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Structuring knowledge in inventive design of complex problems

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Abstract

Current Research and Development activities in enterprises built on research findings of design engineering studies postulate that complex systems need to be decomposed for an -a priori- useful complexity reduction. However, this assumption and some engaged work have not answered to the problematic of linking problem formulation, problem resolving stages and existing knowledge. In response to this concern, we postulate that in a context aiming at assuming inventive challenges, specific knowledge decomposition and structuring has to be organized for an appropriate and efficient problem solving process to be engaged. This article focuses in particular on the gathering stage of a generic framework for knowledge representation and reorganization. These representations use several grounding hypothesis of TRIZ and OTSM-TRIZ combined with acknowledged rules of artificial intelligence and graph theory. Furthermore, a procedure aiming at conducting the gathering stage of a complex situation's investigation is described.

Keywords: Inventive design; Knowledge; Complex problem; R&D activities;

1. Introduction

Today's industrial world is facing with new challenges regarding its capacity to respond to society's evolution. To assume the dramatic acceleration of new artefacts' demand, Research and Development activities need to evolve from a capacity to answer quality needs to a capacity to answer innovation problematic. The concerns of quality era were mostly directed towards optimizing existing knowledge, means and procedures within the enterprise. To face with what is imposed now as being innovation era; R&D departments are requested to important changes driven mostly by two new problematics:

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- Dealing with the increasing complexity of industrial situation (both coming from artefact and organizational complexity);
- Dealing with the search, the forecast and the management of knowledge previously unknown by the enterprise in order to efficiently provoke the birth of innovations.

1.1. About complexity challenges in inventive design

Complexity can be seen as a recurrent topic in contemporary research, mostly oriented towards complexity reduction (Simon 1967) (Suh 2001) in order to reach a level allowing a possible mastering of it while not loosing any precision of the initial situation's description. We will not attempt to provide, in this paper, an additional definition to complexity but simply employ the term when qualifying an engineering situation where the amount of components in a system is important so as the amount of technological fields involved in the problematic situation this system covers.

An important finding that current research in design theories and methodologies is proposing resides in the formalization of computerized logics in order to face with difficulties that complexity brings to R&D activities (Lee, 2003). These researches are mostly oriented towards an exhaustive axiomatisation of engineering attributes (Suh, 2001), thus, encounters difficulties to be applied in complex industrial situations in search of time saving when representing realities. Our research orientations are aiming at proposing a new way of representing knowledge in a context of R&D activities for an efficient evolution of its capacity to assume innovation era's challenges. In the next section we would like to underline the grounding differences between three different typologies of design activities.

Optimizing design

A majority of R&D activities are fulfilling the issue of obtaining the best out of the actual elements known to the company (or its immediate surrounding field of competition). By applying laws of physics, following rules imposed by "six sigma-like" formalism, enterprises are trying to reach an optimum efficiency of the ratio between existing means and expenditures for producing added values. In terms of design, the philosophy of this statement is widely supported by known design approaches and theories and numerous research findings.

Inventive design

Sometimes associated with creative design or breakthrough design, it is commonly said about inventive design that the inventiveness of the activity rely mostly on the creative capacity of individuals. Thus, research efforts supporting this vision are mostly oriented towards finding new approach aiming at favouring creativity of designers, based on the assumption that a more creative person will certainly lead to a more inventive design. A counter-hypothesis to this assumption can be the following:

What if creative capacity enhancement would only lead to a more prolific generation of concepts resulting in a more time consuming R&D activity to investigate all proposed possibilities and resulting in efficiency losses?

Our research orientations have taken into consideration these statements and propose the use of a knowledge-oriented mean of driving human creative thinking when in search of inventive design. This knowledge oriented model proposes to monitor a complex situation through specific representation means and by using grounded theories, provoke appropriates R&D decisions and activities resulting in an enhancement of its efficiency. The means of measurement of this efficiency will be discussed in a further section.

