Towards inventive design through management of contradictions

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Abstract

Consumption of innovative products is continuously growing and this has a major impact on industry: the need to rebuild design potential is strongly felt both in terms of human skills and methodological expertise. The question behind the challenges regarding this situation can be summed up as follows: are the tools and methods developed during an era in search of quality optimization still appropriate in the context of the needs of innovation era? Two fundamental aspects make us think this is not the case: the gap between the rate of requests for human creativity and its actual capacity [1]; and the gap between the scopes of knowledge required in view of the level of technical object's complexity and the inherent cognitive abilities of a collective human group within a given organization [2].

In our paper, we would like to introduce that the fundamentals brought by TRIZ (theory of inventive problem solving) [3] and its extension OTSM-TRIZ [4] can become a large part of the answer to this situation. After expressing the limitations of traditional design approaches, two elements will be exposed: the initial mode of representation of the design problem as a net of contradictions and its advantages and the fact that within OTSM-TRIZ, the orientations of the design actions are constructed both in accordance with the laws of engineering system evolution and the specific requirements imposed by the industrial situation. A case study conducted in collaboration with Thales regarding a ground-based radar design will also be partially presented to illustrate practically the efficiency of such a contribution.

Keywords:

TRIZ, OTSM-TRIZ, Inventive design, Complexity, Contradictions, Network

1 INTRODUCTION TO NEW CHALLENGES FOR A RESEARCH IN DESIGN

1.1 The "eras" of industrial challenges

It is universally acknowledged that our industry crossed, over its history, several eras characterized by tendencies [5]. They are also influenced by social evolutions, nature and lead organizations to necessary evolutions [6]. The era which we entered from now on near a decade and that succeeds quality era, is the era of innovation. Our aims in this article are not to define innovation, nor even to give our own definition to it but to contribute to one of its characteristics: the necessity to raise inventiveness of design activities of companies [7].

1.2 Complexification of technical objects

One of the obstacles to design activity towards inventive practices is in our sense linked to modes of representation of technical systems. A large amount of contribution participate in the optimization of its formalism, its computerization, its sequencing but only few become attached to the difficulties of breakthroughs introduction, those which bring important changes in the inventive character of designs results. Besides this, the necessity to manage difficulties is increased when complexification of the technical object is effective [8] [9] [10]. It imposes not only a formalism of representation but also to assist designers by making easier for them the access to knowledge located beyond their fields of competence. There, a paradox of design appears: the mode of representation of technical object must be simple to be understood and managed by designers and complex to be exhaustive in its representation.

1.3 The necessity for modes of representation to evolve

Observing functional analysis with regard to innovation

A large amount of companies are still led to optimize the quality of their products, process and services, task which has already assumed by the era of quality. Under this era, were born an impressive quantity of tools and methods aiming at structuring the nomenclature of objects while beiing easily manageable in quality processes. Functional analysis does not make exception to this and is a flagrant example. This tool has a vocation to give a clear and structured representation of the technical system's functionalities when observing it, inseparable task of the constitution of initial requirements of a design process. But a question that we are tempted to settle is the following: Is functional analysis an instrument adapted to a mode of description which would aim at initiating an inventive step of breakthrough [11], as it is imposed now within innovation era?

Our analysis of expectations of inventive design leads us to express three points expressing that functional analysis may not be ideal when seen as mode of representation of the object in an inventive objective:

- An inventive mode of design imposes to go beyond the need to satisfy customer's requirements but also to verify that the dynamic of chosen evolution is in accordance with laws characterizing the evolution of the technical object [12].
- It is necessary, to bring changes in an object, to formulate and to solve contradictions which stands in the way of his evolution.
- The formulation of a contradiction imposes a system analysis at various levels of observation of the object (Supersystem, System, Subsystems, Elements, Name of the feature, Value). Besides, modes of representation of the complexity of links between these contradictions must also be represented, to lead a consistent management of these contradictions.

