INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'09
24 - 27 AUGUST 2009, STANFORD UNIVERSITY, STANFORD, CA, USA

PERFORMANCE OF THE PROBLEM SOLVING PROCESS IN DESIGN: MEASURE AND IMPACT FACTORS

Nicolas MARANZANA[1], Sébastien DUBOIS, Nathalie GARTISER, Roland DE GUIO, and Emmanuel CAILLAUD[1,2]
(1) INSA Strasbourg - Design Engineering Laboratory
(2) Université de Strasbourg

ABSTRACT
This article focuses on the problem solving process in design. Today, enterprises face an important need of innovation, as they have to regularly propose new products or new services. Design is one of the key activities of enterprises to be innovative, but it is also one of the more difficult activities to manage and especially to appreciate its performance. There exists many tools to evaluate and manage performance in a variety of fields, but the design process is quite poor on this topic. Few tools are proposed to evaluate and manage the performance of the design activity. Some parts of this activity are more or less manageable, but one remains hardly controllable: the problem solving process.
Two parts will be proposed in the article, a first one will propose a set of definitions: definition of the performance, of the enterprise organization, of the design activity and of the role of problem solving in this activity. A second one will focus on the ways to measure and manage the performance of problem solving in design by the proposal of criteria to evaluate it and by the proposal of a set of indicators that impact this performance.

Keywords: performance, problem solving, design, indicators

1 INTRODUCTION
Today's environment imposes to enterprises to be more and more competitive. Due to the decreasing of the products life-cycle, the necessity of innovation becomes essential. The enterprises are thus concerned by performance in any of their activities in order to survive and to make benefits. They are then looking for means to evaluate and manage performance at a global level and also in any of their processes.
This article will mainly focus on a specific process of the enterprises activities: the problem solving process. To be competitive, enterprises have to propose regularly new products or new services; they are thus facing design problems. Design is one of the key activities of enterprises and also one of the more difficult activities to manage. Few tools are proposed to evaluate and manage the performance of the design activity. Some parts of this activity are more or less manageable, but one remains hardly controllable: the problem solving process.
The research about this topic has begun with the publication of a first article about a proposition of a system of indicators to measure performance of problem solving in design.
In this second article two principal parts will be presented:

- A first part of this article will be dedicated to the definitions of the performance and its measurement, the enterprise organization, the design activity and the role of problem solving in this activity.
- A second part will then propose a set of indicators for the performance of problem solving process in design. These indicators will be categorized in two kinds: those to measure the performance and a set of indicators that impact this performance. Criteria to measure will be proposed and a systemic description of the indicators that impact performance will be defined through their interrelations.

2 CONTEXT OF THE STUDY

The objective of this first part is to identify, first, how companies organize themselves to seek the maximal performance. In a second step it is to identify and locate the design activities in the company before ending at a definition of design performance on one particular phase of the design process, namely: problem solving in design.

2.1 Organization of the companies to reach maximal performance

2.1.1 Purpose and organization of the company

A company is an economical and social structure, legally autonomous, operating in an organized way in order to supply goods or services to customers.

To exist, the company has to generate benefits (i.e. achieve a turnover superior to the sum of its costs); one of the best ways to reach this objective is to satisfy the needs of his customers, a goal which is even more difficult to satisfy in a competitive environment.

The performance of a company, and thus its demarcation with the competititors (competitive advantage), results from numerous realized activities; indeed, every activity is going to impact on the company in terms of costs and is going to create a basis for differentiation. Michael Porter proposes to use a fundamental instrument to examine all the activities which are realized by a company as well as their interactions: the value chain [1].

For Porter, the value chain of any company consists of nine categories of core activities which are related to each other (Figure 1); these categories are separated in two groups:

- the primary activities: which imply the physical creation, the sale of the product, its transportation and the after-sales service.
- the support activities: which are support for the main activities.