From Inventive to Innovative design

The place of inventive design in frame of innovative design is critical to sate. Inventive design is targeting the novelty of a design concept through the fact that new knowledge have been introduced in a solution in order to satisfy inventively (without compromises) driving evaluating parameters of a given R&D activity. The fact that Inventive Design efficiency will have a great chance to participate to the enhancement of Innovative design remains to be proven despite the fact that we can build a positive hypothesis out of it.

Innovative design is commonly stated in relation to a successful society's adoption. Then novelty of the solution proposed by the artefact can be appreciated relatively to a given space of what was previously totally, partially or not done by other artefacts. Our definition of Inventive design enters in contradiction with Innovative design when situations of compromises in existing solutions proposed by a company are successfully adopted by society. As an example, an insulating polyurethane body around a beverage can (in order to preserve coolness) can be recognized as resulting from an innovative design due to its marketing success but in our sense has no inventive contents, thus, cannot result from an inventive design and can simply been obtained using optimization design.

1.2. Knowledge manipulation for driving R&D issues in Inventive Design

Knowledge management appears as a key element of research in innovative challenges for R&D practices' evolution. In frame of this research it is clearly stated that level of understanding vary as knowledge evolve from tacit individual experience to accurately defined data. In our research, we focus on all possible elements to be extracted in an initial statement (knowledge, information and data's) useful for filling the structured domains we have established.

Three stages of Knowledge treatment are distinguished in our approach:

- Gathering: extraction, collect, retrieval of all possible elements from known in order to document the initial statement and start problematic understanding.
- Representing: Appropriate storage, completion and validation/refinement of elements gathered in the previous stage.
- Reorganizing: Graphical reorganization, layout and display of the elements in order to build the appropriate tools to ease R&D decisions.

1.3. Towards a new way of structuring knowledge

Various research findings and theoretical groundings already exist, these findings have been scientifically explored and tested, they becomes grounding elements in our proposed model.

- Graph theory: Graph theory has stated that “A graph is a symbolic representation of a network and of its connectivity. It implies an abstraction of the reality so it can be simplified as a set of linked nodes” (Mineau et Al., 93). In our approach, the axiomatic fundamentals of graph theory will enable computerization of data's (attributes) associated to contradictions in order to ease their graphical representation and manipulations.
- OTSM-TRIZ: What has been published around OTSM constitute the major grounding of our approach. We have learned from OTSM the importance of multi- disciplinary approach and the notion of problem flow in knowledge management (Khomenko et Al., 2006).
- TRIZ: The Theory (Altshuller, 1991) proposes the holistical building of ideal system’s portrait and the solving of contradictions standing on the way its logical evolution. Described by its main axioms (laws of technical system evolution, contradiction, specific conditions), TRIZ is essential to our approach in the sense that contradiction is a mean of expressing a problem through specific formalism allowing targeting an inventive goal. The way knowledge will be formalized allows us to postulate that contradiction formalism will impact significantly on knowledge complexity reduction and ease a clearer general understanding of actors resulting in a more pro-active participation. The axiom of laws of engineering systems evolution will enable us to reorganize and priorize contradictions in the sense that contradictions standing on the way of ideality can be scheduled and their solving appropriate to pursue a specific goal.

2. Key characteristics of our proposed approach

Knowledge useful for an efficient inventive R&D activity's driving are numerous and multi-disciplinary. They appear randomly to designers. Our approach proposes to allocate gathered elements of knowledge at various stage of formulation's clarity in appropriate spaces, all spaces being in relation to others. Organizing relation both with knowledge holders and existing documents in order to optimize gathering stage efficiency and impact on reliability of problem formulation is eased by contradiction formalism. Computerization and manipulation of allocated knowledge is ensured by the formalism of graphs. Finally, we postulate that contributing to the efficiency of R&D's inventive challenges through dynamic problems representation and management will favour innovation strategies in organizations.