The limits of brainstorming regarding complexity

The actual approach which consists in supporting inventive initiatives in a process of design using brainstorming (we shall qualify it as "divergent" at least in its first stage) has as main objective to issue a maximum of ideas so that they constitute a sufficient statistical population allowing to launch successive sorting (here we can speak about convergence) isolating the idea the most in accordance with the initial requirements of the project [13]. The sorting of these ideas are, either simple filters blocking ideas considered harebrained, or filters blocking ideas not allowing to assume data's placed forward in the requirements of the projects. The issue of these successive sorting is to restrict ideas to the most appropriate of them, to prioritize them to have alternatives opportunities of development more or less in rupture with the present state of knowledge of the company. It is then up to the decision-makers to choose the alternative which will be in accordance with their own strategy.

Such process drives to two obvious limits:

- Chosen direction is –*de facto*- led by ideas issued during creative sessions and therefore relies on an unpredictable process of exploitation of knowledge of individuals and at no moments allows us to guarantee that chosen direction is the optimum one.
- The exhaustiveness of the collected ideas relies only on competences and knowledge of individuals having participated in the sessions of creativity. Thus, it is impossible to guarantee that the statistical spectrum of issued ideas contains the one leading to the best possible resolution in the given situation.

We shall therefore sum up this paragraph by this postulate: the implementation of a divergent design process supported by brainstorming and functional analysis does not allow guaranteeing that directions of design are ideal in the sense of inventiveness. Because of this, expenses engaged to iterate on the basis of the unsatisfaction of acquired results (whether it is by prototyping actions and tries, by calculations or R&D) put the firm in a logic of trial and errors, costly for the profitability of its R&D, so as for the man/hours expenses that are engaged.

2 TRIZ, ITS LIMITATIONS AND EXTENSIONS (OTSM-TRIZ)

The theory developed by Altshuller allows treating these problematic partly to design the technical system in accordance with objective laws which govern their evolution, so as to guarantee the workability of the inventive processing of a problem. However, the actual limitations in the evolution of classical TRIZ can be summed up in two ways:

- **The formalization of the problem**: It is necessary to allow designers to represent their problems by reducing risks of forgetting elements of knowledge, and prevent then from errors of representation. So as to allow tools conducting this formalization to manage complex problems representation [14].
- **The instantiation of solution models**: It is necessary to assist the designer, since the problem formulation stage, to objectively build his model of solution by allowing him to access the necessary generic knowledge and the essential elements of an inventive and robust solution [15].

Our contribution is located in the first of these two ways and concerns OTSM-TRIZ developments. OTSM is a Russian acronym of General Theory of Strong Thinking (the adjective « strong » has to be entended here as robustness). The main feature of OTSM is that its system of models, useful for problem solving, does not depend on the area in which the problem arises. OTSM could be considered as an interdisciplinary language for knowledge representation in order to organize the process of solving complicated interdisciplinary problems. Our research proposal aims to create a step allowing the designer to be driven in the formalization of its problems of product/system development, in the management of its complexity and in the choices of directions of resolution to be taken.

2.1 Convergence: a network of contradictions towards a portrait of an ideal solution

All design acts are carried out as cognitive acts encouraging the designer to solve a contradiction introduced by his act. This essential notion in TRIZ stipulates that the contradiction symbolises the obstacle which has to be understood and solved to enable the technical system to evolve in keeping with the laws. While cognitive reflexes often drive designers to a compromise solution, Altshuller purports that compromise does not arise from an inventive approach and that to move in the direction of inventiveness, the designer must refuse compromise despite his psychological inertia to solve the dilemma posed by the contradiction. The level of complexity involved in designing a technical system implies that a network of contradictions should be built up in order to place the designer face to face with the challenges he has to raise.

Then, the contradiction network helps the designer to build a model of the problem in order to reduce its complexity. A set of guiding factors must then be designed for this network to enable the designer's problem-solving actions (or possibly his choices) to be directed towards an inventive approach, bearing in mind the company's strategy problems.

3 DRIVING THE DESIGN ACTIVITY USING A NETWORK OF CONTRADICTIONS

3.1 Network constitution

In this paragraph we offer a method for representation of the complexity of a problem “contradiction oriented”. Most of the representation modes are “functionally oriented” or oriented ”morphology of the object”, but very few provide (when modeling) a clear representation of problems. That's why the model which we offer proposes to carry these essential notions:

- represent an association of parameters linked to the object: as a network;
- provide a representation of links between these parameters: the internal links of this network;
- point out influences of the values of a parameter’s evolution: the nature and the directions these links are taking;
- Facilitate the management of the network (its evolution): the graphical representation (mostly its visual aspect).

