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Article

Contribution to Integrating Maintainability into Preliminary Design Based on TRIZ

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Abstract. In the face of the competition, the companies have, possibly more than in the past, a need to innovate. However, if the innovation can be of various natures (product, process, methods, organization…), the search for new solutions to technical problems as soon as the Design phase takes a non-negligible part, and certainly constitutes most of the Innovations "radical", especially when they relate to the product. Conventional methods designed to resolve these problems are often psychological character: methods of creativity. The best known example is the brainstorming session.

In all object creation models, of products or of development it is essential, today, to take into account the dimension safety of operation and valuing each project of creation. Of this fact, in addition to the factors related to the optimization of resources, the use of materials and the minimization of releases, it is important to be attentive to the parameters of the safety of operation in the design phase and more specifically to the maintainability of a system repaired.

In effect, for its successful integration, and in order to assist teams of design in meeting of creativity or small businesses in the development of their product, we propose a methodological approach based on TRIZ that will solve the problem of the integration of the maintainability in preliminary design phase by generating new concepts of solution in a time reduces which constitutes a decision aid for designers in the case of innovative concepts of product, of space or process.

In fact, to succeed its integration, and to assist creative teams in creative sessions or small businesses in the development of their product, we propose a methodological approach based on the TRIZ that will solve the problem of integrating maintainability into the preliminary design phase by generating new solution concepts in reduced time that provide decision support for designers in case of innovative concepts of product, space or process concepts.

Keywords: Maintainability, preliminary conception, TRIZ.

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1. Introduction

The process of developing innovative products opens on ideas that, taking shape, are reformed into creations (discovery, invention,…). When the creation has taken a communicable form (equation, schema, drawing,…), it began the phase of so-called innovation [1]. An entity, (a company, a research laboratory, an association, an administration, etc.), is a system both complex and simple. Complex, because it fits in an environment frequently in evolution and adapts to them at all times; so, it changes continually.

Complexes also, because it implements a multitude of settings to control in order to be able to pilot the whole. Simple, because a system is made up of three basic components that are human resources, physical resources and the work [2].

In an entity, a design process is considered as a tool for innovation which confirms a real competitive advantage. The choice of a design process adapted to the constraints inherent in the products and its environment represents a strategic issue in the success of the innovation approach [3]-[7]. In effect, in the literature the designers found many models of the design process, which differ in their approaches, in their organizations and in their objectives [8]-[10]. But in front of this multitude of models, the designers of a research entity may find themselves in trouble in choosing an appropriate design process to adapting an existing design process to their own limits.

Give to an entity the tools and necessary methods as an adapted or generated process by a tool is an approach of research in full evolution. We are in the field of selection where of generation of a design process through the identification of basic trades, methods and tools for the development of an innovative product.

Control the process design is to prepare the upstream phase with more participants and stakeholders on the development of the product and which should generate parameters and actionable data in the preparation of the upstream phase of the process design to ensure a global optimization of the product and the process of implementation [3], [11]. The subsequent stages of the design process consider the design as a systemic approach where the tasks and activities in the upstream phases, their structures and functional modular [12].

The design raises many questions and its study is far from being completed. Act of man since the beginning of humanity, it participates to improve his daily life and to push toward a continuous evolution. However, the design was not, for a very long time, a search object, as evoked by Garro [13] The need to clarify, to pass the knowledge, was not felt by designers wishing to be the only guarantor of their creative process. Of this fact, the study of the design is recent and its approach can be confusing, considered as an act innate, a process, methods, a theory; everything has been said on the design, but no consensus has emerged. And as the design process is considered as well the vertebral column of the innovation process (Fig. 1) [14], the integration of the parameters of the safety of operation is also found in the formalization of the design process.

In this context, we are going to make the point on the different concepts related to the design and to define our context for the integration of the maintainability in preliminary design phase based on the theory TRIZ.

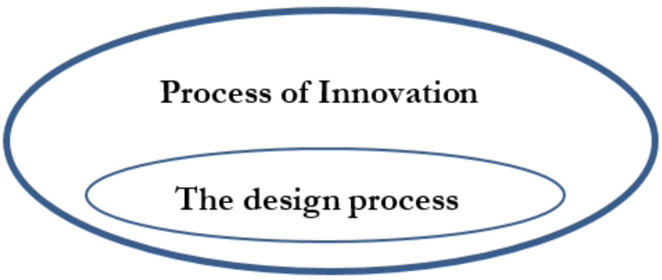

Fig 1. The design process as a vertebral column of innovation.