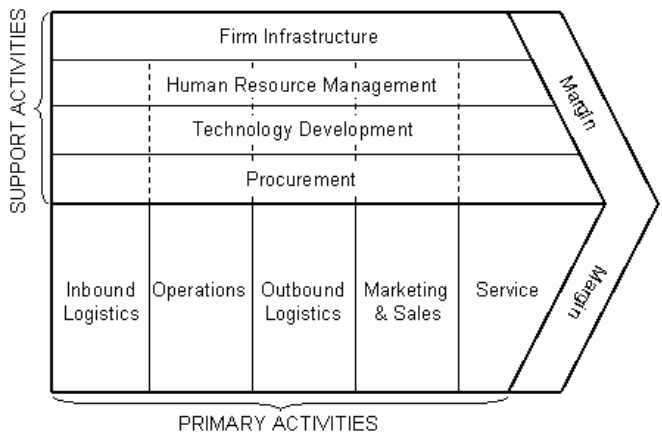

Figure 1. Value Chain [1]

Having defined the various activities in a company, and having for objective to increase the performance, two questions arise: What is performance? How to evaluate the performance?

2.1.2 Companies performance, activities performance

The first question is related with the definition of performance.

Managers, like Lorino, qualify the performance as everything that contribute, for the company, to reach the strategic objectives [2]. The company being essentially an economics purposes institution, one can assume that his performance could be mainly financial. However, other considerations must be taken into account to calculate his global performance; such as its ends, its ecological considerations, its social issues, its jurisdiction. It is thus obvious that the company performance is multidimensional. In figure 2, performance is positioned by Gibert at the centre of a triangle

combining the notions of efficacy, efficiency and relevance [3]. These concepts can be defined in the triptych: objectives, means, results.

- objectives-results axis : defines efficacy as relative to the use of means to obtain given results within the framework of fixed objectives ; i.e. the objectives achievement.
- results-means axis : defines efficiency as the ratio between outputs and total resources deployed in an activity ; i.e. objectives achievement with minimal cost.
- means-objectives axis : defines relevance as the ratio between the means deployed and the objectives to be achieved ; i.e. the good resources allocation.

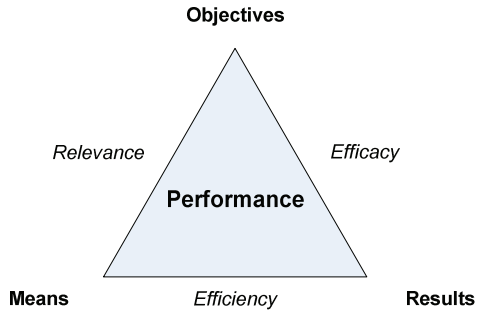

Figure 2. Performance triangle [3]

The company including various activities, it is necessary to evaluate all of them to obtain the global performance of the system. In figure 3, Gartiser et al. propose to expand the Gibert triangle's to all the organization activities to build a global coherence (triptych: ends, culture, structure) [4].

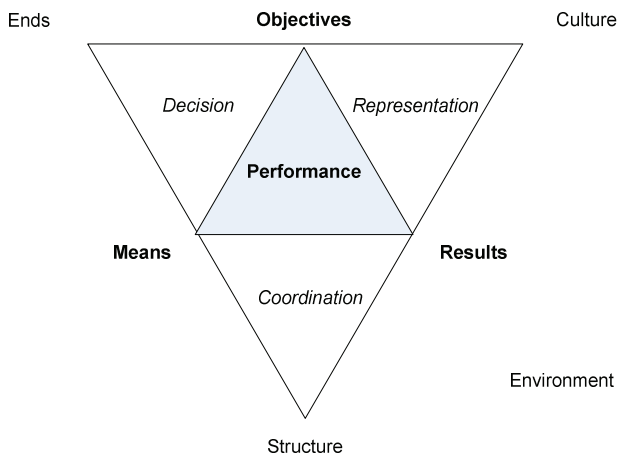

Figure 3. Company general politics [4]

Indeed,

- objectives and results depend of the set of shared values (corporate culture)
- resources allocation and results of the activities depend on the structure of the organization
- objectives and means must be decided in coherence with the ends

Thus, any activities of the company evolve in such a system.

