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THE COMPETENCY-DECISION LINK IN DESIGN PROCESSES

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Abstract

The aim of this paper is to present a new formulation of optimisation problem related to decision-making during design processes. In fact, usually we built objective function based on product and process aspects neglecting the human aspects. With this work we start a new thinking way that allows us to model competency as a non-classical resource entity, which evolves during the design processes and evolve differently according to contacts with other competencies. Our purpose is to defend the thesis, which claims that human considerations should be of interest during the next decade for the design community. After presenting the context we considered for this problem we would report the results from the bibliography and related works. The third section is focused on the description of a case study that gives the different aspects of this problem. In the following section we claim that it is possible to build an objective function that describes a decision-making problem taking into account some aspects of competencies. A discussion section follows in order to promote this new reflection.

Key words: *Human aspects, Competency, Design Process, Optimization, decision-making.*

1. Introduction

The continuous evolution of competition on markets and the increasing acceleration of technologies put new challenges in the scientific community as well for universities as manufacturers. Although industrial objectives seem to remain the same, expressed under the shape of optimization of quality-cost-delay triangle, the complexity of industrial questions has been increasing during the last decade. Ten years ago it was still possible to answer these objectives by a local modeling sub-systems (such as organization of production's tasks or still minimization of raw material consumption). Now this optimization of sub-systems arbitrarily compartmentalized is not sufficient any more to increase the industrial global performance. One can again say that competitive advantage in such situations is not certain.

So among techniques used to look for better configurations, optimization is for several years in the point of methods stake in work. This was often checked by the obligation to formalize completely problems. Nonetheless, the necessity of bringing in more and more numerous variables and different mathematical forms are increasing. The mathematical writing of associated problems becomes laborious and often goes out of the field in which methods were developed. This evolution obliges us to work without any theoretical safety notably on the existence of an optimum.
In this article we claim that it is possible to make new investigations by taking into account parameters studied in scientific domains, a long time out of reach of the engineer researches.

However these parameters model one or several particular characteristics of actors in the decision-making process.
In this article we observe practices in a medium-sized company. This observation underlines how decision-maker take into account the competency dimension to optimize design process.
Of course we need to clarify that the concept of competence. It is not a classical resource and cannot be so modeled in the same way. Indeed, competence is not an object; it exists only by action. This entity can make sense only some times during a process. It can be in constant evolution, and depends of the environment. Considered within the collectivity, adding competencies can form a particular competence or even can form a non-competence. Two questions arise then: how to characterize the competence variable? How to measure it so as to integrate it into a calculable function? The objective our search presented in the lines that follow is to bring lightings on these questions.

2. Related Works

2.1 The introduction of competence in design process

Mastering the design process represents a major element of firm's global performance. Walsh and Roy demonstrated that companies presenting the better indicators of design show the strongest rates of return on investment and the best performances on export [29]. In the electronics field, Reinertsen [24] studied laser printers design and estimated the impact of various factors on the profit accumulated during the product life cycle. This study states that a 6 months delay in the design phase of the product leads the strongest negative impact on profits: - 31,5 % (while an increase of 30 % of the design cost reduces profit only by 2,3 %).

More recently in the United States, the "Manufacturing Vision Group" (around thirty universities and managers of large companies) analyzed about twenty projects of conception. The main conclusion of this group is that one of the success keys of a design process lies in the learning process. "*Without exception the most successful projects were those in that the teams of conception operated in a context of learning. On the other hand, the less successful projects took place in an environment which did not grant any importance for learning* "[19].

Actually, this analysis leads us to the cognitive approach of design process widely developed by Dixon for whom " *design theory is simply leaves of has greater study of cognitive process* " [21]. For Dixon, researches should to bring us to study the effects of the various levels of designers' knowledge on the design process and in its final result.
Indeed, in spite of the integration of computational models and artificial intelligence aiming to help decision process, the designer remains the key character of design process, as well in the phase of " problem forming " than in that of " problem solving "

In the cognitive approach, the designers are going to mobilize mental models [20], formed by theoretical knowledge enriched by the accumulation of experiences. These mental models are mobilized to build the conceptual design of the invention [23] and enriched by the learning.