2. Definitions of the Concepts

2.1. System Design

The design as a generalization of the design refers to the construction of a generalization of intellectual property and objects. It is therefore necessary to abstract the objects in order to build concepts; therefore, a question arises: what elements introduce in the generalization? Why take into account such as constituting an object in the conceptualization, rather than another? We can see in the literature that one of the axioms of the modeling is the point of view [6], [13]; in the case of the design, the point of view depends on the objective of the latter and of the knowledge of the designer. As well the design is the passage of a need to the identification of a concept, guided by the objectives to achieve and limited by the available knowledge, in order to recognize, in this concept, a solution. The second definition refers to the understanding of an object; there is a need to move from a vague idea of behavior of an object to the understanding of the mechanisms and laws governing this object. Finally, the third definition refers to the visualization of a concept, a mental representation, general and abstract of an object. These last two definitions go hand in hand: it must understand to build a good representation. In creative design of technical systems, it is to move from the idea of achievement of a function, to the understanding of the mechanisms and laws allowing, physically, the satisfaction of this function. The design, in the framework of the Creativity on technical objects, can then be understood as the achievement of technological choices.

There are many technological choices to validate, depending on what you really want to separate, and resources to use. The design is therefore understand the goals, constraints and resources useful to the satisfaction of a goal.

In the literature they are several definitions for the design, one who defines as synthesis [13] and on others as a creative activity [15]. In addition, since the 1950s, the vision of the design is oriented toward the description of a process [16], In order to increase its efficiency and to control its process. Lawson [17] specifies that it is today popular to consider the design as a sequence of activities, but that, more and more, it is necessary to consider not only the process of design, but also the creative thinking who realizes, on the basis of design approaches.

2.2. The Design Process

A design process is a sequence of design activities, necessary to create one or more representations of the product [18]. Several descriptions of the design process exist in the literature, we will retain the three types of the following Modeling: The sequential processes, the iterative process and the sequential processes/iterative.

2.2.1. Sequential process

The first process of sequential design that have made their appearances, are those of Zwicky in 1948, Asimow and Buhl in 1962, Fasal in 1965. These authors propose a systematic approach to design based on three main phases [19]:

- The feasibility study (definition and validation of the required)
- The preliminary design phase (choice of concepts) and architectural significance
- The detailed design (preparation of the technical file)

These processes are based therefore on a chronological succession of all phases to achieve. However, the characteristic of a sequential process lies in the fact that the result of a phase is the input of the next phase [20].

Pahl and Beitz have proposed, in the years 1980, a model of sequential process based on four phases [21]:

- Determination of specifications
- Emergence of concepts
- Architectural Design
- Detailed Design

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From the determination of specifications, this model allows to reach a solution ready to be manufactured. The figure below (Fig. 2) details the different phases of the process of Pahl and Beitz [22].

The design process proposed by Pahl and Beitz (Fig. 2) is broken down into phases, sub-phases and steps. This hierarchical decomposition adds more precision in the organization and the description of the design activities.

Ulrich and Eppinger add a phase of prototyping and implementation of industrialization by report to the model of Pahl and Beitz to propose as well his model, a little more detailed than the other authors, based on six phases [23].

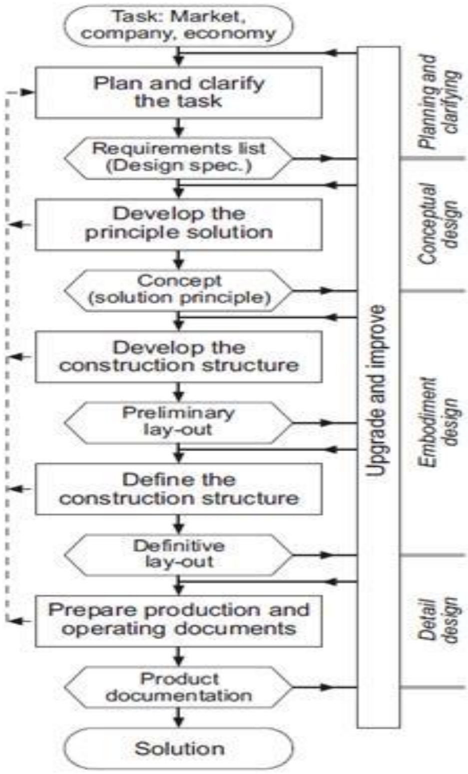

Fig. 2. Process of design according to Pahl & Beitz [22].