The second question is related to the evaluation of the performance. Performance is considered as a latent variable. A latent variable can be defined as a variable which is not directly observable but not

deducted from one or several variables (indicators) belonging to the field of empirical investigation. It seems thus necessary to define these measure variables allowing to characterize the performance: the performance indicators.

A performance indicator is, as Fortuin defined it, *« a variable indicating the effectiveness and/or the efficiency of a part or whole of the process or system against a given norm/target or plan »* [5, 6]. It must be measurable, observable and controllable all being simple, clear and easy to understand. *« Performance indicators provide management with a tool to compare actual results with a preset target and to measure the extent of any deviation »* [5]. For Lorino [2], the performance indicator can have two roles; help an actor, individual or more generally collective, to drive the course of an action towards the achievement of an objective or to enable it to assess the result.

To have a global vision with the help of indicators, it is common to group them together in a system: a Performance Measurement System. All indicators are defined using multiple criteria, at many levels, and having interactions between them.

For companies, it is interesting to measure the performance at different levels; first of all at the activities level of the company, then indeed, at the global level of this one. Various means or methods exist to evaluate these various performances:

- global (or enterprise) point of view: an economic evaluation via business accounting (turnover, financial reports, ...), and,
- activities point of view: a physical evaluation via performance indicators ; some examples :
  - production activities: Overall Equipment Effectiveness (OEE), scrap rate, input/output ratio, quality, …
  - marketing or commercial activities: market share, assets ratio, capital requirements, self-financing capacities, …
  - after-sales service activities: number of returns, number of customers complaints, …
  - design activities: cost, time, quality, …

We have seen that performance indicators can have two roles: either drive the course of action towards achieving a goal (monitor) or allow to assess the results (measure). In addition, the triangle Gibert has shown us that to be successful it must be effective, efficient and relevant. We notice that some activities have advanced evaluation repository to monitor and measure the activity in all its forms (i.e. production activities), while much less in others (i.e. design activities).
The next part will be focused on the design activity; one supplementary step towards the definition of the design performance.

2.1.3 Design activities and design performance

Porter's value chain will allow us to locate the design activity among the various activities of the company. Relying on this model, the design activity is a part of the support activities which come in support of the primary activities; as well as the basic research, design product or equipment of transformation is more particularly situated in the category *« technology development »* of Porter's model.

What is design?
« Design is an interplay between what we want to achieve and how we want to achieve it » [7]. Two dimensions emerge: design, i.e. the product, the object; and the activities sequence which allow to obtain it, i.e. the design process.

The standard AFNOR[1] (NF X 50-127) proposes the following definition of design: *« a set of processes which transform requirements into specific characteristics or into product, process or system specifications »* [8]. The design process itself is defined, by the same standard, as follows: *« The design process defines step by step defines the product which has to meet the customers needs and waits, by successive choices concerning more and more detailed points ».*

[1] French National Organization for Standardization

Various stages compose the design process, among the different approaches, it is proposed to focus on the following two:
On the one hand the systematic approach of design proposed by Pahl and Beitz [9] represents the design process as a hierarchical succession of stages enabling to converge to the best solution. The decomposition of the process is based on four main stages: clarification of the task, conceptual design, embodiment design and detail design.
On the other hand, the axiomatic approach, resulting from the work of Suh [7, 10] establishes fundamental principles and methods to drive the decision-making during the design process. Suh identifies four domains, differentiating four types of design activities, namely the customer domain, the functional domain, the physical domain and the process domain. He also identifies five relations connecting these domains to each other and forming the design process: know or understand their customer's needs, define the problem they must solve to satisfy the needs, conceptualize the solution through synthesis, perform analysis to optimize the proposed solution and check the resulting design solution to see if it meets the original customer needs.

The objective of the design activity consists on the proposal of an artefact, a product or a process, satisfying determined objectives, in accordance with fixed means.