Knowledge and practical experiences are regrouped under the generic name of competence. It is this term of competence that we shall keep in the rest of the paper.
In this definition the word competence characterizes:
- A combination of know-how, understanding capacity, capacity to combine resources among which knowledge, information, networks,
- Contextualized in a field of constraints and determined resources (financial, human, technical, logistic, temporal resources),
- Confirmed by an external referent,
- Finalized by a goal.

Besides competence presents the following characteristics:
- It can be individual or collective,
- It is dynamic and the variability depends on the process of learning
- It is measurable through the practices of evaluation of competence that we present part 2.

Because the designer competencies represent a key element of design process, the question that we put is: how can we introduce competence in design optimization?

2.2 The competence's measure

To ask the question of the competence's measure brings us to the field of employees' evaluation. The evaluation of the employees is not a new question: the first formalized system of annual appreciation was implemented 1912 in New York in the Lord & Taylor department stores [27]. Then evaluation of employees has developed within the Taylor's organization. At that time the question was to appreciate the employees capacity to work according to the "one best way " [26]. In the 1940' s, researches on organization conducted to wonder about the role of group's dynamics, communication and relational ship [25]. Then evaluation evolved from control of results to a dialogue aiming to improve the global performances of employees. In the 1960' s, Management by objectives (DPO) launched by Peter Drucker, simplified the devices of evaluation by centering them on the negotiation and the appreciation of objectives.

Since, the evaluation of the staff widely spread. Already in 1988, 90 % of American companies used it [22].
Throughout XXth century, the evaluation practices evolved a lot, combining quantitative control of results made by the supervisor and a dialogue on the global performance and the competence of the employees made by different people. This evolution appears in the language: the term *evaluation* was progressively replaced by the term *appraisal*.

On the other hand, these changes materialize also in the methods: the employee is not appreciated only by his supervisor but also by his peers, his internal customers, his subordinates and he gives his own auto-appreciation (360° feed back method).
Appreciation stand on a combination of indicators: results, competence, behavior and potential of learning. This appreciation is built with three types of references: *"objectives", "competence",* and "*behavior"*. The use of references illustrates how culture and company's values impact the appraisal process. Thus the competence measure seems totally contextualized.

It is necessary to note that the appreciation of results can involve individual objectives or contributory objectives to the group's performance.
Appreciation of competence and learning potential asks sometimes the question of the subjectivity. In this domain, the method of critical events allows to limit subjectivity. The method of critical events consists in identifying over the last 12 months the events that impacted for the performance according to the evaluated employee, the customers and the supervisor. The analysis of these events permits to isolate the competence that brought problems solutions [28].

Evaluation can lead to a unique indicator, a score. A unique score is necessary when evaluation is used for salary's increase. Very often, evaluation is established in a multi criteria approach that builds a individual competence cartography. The question is then how to translate competence into evaluation criteria.
For design process, competencies' cartography may be established on the following graph from which we can also calculate a global score. This score will then let us integrate competence as a variable of the design process

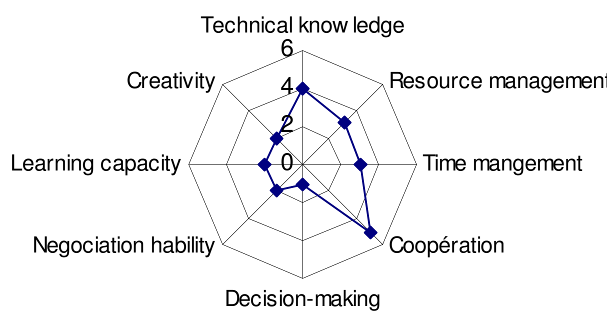

Figure 1: Translation of design competency into evaluation criteria.

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We can also measure the distance between required competence and available competence. This distance may explain dysfunctions in design process and permit simulation of future dysfunctions in design process.

3. Case study

Created in 1980, the studied company works mainly with the following technologies: mechanics, hydraulics, pneumatics, electronics, optics and computer, to conceive and to produce products in the following domains: metrology, industrial data processing and microprocessors, test and control systems.

This company counts 100 employees with a very strong technical culture of innovation and quality.

The company is facing an environment with two constraints:

- On one hand, as in most sectors, it encounters strong economic pressures for cost and delay reduction
- And on the other hand, the design projects treat with rapidly changing technologies and present an insignificant recurring part.