2.2.2. Iterative process

The iterative process has been developed in order to respond to a need for a reduction of the time and costs of design and development. For this case of modeling, the process is no longer seen as a linear succession of phases but earlier a set of problems to solve successively.

The Dutch, N. Roozenburg and J. Eekels [24], have proposed a modeling of the design as the iteration of an elementary cycle of design (Fig. 3).

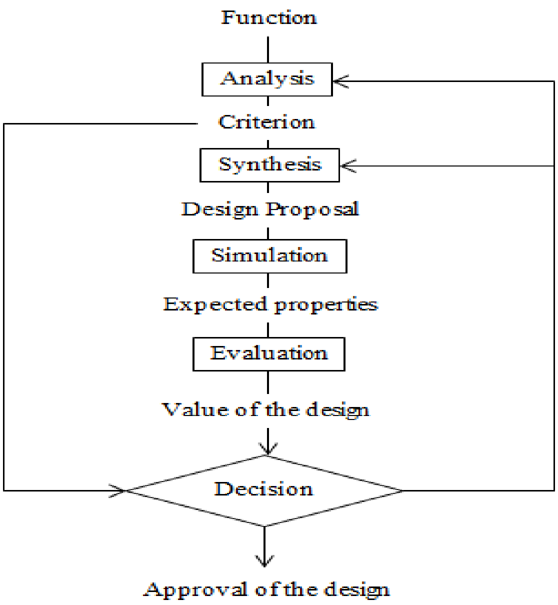

Fig. 3. Design Process according Roozemburg & Eekels [24].

In the iterative modeling proposed, design solutions and the specifications evolve simultaneously (Fig. 3). At a given time in the design process, a set of specifications determines a design solution which in turn will help to define a new set of specifications.

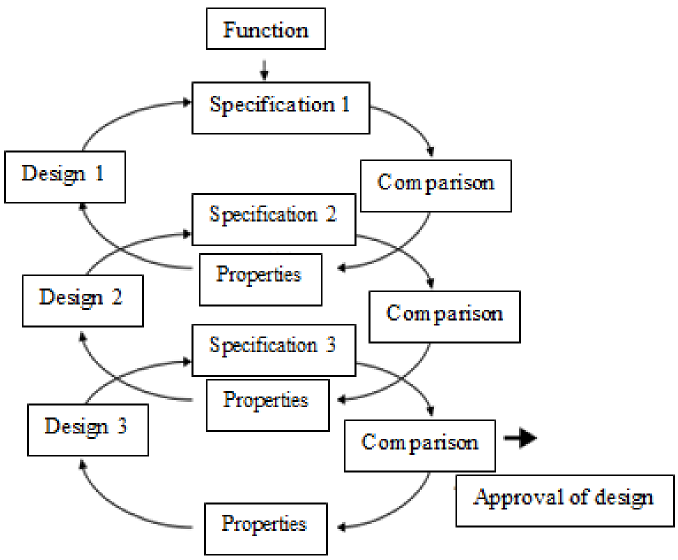

Fig. 4. The iterative structure of the design process.

2.2.3. Sequential process iterative

Aoussat has proposed a sequential model but iterative, presented by Fig. 4. It incorporates, as soon as the upstream phase of the process, all the phases of design in order to identify and take into account all the constraints relating to the life cycle of the new product, process or machine. The fact to integrate all areas (the technique, ergonomics, design, marketing,…) makes this multidisciplinary model [25].