Rules concerning its constitution could chain themselves following this pattern:

1. Extract expression of problems from the engineers responsible of the study, by constituting a group including all individuals carrying the knowledge (people from every field concerned by the technical system in question)

2. Isolate, during these expressions, the key words implicating the ontology of the model to be constructed.

3. Clarify the model by completing its form using additional questions aiming at reaching an exhaustive representation

4. Verify the model with the members of the group and improve/correct possible errors/forgotten elements in representation/perception of the problem.

Semantic rules

Some semantic rules must now be established. The diversity of the typology of parameters concerned in the problem representation imposes a consistent ontology in order to represents a parameter so as to carry all elements included in its formulation. The following table specifies the semantic definitions of used terms:

Active parameter	Parameter which provokes possible changes in evolution of its values and whose management remains controlled by designers
Evaluation parameter	Parameter which has values influenced by the result of an evolution of values of one or several active parameters
Influence	Characterize the relating influence of a parameter in comparison with its network
Value (A and opposite of A)	Characterize the state of a parameter in the limit of its values
Element	Part of a decomposition of the studied system having a sense with regard to the key parameters of network
Parameters contradiction	Association of an active parameter, and the couple of evaluation parameters influenced positively by the evolution of its opposite values
Macro-network	Group of contradictions linked between them and covering exhaustively the whole fields implicated in the initially stated problem
micro-network	Reduced group of contradictions restricted and pruned by directives of specific conditions linked to problem
Subsequence	Relative influence between two evaluating parameters leading to the fusion of these last

Table 1: Vocabulary used in the representation

Rules of representation

Modes of presentation must be graphically comprehensive, iterables, instantiables and allow the management of this network. We offer therefore to establish certain rules allowing visualizing the interrelations of contradiction’s belonging to several domains of parameters expressed in a micro-network.

The Yin-Yang symbol (understood here in the sense of its graphical representation) carries, in our approach, the idea of representing a heart of a contradiction, the starting point of the birth of two oppositions (here applied to the parameters of a system) and of their influence on other centers. From these active parameters, and the states of their values, directions are initiated (at the same time positives and negatives) towards other evaluating parameters [16].

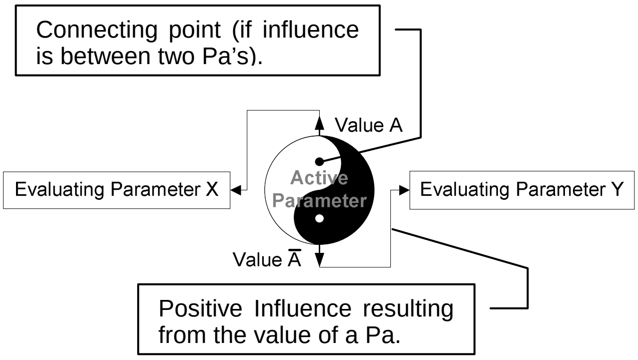

Figure 1: Representation of a Pa and its influences on Pe's

3.2 Driving of a network

To evolve in coherence with the model of convergence proposed by OTSM-TRIZ, we established rules of managing a network of contradictions. These rules have as objective to reduce a macro-network in a micro-network allowing easing a formulation of key problem to be solved. Let's remember that the sense of a "key problem" must be understood here only in the sense of a problem towards which converges mutual interests:

1. The monitoring of specific terms imposed by the situation;

2. The coherence in the evolution of the studied system with the objective laws which this system obeys.

Modes of driving the network are of three types:

Driving oriented "centers of importance": Network reduction passes by the priorisation to the most solicited evaluating parameters; at the same time by the active parameters and by subsequence.

Driving oriented "evolution": The analysis of the logic of systems evolution often reveals obstacles to this evolution. These obstacles, in the preliminary stages of formulation, are still only embryos of contradictions but lead, at the stage of convergence, to focus on parameters resulting from these obstacles.