As a consequence, the only way to maintain a competitiveness combining costs reduction and innovation, tends to optimize the design process.
To optimize the design process, competence has been introduced for several years into the reflection of the decision makers with the view to optimize two levels of decision: decisions concerning actors' choice and decisions concerning technological choices.
This integration of competence in the process optimization stands on two fundamental elements: capitalization by memorization of the past process and evaluation of competence.

Capitalization on past design processes concerns as well errors and dysfunctions as individual and collective decision-making.
This capitalization brings at the same moment a better understanding of decision-making in design process and a better visibility of competence. Indeed, the capitalization brings a cartography of competence developed in the company.

Actually the principal point of capitalization arises from the knowledge of knowledge that is a genealogy of the designers' experiences and knowledge. This genealogy of competence grows rich of the evaluation of the designers, which on an annual basis, are appreciated on their results, their professional practice, their behaviors and their contribution to the global performance. This appreciation gives place to a multi-criterion score.
The characterization and the measure of the competence are introduced systematically into the search for optimization of the design process. This consideration remains for the moment not modeled.
Then we decider to answer the question of the introduction the competence's score in a function of optimization. This is the objective of the following section.

4. Proposition of a framework

Consider a given Design Department dealing with n projects $P_i, i = 1,\dots n$ each of these projects P_i is characterized by a starting and due date dented respectively by t_i^s and t_i^e.
Each project needs a certain amount of competencies denoted by $C_i, i = 1,\dots 8$ and refer to the competencies defined in figure (1). The projects are also characterized by the nature of the required competencies. In other words, this set of competencies may be divided into two subsets: A subset of the competencies that considers the "innovation" aspect of the project, and the second

subset that point to the "process mastering" aspect of the project. Consequently, one can understand that we are dealing with two kinds of projects: innovative and routine.
We then can write:

$$P_i \to \{\ N_1^i, \ldots N_8^i\ i = 1, \ldots n;\ j \in [1,5]\ \}$$

Where N_j^i denotes then the level of competency j needed for the project P_i.

Any organization possesses a set of competencies distributed among the whole actors. Let's denote by $V_{i,j}^k$ a person i with the level N_j^k for the competency C_k. The whole set of a company competencies is defined by:

$$V = \{V_{i,j}^k\ ; i = 1, \ldots q\ ; j \in [0,5]; k \in [1,8]\}$$

Since the projects do not start at the same date, one have to consider that each actor is involved within some or all of the actual projects. Let un define this working charge by: H_i and define the limit that we cannot exceed in term of actor charge by $\tilde{H}$.

Let P_r be the project to be studied. We have to answer to the following questions: Is it possible to treat it? Do we have enough resources to manage it within the time constraints?

Trying to answer these questions, leads to the formulation of this problem as an optimization problem.
i.e: minimize the difference between what is required in an ideal world and what is available. For P_r:

$$P_r \to \{\ N_1^r, \ldots N_8^r\ \}$$

and consequently, the objective function may be written as:

$$\Phi_1 = \underset{a}{Min} \sum_{i=1}^{8} \left| N_i^r - N_i^a \right|$$

where a denotes the index of the available competency.
However, this mean square difference has a bias effect. Indeed, this optimization problem should give mean results without considering the project nature. Thus, one has to consider functions that express this need.
ie:

$$\Phi_2 = \begin{cases} \underset{a}{Min} \sum_{i=1}^{8} \left[N_i^r - N_i^a \right]^2 \\ \underset{a}{Max} \sum_{i=1}^{4} \left[N_i^r - N_i^a \right]^2 - \sum_{i=5}^{8} \left[N_i^r - N_i^a \right]^2 \end{cases}$$

While studying this case, we have observed that there is another bias due to the fact that the squared difference consider the gap between two competencies as equal for either a required competency is greater or less that the available one. We have so to express this constraint by a penalty function and obtain the following optimization problem:

$$\Phi_2 = \begin{cases} \underset{a}{Min} \sum_{i=1}^{8} \left[N_i^r - N_i^a \right]^2 + \beta \sum_{i=1}^{8} \left[N_i^r - N_i^a \right]_+^2 \\ \alpha(\underset{a}{Max} \sum_{i=1}^{4} \left[N_i^r - N_i^a \right]^2 - \sum_{i=5}^{8} \left[N_i^r - N_i^a \right]^2 \ ) \end{cases}$$

Finally, while we want to answer to the question: " If I cannot manage it now, when can I do it?", we have to introduce in the optimization problem the date associated with a competency. To do it simply, we make the choice to consider only the starting dates and the finishing dates of the projects as possible time steps.