His model is based on four phases of Iterations:

- Translation of the need: it is the formulation phase and determination of the characteristics of the product to design. The final product of this phase is the book of functional load of the product
- Interpretation of need: it is the research phase of concept, based on the creative. Different tools can be used in this phase such that the brainstorming session. The ideas chosen must subsequently be validated
- Product Definition: This phase allows you to connect the different data relating to the product and the structure in a product folder
- Product validation: it is a phase of prototyping and testing in the outcome of the third phase in order to validate the product and launch its manufacture

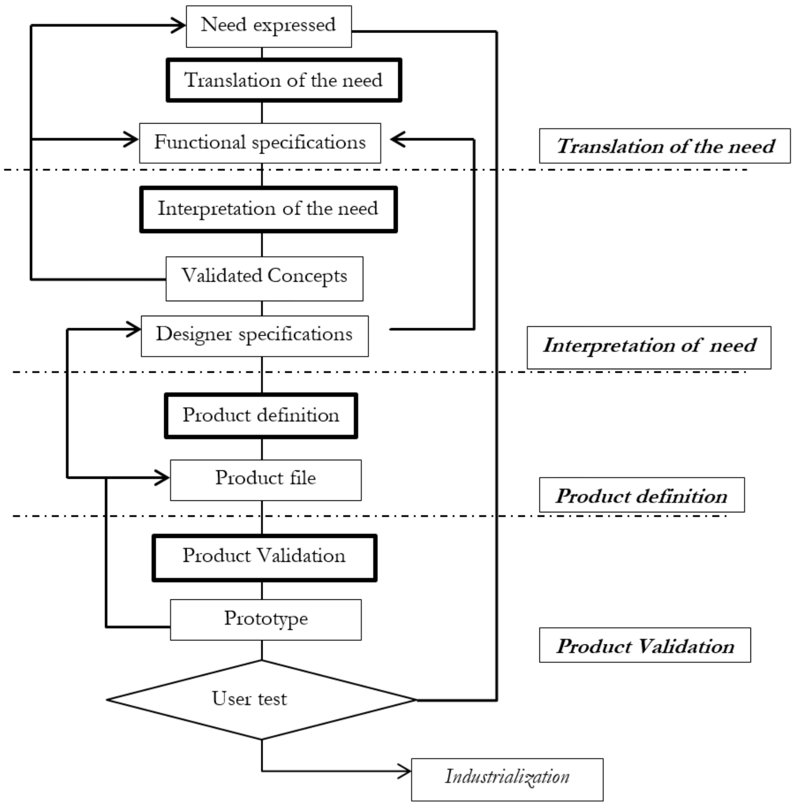

Fig. 5. Design Process according to Aoussat.

2.3. Typologies of Design

Three types of design have been retained by Kota and Ward [26]: Creative, innovative and routinely. The routine design or redesign is a step of changing the characteristics of an existing structure while the creative design and innovative have for object, respectively the functional decomposition and the choice of technical principles associated [14], [27]. We can consult the different definitions in the writings of scarvetti [19].

3. Resolution of Problematic in Innovative Based on TRIZ

In some cases, solutions to the problem do not exist a priori. The design activity was then to develop them. Conventional methods designed to resolve these problems are often psychological character: the methods of creativity [28]. The most well-known example is the brainstorming session.

Since a few years, a theory of resolution of Inventive Problems emerged in the west. It is the TRIZ methodology (Russian acronym for "Theory of Inventive Problem Solving") which is an algorithmic approach for the resolution of technical problems [29].

3.1. The TRIZ Theory

TRIZ, a Russian acronym, can be translated into English by "Theory of Inventive Problem Solving"" (acronym anglo-saxon tips) or French by "Theory of the Solution of Inventive Problems".

The origins of the methodology date back to the end of the years 40 in ex-USSR. Genrich Saulovich Altshuller, the father of the work on TRIZ, was one of the victims of arbitrary convictions of the Stalin era and was imprison (1950 to 1954). He was subsequently transferred to the camp of Vorkuta, where he was detained with engineers, physicists, lawyers, architects and other scientists. It is there that Altshuller capitalisa the knowledge which will enable him, later, to develop the methodology and tools TRIZ [30].

Altshuller was trying to understand the evolution of the systems since the dawn of humanity. He analyzed 40000 patents of different classes of the International Classification of Patents for draw 39 universal criteria for the design for an engineer. The extension of this work, in the years 60-70, on 400000 world patents permit to identify the 40 principles of innovation set out in Table 1 [31].

Table 1. The 40 principles of innovation of the TRIZ theory.

