define the enterprise strategy" and "Find ball bearing orders" including marketing activities.
- **Core business processes:** "Develop new products", "Produce ball bearings" and "Deliver produced orders".

- **Support processes:** "Plan and manage resources", "Stock up raw materials", "Manage new industrial process", "Equipment maintenance" for production machines and logistic issues.

The implemented strategic objective considered in this paper is the following. It is necessary to “*Enhance the autonomy level of production site B by allowing internal production planning, to drastically reduce the production timeframes and stock levels which represent an important part of the production costs for the SCR Company*”. This must be achieved within less than 6 years and this must cost less than 100 k€.

## 5.2. ENTERPRISE STATE FORMALISATION

Applying the like-Ecograi top-down technique for decomposition of the previously proposed strategic objectives allows identification of 49 linked performance indicators within the performance indicator trees. These indicators are classified in the following table (Table 3).

<i>Class of performance indicator</i>	<i>Number of identified indicators</i>
Stock of products	8
Stock of semi-finished products	8
Production lead time	8
Design timeframe for new products	1
Supply timeframe	6
Supply flexibility	6
Failure rate	4
Machine breakdown time	4
Tool change time	4

Table 3: Classification of performance indicators linked with the strategic objectives

All of the identified indicators belong to the "Product ball bearings" enterprise process. Besides these indicators, it is important to consider the global (control, adaptation, anticipation) performance indicators of the studied process. Then, finally, the generic formulation of the enterprise state for the current strategic objectives consist of 58 performance indicators.

In the following, just the most representative indicators will be presented to clarify the explanation. Moreover, a global evaluation of the control, adaptation and anticipation performance was performed by aggregating the performance indicators belonging to each of these dimensions using a simple mathematical mean.

The initial state was assessed according to an evaluation of the performance indicator tree leaves. These values have been set by experts. Considering the "Product ball bearings" process, for the triplet (control, adaptation, anticipation), the corresponding initial values are equal to (0.21, 0.29, 0.28).

For the final expected state, since the initial state was rather poor, the experts propose to attempt to reach a level of above 0.5 for each of the 49 identified performance indicators and for the global control dimension.

## 5.3. CHANGE TRAJECTORY: RESULTS AND ANALYSIS

For the studied strategic objectives, with the current initial state and change method database, 38 change trajectories meeting the preset final objectives and constraints were identified. Only the best one is discussed hereafter. Moreover, each figure represents the pattern of a given performance indicator (from 0 "very poor", to 1 "excellent") versus the project time explained in months. The change methods used are shown horizontally.

The best trajectory consists of the following change method sequence:

- Best information feedback to and between operators.
- Negotiate with suppliers to obtain best flexibility and price.
- Operator training on new production methods, maintenance or design techniques.
- Machine adjustment for better operational performance.
- Application of the SMED method at site B.
- Application of FMEA method at site B.
- KANBAN integration.

Figure 10 shows the performance indicator patterns: Failure rate, Machine breakdown time, Supplier flexibility, Product stock, and an overall project period of 50 months (more than 4 years). The corresponding estimated cost is approximately 50 k€ for the actual change method characterization. Each performance indicator clearly reaches a level of above 0.5.