Driving oriented "resources": The mode of instantiating contradictions states that a list of resources should be established for every contradiction. The resource appearing most often in these lists (the most commonly present in the active parameters) becomes centre of preference. This last is logically carried by an element of the system (more than by the others) and induced therefore to converge on the parameters of action carried by this element.

4 CASE STUDY OF A GROUND-BASED RADAR: THE M3R OF THALÈS

4.1 Summary of M3R's project

Impulsed by DGA, M3R technology (M3R stands for Radar, Mobile, Multifunctional & Modular) acts as preamble in the development of future radars of air defense enlarged to active antenna. They will allow to discern, to follow and to indicate in systems of interception (batteries of missiles) of classical air targets such as planes or drones, but also ballistic missiles. The realization of this demonstrator, M3R served, for one of its sub-problems, frame in the spreading of the contribution offered in this article.

Initial situation shows a group criterions considered important by the responsible of the project and several directions are initiated to collect ideas allowing, case by case, to treat the evoked problems. Our collaborative work aimed at implementing a mode of representation of the situation in order to understand influences of a network of active parameters influencing evaluating parameters. Expected results are to converge towards a physical contradiction in order to proceed to its resolution using a classical problem solving method.)

Illustration 1: Situation of one of the latest radar generation: Master A

4.2 Network of problems representation

After the establishment of a team constituted from the persons possessing the knowledge linked to the study. It was possible to set up, using a synthesis method, their problem in the form of a macro-network (see figure 2). The constitution of this network allowed several reformulations of contradictions; they constituted a determinant factor for the added value of the employed method. These successive reformulations became a guarantee of a good understanding of the situation and provided mutual confidence within the engineers of Thalès to evaluate the relative importance of the challenges of each technical data.