1. The segmentation	2. The extraction
3. The local quality	4. The asymmetry
5. The combination	6. The univesalité
7. The pullout dolls	8. The Counterweight
9. The contrary action prerequisite	10. The anticipation
11. The prevention	12. The equipotential bonding
13. The alternative	14. The curvature
15. The Adaptability	16. The action reduced or excessive
17. The change of the dimension	18. Mechanical Vibration
19. The periodic action	20. The continuity of an action of usefulness
21. The quick action for security	22. The transformation of a detrimental effect in useful effect
23. The enslavement	24. The Intermediary
25. The self service	26. The Copy
27. The ephemeral cheap	28. The evolution of the mechanical system
29. The Fluids	30. The deformable,
31. The porous materials	32. The color change
33. The homogeneity	34. The rejection and regeneration
35. The change of ownership	36. The phase transition
37. The thermal expansion	38. The oxidation
39. The inert environment	40. The composite materials

Altshuller proposes to resolve a problem outside of the industrial realities. A generic representation of its approach is proposed by Fig. 6.

Table 2. The 39 criteria for design.

01: mass of the moving object	14: resistance	27: reliability
02: mass of the static object	15: duration of action of the moving object	28: accuracy of measurement
03: length of the moving object	16: duration of action of the static object	29: manufacturing precision
04: length of the static object	17: temperature	30: harmful factor to the object
05: surface of the moving object	18: light intensity	31: harmful factors induced
06: static object surface	19: energy used by the moving object	32: ease of realization

07: volume of the moving object	20: energy used by the static object	33: ease of used'usage
08: static object volume	21: power	34: maintenance
09: speed	22: loss of energy	35: adaptability
10: strength	23: loss of substance	36: product complexity
11: voltage, pressure	24: loss of information	37: complexity of the piloting
12: form	25: waste of time	38: degree of automation
13: stability of the object	26: amount of substance	39: productivity

At each intersections of a matrix of contradictions are listed the numbers of the 40 principles of inventiveness that correspond to the resolution of the technical contradiction considered.

Table 3. Matrix of contradictions.

	parameter that degrades															
	01	02	03	04	05	06	07	08	09	...	16	17	...	37	38	39
01: mass of the moving object			15,08 29,34		29,17 38,34		29,02 40,28		02,08 15,38	...		06,29 04,38	...	28,29 26,32	26,35 18,19	35,03 24,37
02: mass of the static object				10,01 29,35		35,30 13,02		05,35 14,02		...	02,27 19,06	28,19 32,22	...	25,28 17,15	02,26 35	01,28 15,35
03: length of the moving object	08,15 29,34				15,17 14		07,17 04,35		13,04 08	...	01,08 35	01,08 10,29	...	35,01 26,24	17,24 26,16	14,04 28,29
⋮	...	...	...	...	...	...	...	...	...	...	...		...	...	...	...
39: productivity	35,26 24,37	28,27 15,3	18,04 28,38	30,07 14,26	10,26 34,31	10,35 17,07	02,06 34,10	35,37 10,02		...	20,10 16,38	25,21 28,10	...	35,18 27,02	05,12 35,26	

The general process the have a specific solution is as follows:

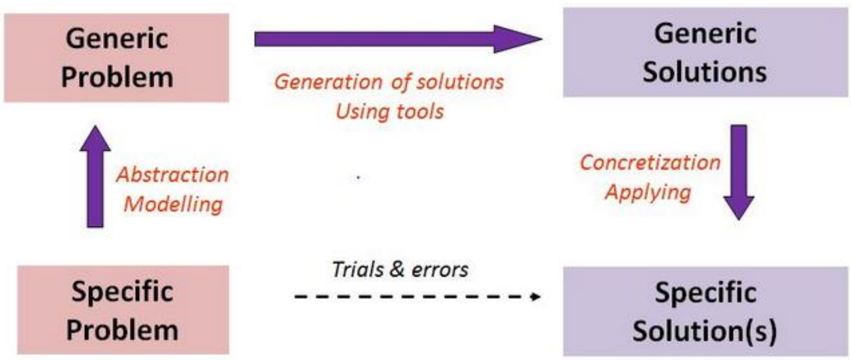

Fig. 6. Generic Model of the TRIZ approach.