Now, one question remains: what is design performance? Design performance subject has received some considerable attention over recent years. But there remain particular challenges to be able to define measure and manage performance. It is important to propose a solution for these points to be able to deal with the complexity, the short-time resources, the increasing degree of required novelty, the high competitive environment, … of design activities [11].
Quite as there are two design dimensions, two areas of design performance appears (Figure 4), namely:

- the product performance, which can be characterized by the product value according to the customer expectations, and
- the design process performance which can be defined in consideration of the triptych cost, time and quality

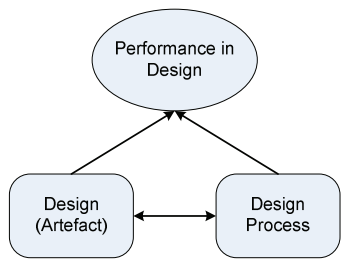

Figure 4. Performance relationships in design [12]

With regard to the objective of the design activity, to be successful, it is necessary to maximize the adequacy between the objectives and the results by minimizing the means.

2.1.4 Problem solving in design and how to evaluate performance of problem solving in design?

The next part of our study is going to concern one of the phases of the design process (*« conceptual design »* phase in the model of Pahl and Beitz, and the relationship *« define the problem they must solve to satisfy the needs »* of the Axiomatic Design Suh): namely the problem solving in design.

What is exactly problem solving in design?
Problem solving in design is characterized by various dimensions. Bonardel [13] presents design problems as being open-ended and ill-defined. Design problems are open-ended as they do not imply one single solution, but a set of solutions satisfying problem constraints. The synthesis of a solution to a given problem is the result of the choice of one satisfying solution among many of possible ones. In addition a problem, in design, is considered ill-defined as the initial formulation of a problem is

incomplete and insufficient to synthesize a solution. Information about the problem to solve is collected during the trials to solve the problem. This notion of open-ended problem can be attached to the one of structurized problem, as defined in [14]. Problem formulation and problem solving are two concomitant processes.
Simon [15] describes the designer activities as a problem forming, finding and solving activity. Designing a new system means building a representation of a concept that could be recognised and validated as a solution. Problem solving can thus be described as the building of a specific representation of the world; it also implies parallel thinking process at different level of abstractions [16]. If trying to model these parallel thinking processes, one can detail the process as an 8 steps process.

- P1 the recognition of an unsatisfactory situation, this is the intention required to initiate a design process
- P2 the clarification of the objectives of the design process, where the unsatisfactory feeling is translated into evaluation criteria
- P3 the clarification of the difficulties why the objectives can not be reach by known ways
- P4 the formulation of the root of problem by the identification of the means for resolution
- P5 the building of a generic concept of solution
- P6 the specification of the generic principle of resolution by the identification of the specific way to implement it
- P7 the evaluation of the gap between the proposed solution and the objectives
- P8 the modification of the initial situation

The role of the problem solving process is to change one situation which is qualified as not satisfying. The problem solving can be model as a process transforming one initial state of the situation, where inconvenience exists, into a final state of the situation, in which the inconvenience does not exist anymore.
The resolution of a problem, in design, is generally a group, a team, work, as many actors act on it. Depending of the company strategy, the methodology used to solve problems will imply only internal actors (actors from the company) or resort to external ones. This decision depend both on the availability of competences in the company and on different strategic decisions (external feedback, crisis resolution …).
One can consider at least three main roles in the problem solving process: the project leader, the animator, and the decision-maker, which are three main actors, but these roles do not necessarily refer to three different persons:

- The project leader is the person in charge of the project, which is responsible of the good advancement of the project
- The animator is the person responsible of the good application of one specific method to identify, formulate and solve the problem.
- The decision-maker is the person (or group of person) in charge of the validation of the strategic orientation for solution research and of the development of defined solutions.

The project will also require other resources, knowledge and competences that will be found either internally either externally.

It is now possible to tackle the evaluation of the performance of problem solving in design.
In the frame of inventive design, problem resolution is the research of unknown solutions. Due to the open-ended and ill-defined characteristics of inventive problems, processes of resolution are still difficult to manage. To build robust process, it is necessary to understand which criteria make a process competitive. However the different criteria able to influence the process are various and seem to operate systemic way, as they do not seem to be independent.