2.1. Developing the methodology

As it has been presented in (Cavallucci et Al., 06) four layers of knowledge belonging to four domains is proposed. In order to synthesize the procedure to be applied in the overall approach, we will use a graphical representation and detail its first stage (gathering).

Several definitions needs to be given in order to follow the algorithm presented appendix 1.

Documents: They include all possible written *Elements* where knowledge at different stage of expression can be located. Patents, list of requirements of project and norms are probably dominant in this area but any internal corporate document can also be associated. The objective is to semantically exploit them in order to extract partial data's for contradiction definition's assistance.

Elements: They represent any knowledge, data or information gathered both from documents and knowledge holders.

Processing: This term defines an operative stage of data's extraction from Documents; a text mining procedure is currently in progress for partial contradiction extraction.

Knowledge holders: They represent all possible persons within the area of the company available for questioning sequences operated by the expert. The expectations regarding these persons are of two orders: extracting their tacit knowledge related to the studied subject and transform it into explicit exploitable information (or data's). Using their know-how, conduct with their help reformulations for an appropriate element allocation.

Ontology: A clearly defined ontology needs to be achieved for a proper domain definition of terms and interactions. In our case, this ontology concerns the domain of expression of all terms used in problem formulation and solving of complex engineering situations.

Elements: They define all knowledge, information and data's at various stages of their definition (from totally fuzzy to clearly state).

Eligibility: This operation is enabling to defined weather or not an element is appropriate for allocation in the layers of knowledge. It is a crucial point of the algorithm since depending on the reliability of this operation the overall model of knowledge manipulation and stability is engaged.

Partial Solutions: They represent any existing and known solution (both fully and partially solving a given problem) extracted both from knowledge holders or documents.

2.2. Description of the deployment

Using flowchart formalism, we have drawn an algorithm illustrating the processing of knowledge when in complex inventive problem solving situations (appendix 1). The expert is conducting the deployment of actions. A computerized procedure is under validation for assisting data extraction from documents and the other phases of our approach (representation, reorganization) will be developed in further publications.

The loop expressed in the overall algorithm (new element arrival) concerns the dynamic of the representation, allowing a new element (new patent, new inputs from norms, new technological discovery) to be taken into consideration into the overall framework of representation and iterate the model from Tn to Tn+1.

2.3. Metric of evaluation

In worldwide literature, R&D efficiency is traditionally evaluated through company operating profit in the past years divided by company internally used R&D expenditure in these same years (Naoto, 1991). This evaluation approach is widely accepted through managerial concerns but we would like to setup an "engineering-oriented" mean of evaluation, allowing monitoring the impact of our approach at all levels.

Assuming that we are aiming at improving the reliability of R&D activity, a factor impacting on the emergence of relevant Inventive Solutions should be visible. Thus, we might observe an evolution from a random to a more evenly distributed appearance of Inventive Solutions. Through a better predictability of these emergences, the mastering of Inventive strategies may be improved and it’s organizing more pertinent.

Time saving & cost reduction can also (as a consequence) be measured since more reliable elements are taken into account in R&D activity and less expenditure for dead-end directions will be reduced.