In this representation (Fig. 6), specific problems and possible solutions are the responsibility of the physical domain while models of problem and the models of solutions that fall within the field of the abstract. The approach starts from a specific problem. It is in a first time to formulate a problem "standard" or general, and then to use the tools TRIZ to determine generic solutions, and finally to interpret these generic solutions to draw specific solutions. To these three steps, however, it is appropriate to add steps which, without being specific to TRIZ, are used in the approach: a step upstream of the identification of the problem to deal with, and a downstream step of evaluation.

The TRIZ approach proposes a detailed methodology to assist the actor in the identification of models of problem and of the concepts of solutions. On the other hand, the model describes does not lead to an innovative solution of immediate manner. In effect, a specific solution of a specific problem is in general at the origin of new specific problems, for which new solutions must be found. The solution chosen in fine thus follows a process of converging resolutions of specific problems in succession (Fig. 7).

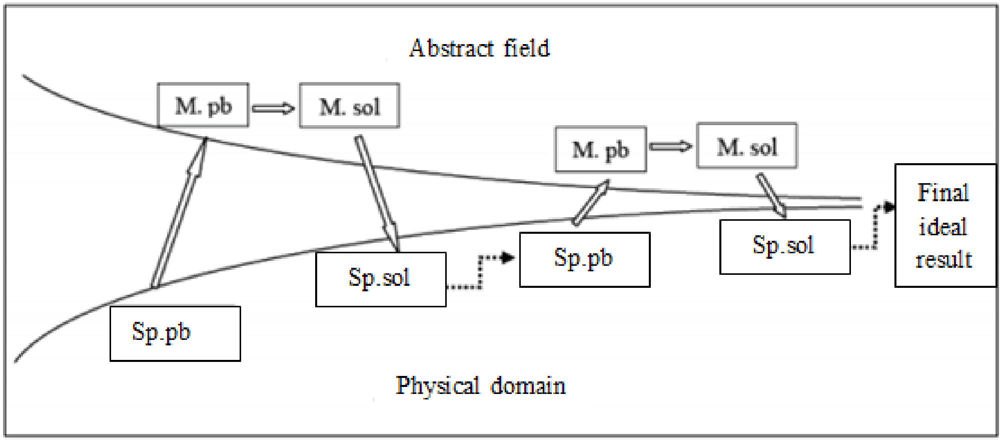

Fig. 7. Convergance of the approach of TRIZ.

With :

M.pb : Modeling of problem
M.sol : Modeling of solution
Sp.pb : Specific problem
Sp.Sol : Specific solution

However, even if the TRIZ approach is often considered interesting by the companies, it is also qualified too complex, heavy and particularly difficult to be captured by small businesses [32]. Experience has shown that it is very difficult for an SME-SMIS to implement the approach TRIZ. In effect, the learning time of this method is important.

The TRIZ tools require conventional knowledge of a vocabulary, the accession to specific procedures and a systematic drive. In addition, there is no procedure completely defined for the formulation of the problem: a specific problem, well defined in a given context, will be transformed into a generic problem in terms specific to TRIZ [33]. In order to facilitate the initial phase of analysis and structuring of the process of creativity and better deploy the tools of creativity with implementation time relatively short and the TREFLE laboratory has developed and carried out a software of conduct studies of technical creativity and innovation MAL'IN , methods of assistance for innovation [34], [35].

3.2. The Proposed Approach

The process of conceptualization of the approach is often presented as shown in Fig. 6.

From the specific problem, it is initially a question of formulating a "standard" or general problem, then of using the tools TRIZ to determine the generic solutions, and finally to interpret these generic solutions to draw solutions specific.

To these 3 classic stages, however, it is appropriate to add steps which, without being specific to TRIZ, are actually used in the facts: an upstream step of identifying the problem to be treated, and a downstream evaluation step.

The steps of the proposed approach are as follows:

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Identification/documentation of the problem

We have as a problem of study, the integration of maintainability in preliminary design phase for repairable systems.

This important phase is not strictly a step of TRIZ, but it is consistently present because it is indispensable. It may take different forms: a presentation of the product, its features, the general context etc. using different tools such as trending, strategic planning techniques, QFD elements, state of the art analysis, benchmarking, ….

In this context, we propose to use different methods of safety analysis and more specifically to the functional analysis and the analysis of the modes of the failures of their effects and of their criticality. The purpose of using these methods is to identify failures that have a major impact and severity on the system and the various components.