This is done by introducing the repartition of the actor charge during the project processes. Consequently, we obtain our final formulation of this cost function Φ_4:

$$\Phi_2 = \begin{cases} \underset{a}{Min} \sum_{i=1}^{8} \left[N_i^r - N_i^a \right]^2 + \beta \sum_{i=1}^{8} \left[N_i^r - N_i^a \right]_+^2 + \gamma \sum_{i=1}^{q} \left[H_i - \tilde{H} \right]_+^2 \\ \alpha(\underset{a}{Max} \sum_{i=1}^{4} \left[N_i^r - N_i^a \right]^2 - \sum_{i=5}^{8} \left[N_i^r - N_i^a \right]^2 \ ) \end{cases}$$

where: $\alpha, \beta >> 1$ and $\gamma < \alpha, \beta$.
This cost function is non convex, one can use appropriate algorithm such as simulated annealing to reach optimal minimum. If $X^{(k)}$ denotes the solution at the iteration k of the algorithm, then $X^{(k+1)}$ is a function of N_i^a, that is: $X^{(k+1)} = X^{(k)} + f(t_i^s, t_i^e, V_{i,j}^K, H_j, \tilde{H})$. Where $f(\bullet)$ is any arbitrary displacement function.

5. Discussion

Optimization relies on a mathematical formulation of the objective function. This objective function should be elaborated with caution. In fact the computation of the mean error hides the real needs of the decision maker. We have to go further and interact with non-expressed rules that guide decision-making. This conducted us to add a specific penalization function.
This framework constitutes a decision support for different level of decisions.

It allows the analysis of the acceptability of a design project in terms of company's competencies. The models build comparisons between required and available competences. For each design process the design department can measure the risk inherent to a lack of competencies. This evaluation gives support for the decision to launch or postpone the project.

The framework is a support for the optimization of competencies allocation for a given design process. For each design process or project the human resource is optimally allocated.

It guides upgrading of competencies by training. By analyzing the optimization results the design manager or project manager may decide to ask for special training in order to improve a given competency for a given actor.

The framework may also supply elements for out sourcing decision. The analysis of optimization results may also conduct to the decision of subcontracting the parts of the design process for which competencies are not available in the firm. The design team will find required competencies within partners or subcontractors.

6. Conclusion

This study emerges from industrial practices. We tried to model intuitive practices usually developed in management fields. This work stands on the thinking that our design community could benefit from viewpoints coming from management sciences. In fact, optimization of design process and resource allocation has to handle new parameters such as behavior and potential of the human resource. In this paper we consider individual competencies. We take into account two sets of competencies: those required for innovative design process and those necessary for routine design process. In fact we consider that design project distinguish different levels of innovativeness and various levels of process mastering. We treated this question as an optimization problem. However, usually optimization considers the final numerical result as the solution of the decision problem. We suggest in this study to analyze intermediate and final results.

Integrating a collective approach of competencies should continue this work. In fact collective competence is not the sum of individual competence.
Concrete results are being studied in companies at this moment.

7. References

[1] Marko Torkkeli and Markku Tuominen, The contribution of technology selection to core competencies, International Journal of Production Economics, Volume 77, Issue 3, 11 June 2002, Pages 271-284.

[2] Salem Lakhal, Alain Martel, Ossama Kettani and Muhittin Oral, On the optimization of supply chain networking decisions, European Journal of Operational Research, Volume 129, Issue 2, 1 March 2001, Pages 259-270.

[3] Ewan Oiry and Alain d' Iribarne, The notion of competence: Continuities and changes in relation to the notion of qualifications., Sociologie du Travail, Volume 43, Issue 1, January-March 2001, Pages 49-66.

[4] Ting-Yu Chen, Using competence sets to analyze the consumer decision problem, European Journal of Operational Research, Volume 128, Issue 1, 1 January 2001, Pages 98-118.