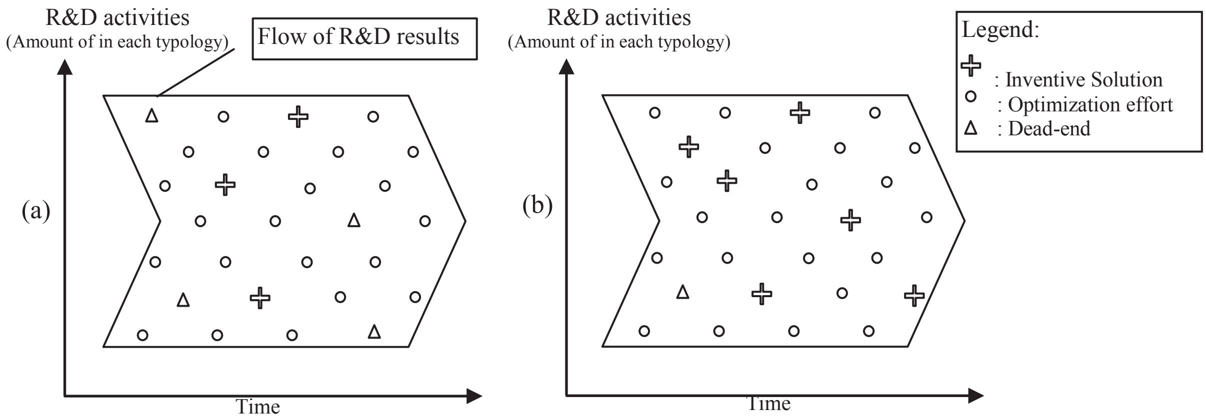

Figure 1: Flow of R&D results in traditional mode (a) and in Inventive mode (b).

3. Example of knowledge gathering: Case study of a Standard Fuel System

3.1. Presentation of the initial situation

Due to ecological constraint, significant changes are forecasted in the design of future cars and European norms have been planned to reduce polluting waste emission; they are referred as Euro0 to Euro5 (Table 1). These norms are specific requirements that automobile designers need to introduce as an element of knowledge in our representation framework (in our case an accurate data).

Norm	Euro 0	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5
Azote oxydes (NOx) [g/KWh]	14,4	8	7	5	3,5	2
Carbon monoxyde [g/KWh]	11,2	4,5	4	2,1	1,5	1,5
Hydrocarbures [g/KWh]	2,4	1,1	1,1	0,66	0,46	0,25
Particles [g/KWh]	-	0,36	0,15	0,1	0,02	0,02
Applied for cars sold in period	1988-92	1993-96	1996-00	2000-04	2005-07	2008-09

Table 1: Extract of the European Norms XX

Fuel systems for automotive applications have risen in complexity in the last decade in integrating a lot of components, and fulfilling a lot of sub-functions (figure 2). One of the sub-problems linked with the R&D activity of Fuel tank is the following: First as hydrocarbures diffuse in polymer material, a protecting layer is added in order to avoid excessive hydrocarbure emission. Then, hydrocarbure emissions are facilitated by any discontinuity in the wall of the plastic shell. Hence, the norms induce strong constrains on the plastic shell manufacturing process: if the shell is made of two glued halves, hydrocarbures will easily diffuse in the glue; on the other side, blowing a fuel system plastic shell is difficult due to the size of such part.

To address this problem, competing area is covered by patents aiming at reducing hydrocarbure emissions. As an example, a method for fixing a component onto a plastic shell is represented (Figure 2). The main problem addressed is hydrocarbure emissions through accessories mounting flanges (electrical connections, venting lines, recirculation to the top of the filling pipe, etc.). A large hole is cutted in the plastic shell to introduce mounting flanges not to damage the molten plastic material but provokes leakage due to seal aging.

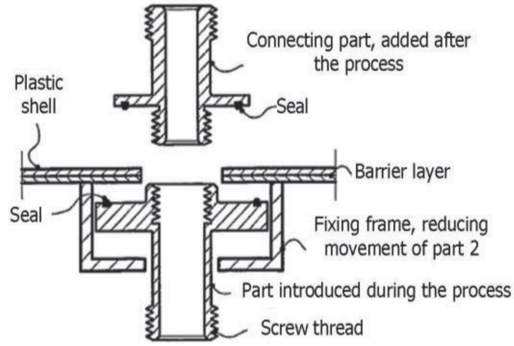

Figure 2: Patent WO 2006/032672

3.2. Exploiting the documents and company's know-how to partially fill the four layers

Figure 3 illustrates the extracted elements from the situation described in the previous section. They have been allocated in the appropriate space in the four domains.