The definition of the performance of problem solving process in design being proposed, the next part will be dedicated to the proposal of a set of indicators to manage this performance. In a first section of part 3, a set of indicators will be presented. In a second section, criteria to measure the performance will be defined. Then a list of indicators which influence this performance will be given, and also their interrelations.

3 SYSTEM OF INDICATORS FOR THE PERFORMANCE IN PROBLEM RESOLUTION IN DESIGN

In this part, the set of indicators, the criteria to measure performance and the list of indicators which influence problem solving performance in design could be considered two ways. On the one hand, from a micro point of view, i.e. at the enterprise level, for the managers, as a way to evaluate and measure its own performance and to have specific indicators to see the evolution of this performance; on the other hand, from a macro point of view, in order to be able to observe and compare different enterprises.

3.1 Presentation of the indicators

As described in previous part, the performance of the problem solving process in design could be qualified by the relevance, the efficiency and the efficacy of this process. In [17] a set of indicators was proposed in order to evaluate the performance for problem solving in design context. It was proposed as a set of elements representative of the performance for problem solving. These indicators have been classified into two sets: indicators to measure the performance and indicators that impact the performance, i.e. indicators that are not directly representative of the performance but which are influent on the performance.

Based on different processes to build a system of indicators, a five step process has been proposed:

- the definition of a strategy and of a set of objectives: the aim is to be able to measure from a certain point of view the result of problem solving process. In an industrial context, it has to be done in accordance with ends, culture, structure and environment of the company. So, the proposed system of measurement has to involve at least those four dimensions.
- the definition of performance inductors is the definition of the set of elements influent on the problem solving process. It is important to notice that the performance inductors work as a system. This system is based on different elements which can have, all together, an impact on performance. The inductors are categorized according to the fact that they refer the definition of the context of the problem and human resources (the animator, the actors of the project, the decision maker and the external resources); the problem resolution process, or the result.
- the definition of performance indicators which are defined to measure the role of the previously defined inductors.
- the synthesis of the indicators in a dashboard, this dashboard is presented in table 1.
- the periodic re-evaluation of the indicators system has to be done to check the exhaustivity and relevancy of the system of indicators.

Table 1. Dashboard of the system of indicators

object	inductor	indicator	measure
animator	evaluate the implication the relationship towards the group	origin	internal external
animator	objective of the study in terms of methodological transfer	goal	training resolution
project actors	evaluate the language gap the cognitive distance	level of training to the method cognitive distance between actors	average number of services
project actors	group composition representativeness	system life cycle experts	yes no
project actors	group inhibitions	hierarchical links	same level, different levels gap
project actors	mobilized resources	number	number
project actors	enterprise culture	age seniority	age average from the group standard deviation
project actors	project priority in the point of view of actors	implication degree	% time allocated to the project / number of projects
decision maker	strategic horizon	term	short-term medium-term long-term
decision maker	implication of the decision-maker	presence in the group	yes no
external resources	mobilized networks	number	internal number external number (group)
process	duration of the project	duration	weeks, months / firm medium length
process	project actors involvement	meetings frequency	/ months
process	group dynamics	exchanges between actors	low, medium, elevated (animator point of view)
process	individual dynamics	activity between sessions	low, medium, elevated (animator point of view)
result	resolution impact	number of solutions	number (short term, medium term)
result	other inputs than resolution	generated knowledge	concepts patents projets kept to be initiated
result	innovative degree area of the solution	firm appropriation	immediately technology transfer research

3.2 Criteria to measure the performance of problem solving activities

The performance has to be representative of the relevance, the efficiency and the efficacy of the process. As defined in part 1:

- the relevance is the ratio between the dedicated means and the objectives,
- the efficacy is the ratio between the results and the objectives,
- the efficiency is the ratio between the results and the dedicated means.