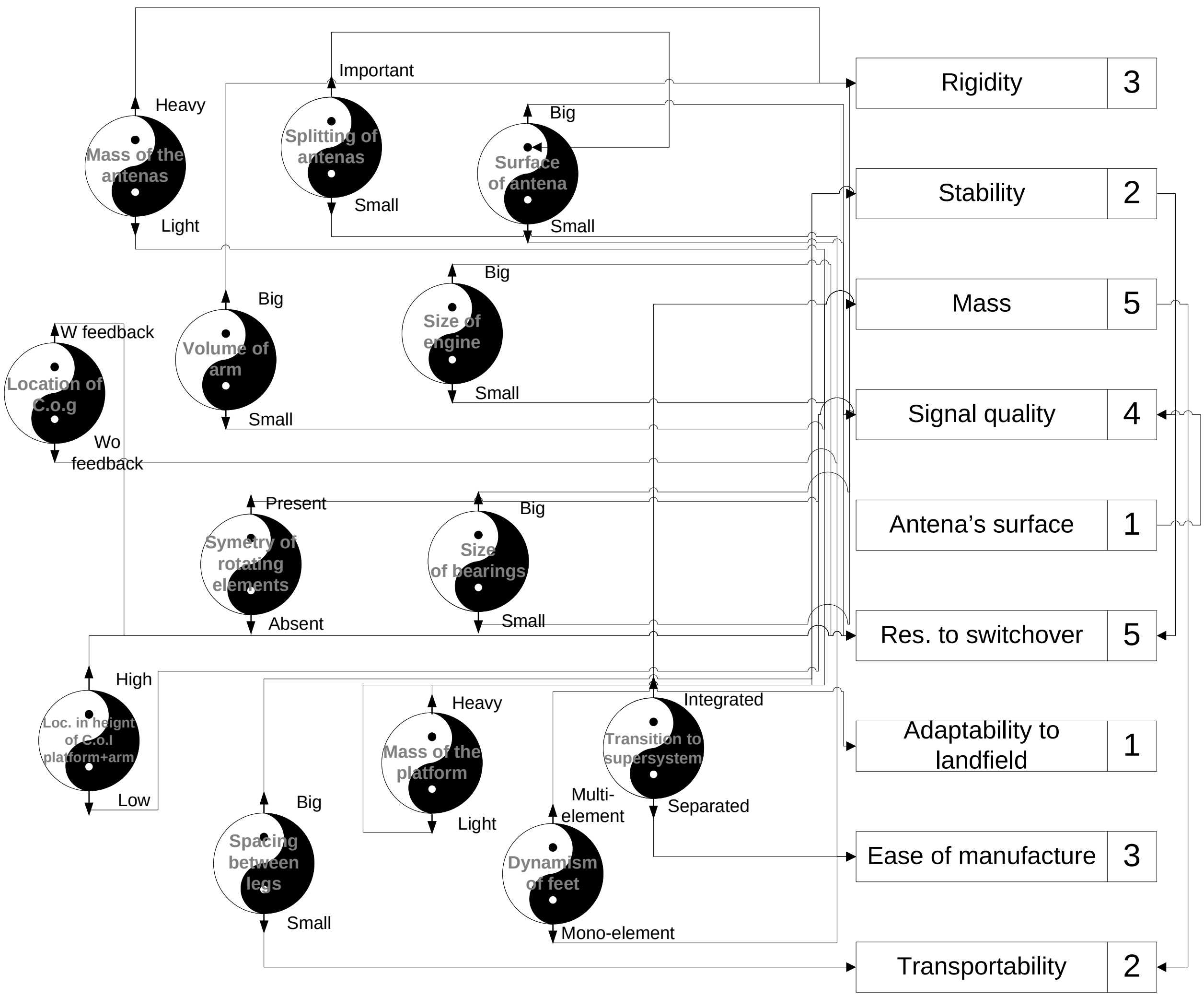

Figure 2: Representation of the macro-network linked to M3R problem

4.3 Used modes of convergence

In our case, the mode of convergence used to deal with this macro-network was by "centre of importance". After a first pruning of this network in eliminating the centers of contradictions implying elements provoking important modifications in the structure of M3R, we managed the rest of the reduction by balancing centers of importance and their subsequences. The result lets appear two contradictions as being the most influencing the problem. These last, were then treated by solving methods of classical TRIZ. Once these main contradictions were brought to evidence, the method allowed us to define two different types of solutions:

- Solutions coming from theTRIZ databases use: for instance the use of a structure in Releau’s triangle alloying better results regarding the compromize between mechanical resistance available space regarding the feet of the antenna.

- Solutions coming from the use of ressources: for instance, the use of the antenna’s feet as elements for transportation, or else, the use of the mass of iso containers mass (traditionnally only used for transportation purposes) to ensure the stability of the antenna when functioning.

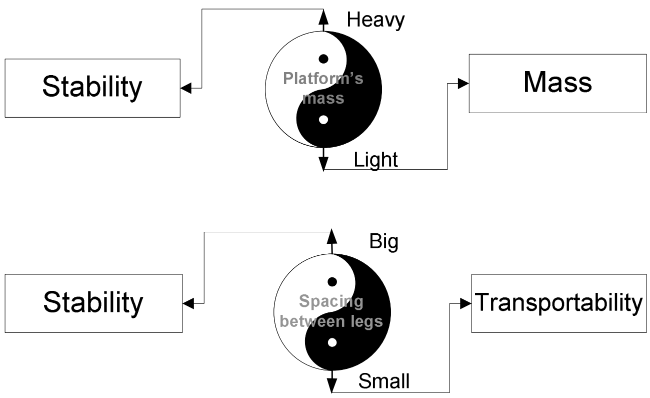

Figure 3: The two contradictions at the heart of the problematic

4.4 Solving process of a contradiction

When the network reduction has reached the state of a prototype of a physical contradiction (sometimes also called conflicting pair), it is then possible to treat the problem using ARIZ 85C. The main goal of ARIZ is to conduct a solving process in a logical way, oriented by fundamental notions of TRIZ like Ideality formulation, physical contradiction formulation, ressource uses, and the most logical use of the databases of TRIZ.

In the case of M3R, the most significative result of the solving process led the enginers of Thalès towards a new architecture of radar with significant weight reduction (approximately 30%), allowing a better transportability (from 5 to 3 iso containers) and a better stability under wind conditions in operation.

These results are of importance not only regarding the improvements of the radars performance, but also on the strategy of the company. If a significant stability is proposed by the solution concept, it is also possible to increase the size of the antena (its surface) allowing reaching a wider range for the radar. So as regarding to the transportability and the weight reduction: If the radar is transportable using lighter and smaller amount of iso containers, it is then possible to reach new marketing targets for the company like offering transportation by helicopter. During the construction of the solutions, the network of contradiction remains a necessary support to guide choices and to drive them in a converging way.