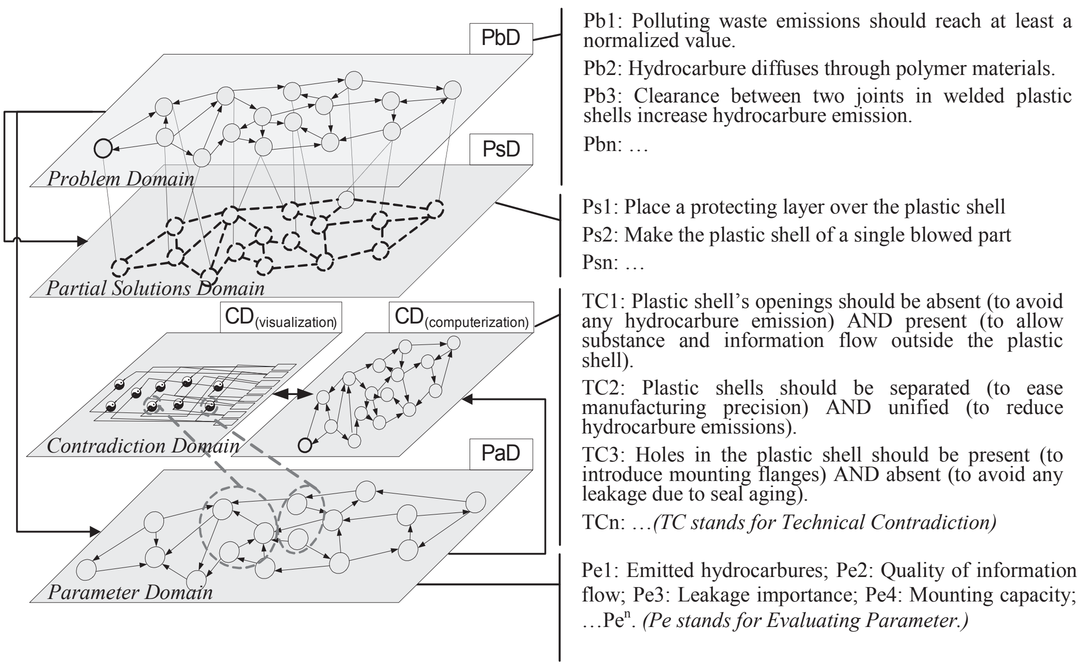

Figure 3: Elements gathered and allocated

4. Discussions

The key points of the benefits of our approach can be expressed through different aspects. First knowledge elicitation (clarity and levers for R&D decisions) is enhanced since we are engaged to evolve from random and intuitive decisions to purposeful orientations of R&D activity (in the context of Inventive design). Second, harmonization of organization' strategy and R&D activities is enhanced through the elicitation of links between engineering parameters and key business drivers of a given market. We also postulate that graphical representations and complexity reduction will lead to a more proactive behaviour from knowledge holders and company's actors to share viewpoints. Thus resulting in a more robust shared model of knowledge representation due to actors' acceptance. Finally, a knowledge storage and representation mean easing (accelerating while increasing pertinence) the teaching to newcomers is essential to company's know-how. This situation will also be useful for holding company's know-how after turnover or key actors.

Limitations and future research of the proposed approach can also be summarized the following way. Redundancies between knowledge need to be observed since they can constitute a useless noise in the accuracy of the representation. To address this problem, tools and methods extracted from Artificial Intelligence are currently investigated and may be partially used. Then, the importance of necessary time to establishing state of the art of a competing area in a specific situation (documents and know-how extraction, analysis and summarizing) is encountering difficulties of acceptance in enterprises. To evolve toward a computer assistance of this stage (resulting in time reduction), some research works related to patents have been achieved by (Cascini, 2004) but needs to be pursued and completed.

Finally, it has been proven that cognitive proximity favors innovation in organizations (Boschma, 2004). Nevertheless, proximities of key actors in worldwide companies is not evident, associating them in a common thinking using accepted and shared models for knowledge representation is part of a difficult but necessary cultural change that logically goes with any paradigm shift in our industries.

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Apendix 1: Gathering stage through basic flowchart diagram