Increasing the performance could be described by the increasing of at least one of the three previous criteria. It means that increasing the performance could be done, either by decreasing the means dedicated the satisfaction of the objectives, either by increasing the adequacy of the results according to the objectives, or by decreasing the dedicated means to obtain the results. The formula (1) defines the performance according to these ratios and the formula (2) defines the performance by the two criteria efficiency and efficacy.

$$Performance = \frac{results / objectives}{dedicated\_means} = \frac{\%\_of\_satisfied\_objectives}{dedicated\_means} \quad (1)$$

$$Performance = \frac{efficacy}{dedicated\_means} = \frac{efficiency}{objectives} \quad (2)$$

The dedicated means could be calculated at micro or at macro level:

- on a micro level, the specific indicator for an enterprise could be evaluated either in Euros, or in man-hours;
- on a macro level, to compare different enterprises, it is necessary to evaluate the value of dedicated means in accordance with the possibilities of the enterprise, thus the dedicated means will be measured as a ratio between real dedicated means and the amount of available means.

3.3 Criteria influencing the performance of problem solving activities

In the table 1, a list of considered parameters has been proposed. To validate the consideration of this list of parameters, the way the considered parameters influence the performance has been studied. Thus it has been established that all those parameters could have influence on the performance, either by influencing directly the efficiency, the efficacy or the relevancy; or by influencing another parameter which one influences one of the three main criteria. A constraint that has been considered in the idenfication of this list is to consider only parameters for which there is no obvious value to be considered. For example, in [17] the parameter priority of the project in regard of strategic point of view was considered, but the authors suppose that a prior project will imply a better allocation of the resources and will enable increasing performance of the process, it has no real interest to consider low priority projects. Then, it means that the considered parameters could lead to contradictions when changing a value of one parameter could imply either increasing the performance or decreasing it, in consideration of the systemic relationships between the parameters.
In the table 2, these contradictions have been listed, by the identification of the impact an evolution of a parameter could have. One can consider two possibilities: a parameter can either impact directly one of the three criteria that influence the performance (efficacy, efficiency or relevance), or it will impact another parameter, making a chain that will finally influence the performance. For example, the parameter *« activity between sessions »* has to be:

- *« Low »* to increase the criterion *« efficiency »*, and
- *« High »* to increase the parameter *« quantity of generated knowledge ».*

Whereas the parameter *« quantity of generated knowledge »* has to be:

- *« Low »* to increase the criterion *« relevancy »*, and
- *« High »* to increase the criterion *« efficiency ».*

If drawing the links between these parameters, as shown on figure 5, one can consider that most of the parameters are considered as roots, some are intermediary ones, and only the efficacy, relevance and efficiency are pits.