[5] David Carson and Audrey Gilmore, SME marketing management competencies, International Business Review, Volume 9, Issue 3, June 2000, Pages 363-382.

[6] Jacob M. Rose and Christopher J. Wolfe, The effects of system design alternatives on the acquisition of tax knowledge from a computerized tax decision aid, Accounting, Organizations and Society, Volume 25, Issue 3, April 2000, Pages 285-306.

[7] Jian-Ming Li, Chin-I Chiang and Po-Lung Yu, Optimal multiple stage expansion of competence set, European Journal of Operational Research, Volume 120, Issue 3, 1 February 2000, Pages 511-524.

[8] Mansour Javidan, Core Competence: What Does it Mean in Practice?, Long Range Planning, Volume 31, Issue 1, February 1998, Pages 60-71.

[9] Lloyd E. Brotman, William P. Liberi and Karol M. Wasylyshyn, Executive Coaching: The Need for Standards of Competence, Consulting Psychology Journal: Practice and Research, Volume 50, Issue 1, Winter 1998, Pages 40-46.

[10] Henk A. Post, Building a Strategy on Competences, Long Range Planning, Volume 30, Issue 5, October 1997, Pages 733-740.

[11] Tony Grundy, Human Resource Management--a Strategic Approach, Long Range Planning, Volume 30, Issue 4, August 1997, Pages 474-475.

[12] Nigel Petts, Building Growth on Core Competences--a Practical Approach, Long Range Planning, Volume 30, Issue 4, August 1997, Page 478.

[13] Aldo Franco Dragoni, Distributed decision support systems under limited degrees of competence: A simulation study, Decision Support Systems, Volume 20, Issue 1, May 1997, Pages 17-34.

[14] Thomas Grisso and Paul S. Appelbaum, Values and Limits of the MacArthur Treatment Competence Study, Psychology, Public Policy, and Law, Volume 2, Issue 1, March 1996, Pages 167-181.

[15] Susan E. Murphy, Dewey Blyth and Fred E. Fiedler, Cognitive resource theory and the utilization of the leader' s and group members' technical competence, The Leadership Quarterly, Volume 3, Issue 3, Autumn 1992, Pages 237-255.

[16] Po L. YuDazhi Zhang, A foundation for competence set analysis, Mathematical Social Sciences, Volume 20, Issue 3, December 1990, Pages 251-299.

[17] S. E. M. EverwijnJ. B. R. GasperszTh. H. HomanR. J. Reuland, Commitment and competence in solving work performance problems, European Management Journal, Volume 8, Issue 4, December 1990, Pages 541-551.

[18] Guillermo OwenBernard GrofmanScott L. Feld, Proving a distribution-free generalization of the Condorcet Jury Theorem, Mathematical Social Sciences, Volume 17, Issue 1, February 1989, Pages 1-16.

[19] Bowen HK, Clark KB, Hollowy CA, “Regaining The lead in Manufacturing”, Harward Business Review, Sep-Oct 1994, pp 108-130

[20] Carlson D, Gorman B, « Understanding Invention as a Cognitive Process », Social Studies of Science, vol 20, n°3 1990

[21] Dixon J. « On research Methodology Towards a Scientific Theory of Engineering Design", AI-EDAM, Academic Press, vol 1, n°3, pp 145-156,1987

[22] Locker A, Tell K, "Appraisal Trends", Personnel, September 1988, pp 139-147

[23] Pahl G., Beitz W, Engineering Design, London Design Council,1984

[24] Reinertsen DG , The Search for New Product Killer, Electronic Business, July1983, pp 62-66

[25] Roethlisberger FJ, Dickson WJ, Management and the Worker, Harvard Cambridge1939

[26] Taylor FW. , La Direction Scientifique des entreprises, Dunod 1957, Paris

[27] Trepo G, « Introduction and diffusion of management tools", European Management Journal, vol 5, n°4 Winter 1987

[28] Trepo G., Estellat N, Oiry E. L'appréciation du personnel, Mirage ou Oasis ?, Editions d'Organisation, Paris 2002

[29] Walsh W, Roy R, " The Design as Gatekeeper in Manufacturing Industry", Design Studies, vol 6, n°4,1985

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