Besides the final outcome concretized by different notions and collected partial solutions (see illustration 2), the first major result of the method reside in the logical guide offered by the network of contradiction to identify contradictions to be solved in priority.

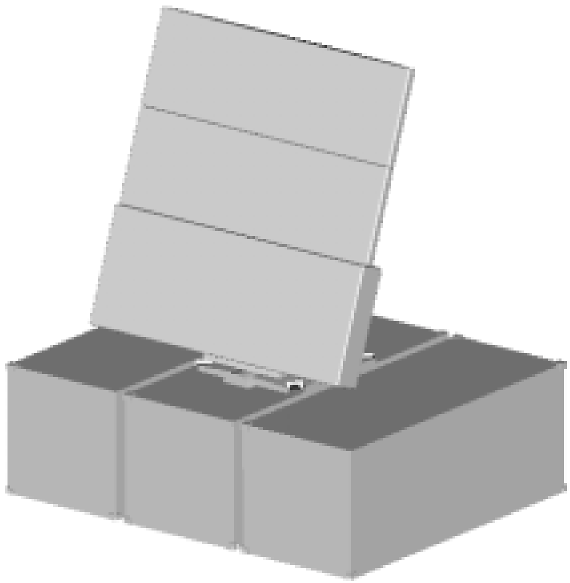

Illustration 2: Solution concept in developpment

In our case, both contradiction obtainned (as shown figure 3) are an essential intermediate result: it allows the creation of rules of formulation for a problem never formulated clearly, and therefore never solved.

5 CONCLUSIONS

5.1 On the use of a network of contradictions in M3R case

As a conclusion to the use of our approach regarding the M3R case, we may conclude around two different aspects. The first one reflects the benefit of the roadmaping offered by the network of contradiction. It has been felt by engineers of the company that compared to their traditional way of conducting the design process, a clear representation of their problems, and a logical way to converge towards a legitimate goal, provided a structurized way of choosing the right problem to tackle. Thus significant R&D time has been saved if instead a traditional trial and error procedure would have been employed. The second one is linked with the "non-compromised" way of treating the problem. Both the fact to formulate an ideal goal and to refuse the simplicity of a compromise to solve it has also been felt as an important improvement compared to their traditional design process. The importance of the value of the result is strongly felt since both of the initial parameters have been improved. In terms of inventiveness of a solution, it is also a significant improvement that, in its turn, touches the strategy of the company and its willingness to offer breakthrough solutions in their market. We can also state that regarding the management of innovation of Thalès, this approach helped the company to switch from a random way, where ideas confront to each other without finding solutions, to a logically constructed process. Both major contradictions pose the problem to be solved using a clear formulation understandable by anyone within the company.

As another element of conclusion regarding the case, we may also state that for the team responsible of new design challenge within a company, to choose solutions also signify to be able to argue and defend them (support them) in front of the client. Beyond the case study itself, the rigourous way to acquire the results is of great important for the team. Moreover, if a parameter is subjected to evolution, this method would now allow restructuring the network and focusing on another appropriate contradiction to be solved in its turn.

5.2 On the expected improvements in design with this driving mode

The impact of such formalization in terms management modes of contradiction's network provide significant advantages in the stages of formulation of strategical problems of the firm. This impact can allow not only assisting strategical decisions concerning R&D activities, but also allows, by its abilities to be managed, for the company to learn about his own problems and to forecast in accordance with technological systems evolutions.

5.3 Perspectives of research regarding this subject

The strategical assistance of the company, at any level, by a representation of its problems oriented "network of contradiction" also provides interesting perspectives for knowledge computerization [17]. This nature of knowledge representation "contradiction oriented" (therefore problems) shall favor, by the creation of computer tools, not only the robustness of problem solving activities but also internal training of teams [18] and the constitution of means to represent the problems of the company's product evolution [19]. Ongoing research works [14] shows that partial representation of a particular technological field of the company ease the robust spreading of inventive processes and thus contribute an important way to increase design practices efficiency's of project teams.

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