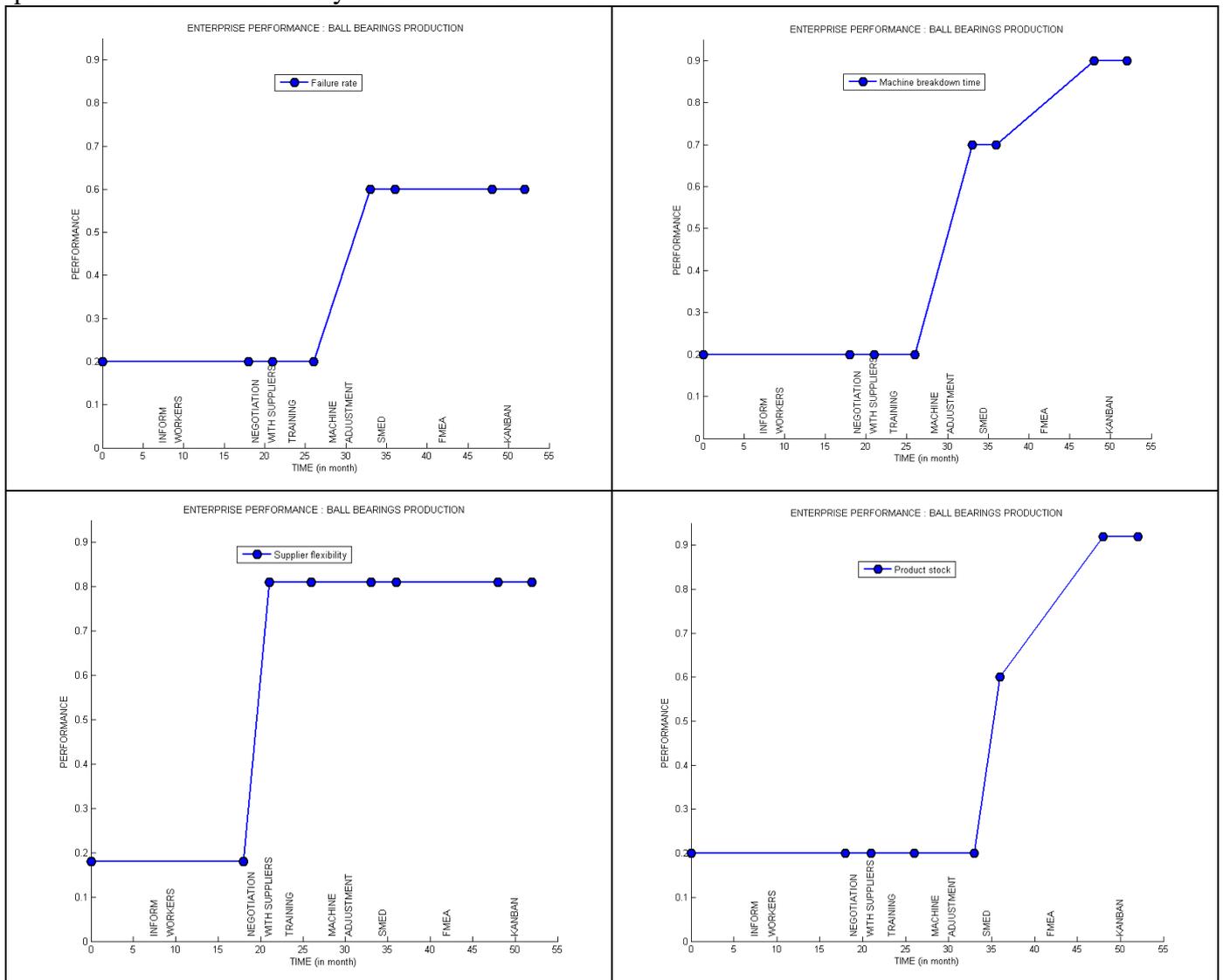


Figure 10: Example of performance indicator change

It interesting interesting to monitor variations in the control, adaptation and change performance viewpoints for the "Ball bearings product" process. Figure 11 shows that the control performance increases in significantly for the trajectory and reaches a value of 0.63, which corresponds to a qualitatively "good" level. Note, however, that the adaptation and anticipation viewpoints also remained practically constant and under the acceptable level.

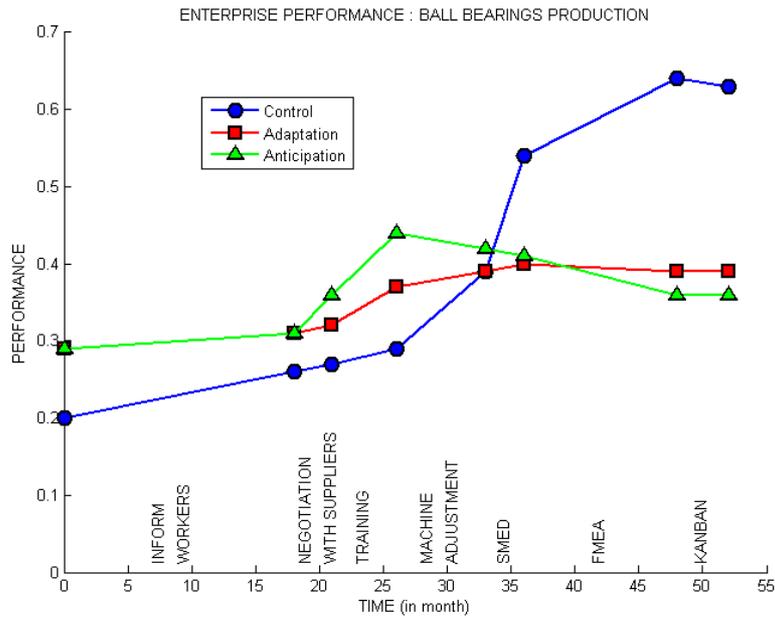


Figure 11. variations in the global performance viewpoints

For example to understand these poor results for the anticipation viewpoint, the variations in the "Reactivity" and "Workers stress" performance indicators can be analysed. In Figure 12, a decrease in Reactivity is noted despite application of the SMED and AMDEC methods. In fact, a Just In Time policy is a good approach to improve control performance. However, without security stock, this policy fragilizes the process reactivity since a machine breakdown will stop the production. The final Kanban integration would theoretically improve the process reactivity by increasing the quality of operator communications. However, the Kanban integration would also drastically increase the operator stress levels (Figure 12), thus diminishing the beneficial effects.