Table 2. List of the contradictions that impact performance

The parameter	has to be	to increase the parameter
activity between sessions	low	efficiency
activity between sessions	high	quantity of generated knowledge
firm appropriation of the results	long	efficacy
firm appropriation of the results	immediate	efficiency
implication degree of actors	high	exchanges between actors
implication degree of actors	low	efficiency
implication degree of actors	high	relevancy
cognitive distance between actors	high	efficacy
cognitive distance between actors	low	efficiency
exchanges between actors	high	exchanges between actors
exchanges between actors	high	efficacy
exchanges between actors	low	efficiency
exchanges between actors	high	quantity of generated knowledge
hierarchical links between actors	no	exchanges between actors
hierarchical links between actors	no	exchanges between actors
hierarchical links between actors	yes	number of solutions
hierarchical links between actors	yes	presence of the decision-maker in the group
level of training of actors to the method	high	cognitive distance between actors
level of training of actors to the method	low	efficiency
level of training of actors to the method	low	relevancy
number of actors	low	exchanges between actors
number of actors	low	efficiency
number of actors	high	number of solutions
number of external resources	high	cognitive distance between actors
number of external resources	low	cognitive distance between actors
number of external resources	low	efficiency
number of external resources	high	hierarchical links between actors
number of external resources	high	quantity of generated knowledge
number of solutions	high	efficacy
number of solutions	low	efficiency
objective of the study in terms of methodological transfer	training	cognitive distance between actors
objective of the study in terms of methodological transfer	resolution	efficiency
objective of the study in terms of methodological transfer	training	level of training of actors to the method
origin of the animator	internal	seniority of the actors in enterprise
origin of the animator	external	cognitive distance between actors
origin of the animator	internal	cognitive distance between actors
origin of the animator	external	exchanges between actors
origin of the animator	external	hierarchical links between actors
meetings frequency	high	implication degree of actors
meetings frequency	high	efficiency
meetings frequency	low	relevancy
presence of the decision-maker in the group	present	cognitive distance between actors
presence of the decision-maker in the group	not present	exchanges between actors
presence of the decision-maker in the group	present	efficacy
process duration	short	implication degree of actors
process duration	long	efficacy
process duration	short	efficiency
process duration	long	relevancy
process duration	long	quantity of generated knowledge
quantity of generated knowledge	high	efficiency
quantity of generated knowledge	low	relevancy
system life cycle experts representativeness	yes	efficacy
system life cycle experts representativeness	no	efficiency
system life cycle experts representativeness	no	number of actors
system life cycle experts representativeness	yes	relevancy
seniority of the actors in enterprise	low	cognitive distance between actors
seniority of the actors in enterprise	high	relevancy
term of the project	long	firm appropriation of the results
term of the project	short term	implication degree of actors
term of the project	short term	efficiency
term of the project	long	quantity of generated knowledge

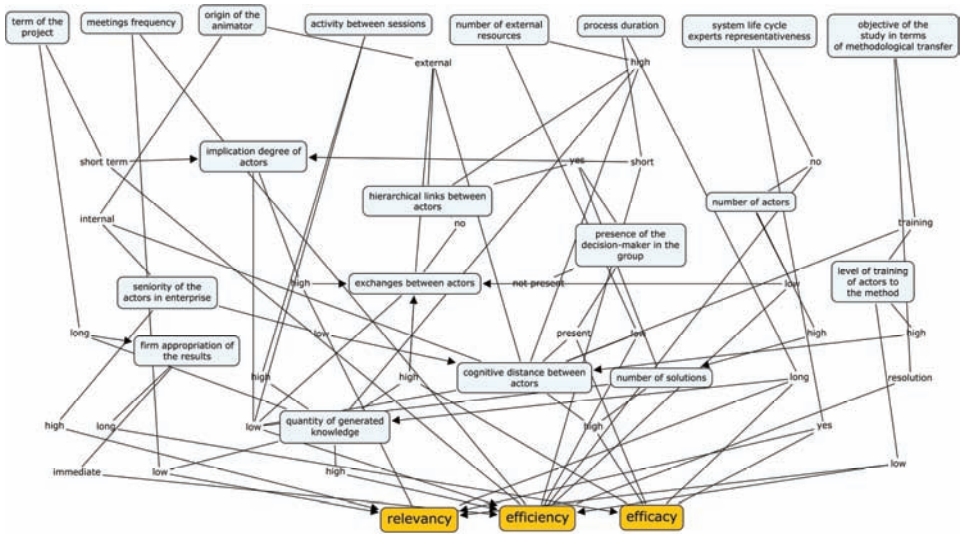

Figure 5. Interrelations between the dashboard parameters

These interrelations put the emphasis on the proposed systemic approach for the performance management of the problem solving process. These interrelations have been defined on the basis of expertise, they are only empirical hypothesis. The objective now is to validate these links, both on the existence of the links and on the exhaustivity of the representation.

4 CONCLUSION

This article is focused on the presentation of the definitions, on the proposal of criteria to measure performance and on the definition of a set of indicators to manage this performance. As already precised this set of indicators and their interrelations are empirical data. One of the first activity will now be to validate these data. A collection of case study has been initiated to reach this goal. This database is not large enough to be representative, and so has not been presented in this article.