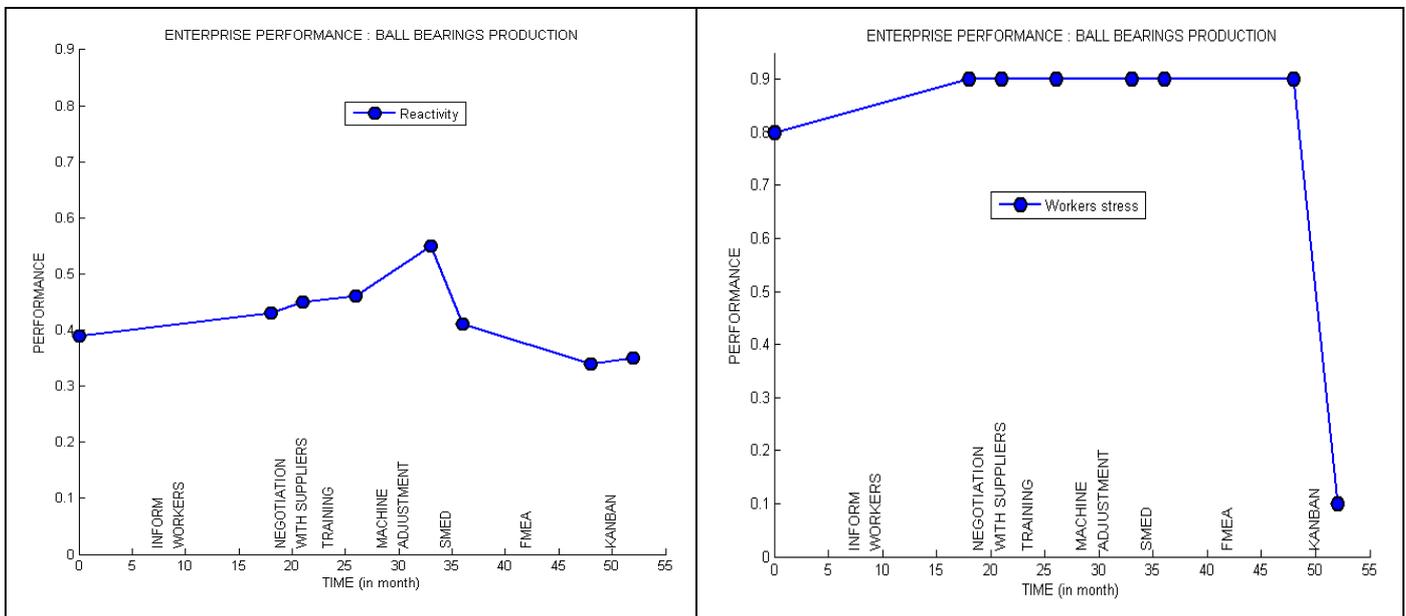


Figure 12: Variations in the "Reactivity" and "Workers stress" performance indicators

## 6. CONCLUSION AND PROSPECTS

In this paper, the problem of the construction of enterprise change trajectories has been tackled. On the one hand, this issue has been largely studied in the management sciences but only from the limited standpoint of "Why an enterprise must change". On the other hand, the engineering sciences focus

essentially on "How an enterprise can change", thus defining many enterprise change methods. From an industrial viewpoint, it appears that there is presently no integrated approach that can assist decision-makers in controlling the change process, providing enterprise modelling facilities, multidimensional performance handling and decision criteria. This issue has thus seldom been globally discussed.

The proposed research study has been successfully tested on a medium scale manufacturing enterprise benchmark. But many shortcomings opening several research prospects must be considered.

- The efficiency of the proposed approach depends largely of the accuracy of the change method modelling and the performance indicator system. Concerning change method modelling, it is essential to conduct broader ranging studies based on benchmark analysis so as to more precisely identify the impacted performance indicators and the value of the corresponding impacts, including the financial cost and time aspects. Concerning the performance indicator system, it would be interesting to improve the performance evaluation quality using like in (Berrah et al. 2008) more efficient aggregation laws based on Choquet integrals (Murofushi and Sugeno 1991).
- One of the main limitations of the present study is the difficulty of evaluating the final state performance. Presently, the impacted performance indicators are identified on from the strategic objectives and their final values are defined by an expert. It is crucial to develop an inference technique to rigorously identify all final states that will help to achieve the strategic objectives. The same performance indicators are involved, but different evaluation combinations must certainly be determined. It would certainly increase the amount of possible change trajectories.
- The developed GTE software also has to be improved to deal with large scale problems: It is crucial to drastically reduce the amount of developed change trajectories. In some tests, more than 60000 states and 7000 change trajectories have been produced (including acceptable and unacceptable trajectories) leading to a very high simulation time. The combinational complexity can be controlled by defining more efficient static and dynamic eligibility rules for change methods, and limiting the number of methods that can be jointly implemented.
- Even though the proposed approach presently only concerns continuous change, it is important to more deeply consider the social dimension of change. In the proposed approach, this dimension is only considered in the change method life cycle during the appropriation phase. This phase often includes personal training and change explanation and motivation. However, the impact of personal change resistance must be considered in the performance evaluation process so as to be able to construct more relevant change trajectories.

Defining and controlling change trajectories remain a strategic issue to ensure the continued existence of enterprises. The present work constitutes a first partial answer to some identified industrial needs. Now, it must be validated on real large scale enterprise benchmarks to turn it into a real operational tool.

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