The validation process is a two-step process: validation of the identified links between the considered indicators, and validation of the exhaustivity and relevance of the set of indicators, to ensure that this set enable the representation of any situation.

The objective is to be able to understand how to act on the problem solving process to make it more performant. The full term objective is to enable to manage the activity of problem solving, with a global enterprise point of view. Being performant on the problem solving process means enabling the enterprise to be globally performant.

Thus this approach could also be enriched by the consideration of other activities and the links with existing activities performance measurement tools will have to be considered.

One of the obvious considerations is that proposing such a dashboard to consider the performance will impact the perception of the actors of innovation on innovation. The nature and the degree of this impact will also have to be evaluated. One of the risks is that such indicators lead to a kind of formalisation of the process of problem resolution, and so some people could oppose formalisation and creativity. But methods issued from TRIZ [18], for example, have demonstrated that having a formalised method could in fact increase inventiveness.

REFERENCES

[1] Porter, M.E. Competitive Advantage: Creating and Sustaining Superior Performance. (Free Press, 1998).

[2] Lorino, P. Méthodes et pratiques de la performance. (Editions d'Organisation, Paris, 2003).

[3] Gibert, P. Le contrôle de gestion dans les organisations publiques. (Editions d'Organisation, Paris, 1980).
[4] Gartiser, N., Lerch, C. and Lutz, P. Appréhender la dynamique d'évolution des organisations. Vers une opérationalisation des modèles de Mintzberg. XIII ème Conférence Internationale de Management Stratégique, Normandie-Vallée de Seine, France, 2004.
[5] Fortuin, L. Performance indicators - Why, where and how? European Journal of Operational Research, 1988, 34(1), 1-9.
[6] Lohman, C., Fortuin, L. and Wouters, M. Designing a performance measurement system: A case study. European Journal of Operational Research, 2004, 156(2), 267-286.
[7] Suh, N.P. Axiomatic design : Advances and applications. (Oxford University Press, New York, 2001).
[8] AFNOR. FD X50-127 : Management de la conception - Processus d'optimisation et d'innovation. 2002.
[9] Pahl, G. and Beitz, W. Engineering Design: a systematic approach. (Springer, New York, 1996).
[10] Suh, N.P. The Principles of Design. (Oxford University Press, New York, 1990).
[11] Hicks, B.J., Culley, S.J., McAlpine, H.C. and McMahon, C.A. The fundamentals of an intelligent design observatory for researching the impact of tools, teams and technologies on information use and design performance. Internationel Conference on Engineering Design (ICED'07) Paris, France, 2007.
[12] O'Donnell, F.J. and Duffy, A.H.B. Design Performance. (Springer, 2005).
[13] Bonardel, N. Towards understanding and supporting creativity in design: analogies in a constrained cognitive environment. Knowledge-Based Systems, 2000, 13, 505-513.
[14] Simon, H.A. The structure of ill-structured problems. Artificial Intelligence, 1973, 4, 181-201.
[15] Simon, H.A. Problem Forming, Problem Finding, and Problem Solving. 1st International Congress on Planning and Design TheoryBoston, USA, 1987.
[16] Kaposi, A. and Myers, M. Systems for All. (Imperial College Press, Singapore, 2001).
[17] Maranzana, N., Dubois, S., Gartiser, N. and Caillaud, E. Proposal of a system of indicators to measure performance of problem solving process in design. International Design Conference - Design'08 Dubrovnik, Croatia, 2008.
[18] Silverstein, D., DeCarlo, N. and Slocum, M.S. Insourcing Innovation: How to Achieve Competitive Excellence Using TRIZ. (Auerbach Publications, 2007).

Contact: Nicolas MARANZANA
INSA Strasbourg Graduate School of Science and Technology
Design Engineering Laboratory (LGECO)
24 boulevard de la Victoire
67084 Strasbourg Cedex
France
Phone: +33 (0)3 88 14 47 00
Fax: +33 (0)3 88 14 47 99
E-mail: nicolas.maranzana@insa-strasbourg.fr
URL: http://www.insa-strasbourg.fr