In addition, it is also a good time to determine the strategy to be adopted later: to face the problem through TRIZ, or to circumvent the problem. For this we chose TRIZ to resolve our problematic study [36], because it's more used in industry.

Formulation of the problem

In a first time, the general problem will be modeled, and even specific problems will be extracted for the following. Here too, the forms are different, but the practices overlap.

When interventions of TRIZ experts, we have seen a modeling of the complete problem in the form of a diagram of functional type. It expresses the interactions between physical entities (substances). This tool built with the technical experts carrying the problem is certainly a quick way for the expert TRIZ to locate (focus) the elementary problems to deal with, which will become as much of specific problems.

Before continuing with clean tools to TRIZ it will be necessary in all cases extract or choose the elementary problems from the general problem: the clipping of the problem fairly "Cartesian".

Of this fact, to help designers to take into account the parameters of the Maintainability in preliminary design, we will have as basic problem resulting from the cutting is to determine the parameters to integrate in preliminary design.

In a second time, with a view to apply tools of resolution, it is necessary to express the specific problem considered in a form adapted to the general problem.

This step of interpretation is probably what makes both the originality, and one of the difficulties of TRIZ. It is well to look at the problem from a new angle, non-conventional, and the "Mold" in a framework that is already defined. In addition to the relevance of tools, the effectiveness of the method takes probably much to the next new focused on the problem, and to the high degree of abstraction thus imposed.

The development of generic concepts by the use of the tools TRIZ

In this phase we have the concept to determine the parameters that influence TTR (Time to repair) and the rate of failures such as resulting from the previous steps.

Of this fact, and from the "Models of problems", the application of tools of TRIZ will lead to "models of Solutions" in a fashion that is almost mechanical: the application of a procedure. Each tool can bring new ideas that can lead to innovative concepts concerning the generic concept resulting. Note however here the character very generic of concepts provided by the TRIZ tools at this stage. While generating generic solutions to resolve the contradictions that result.

Interpretation of generic solution

"Models of solutions" are generic, and they must be interpreted for each particular problem. Two types of interpretations of a different nature are to mention:

a) The first type is the interpretation almost "natural" of a generic concept, which often acts as "inducer" of an idea. It seems that a concept, even generic, is more likely to move toward a relevant solution. A mini-brainstorming on each generic concept is then the rule. The interest of TRIZ compared to other techniques of creativity at this stage comes from a part of the character "quasi exhaustive" concepts possible (they are actually very many), on the other hand the fact that the approach is oriented toward the concepts a priori the more adapted to the type of problem considered.

Potentially, the method can provide a huge time saving: in the extreme case, a few hours facing years of reflection, doubt, disappointed hope, procrastination, unsuccessful attempts etc.

b) The second type of interpretation has been developed by Altshuller and his team in this Purpose: when the node of the problem becomes the answer to a question of the type "I know what should be done, but I do not know how to do it", the appeal is made to databases of not the knowledge of humanity, but orienting them to the knowledge of the "physical effects" likely to provide an answer to the problem. This type of tools is able to evolve further by the use of search engines using techniques of semantic analysis, including a first version is available. [37]

A sub-extra step can be added then: the combination of the concepts. It may intervene naturally by association of ideas, but it can also be made systematic.

Evaluating solutions

TRIZ does not offer for this phase of tool formalized. Of this fact, we are going to opt for the approach for the evaluation of the Maintainability in the design phase, a proposed approach and developed in one of our background work. [38]

In addition to the approach we consider the concept of " Ideal Ultimate Result " which can be resumed at this stage as an evaluation criterion, but we believe that it expresses more the "Elegance" of the solution that its relevance to a case given industrial. It would be more appropriate at this stage to question everything that this new solution can induce vis a vis the client, the company,…. the concept of ideal final result is one of the tools used during the problem definition phase of TRIZ theory, it's outcome in its first stages, reformulates the technical contradiction to translate it into a physical contradiction and mobilizes the resources (fields and substances) that can be used to solve it. Then we use the ideality to identify the ideal solution based on the following equation:

$$\textbf{Ideality} = \Sigma\ \textbf{Benefits} / (\Sigma\ \textbf{Costs} - \Sigma\ \textbf{Harm})$$

The key to choose an optimal solution is increasing benefits while decreasing costs and harm associated with the new design.

3.3. Model for the Resolution of the Problematic of the Integration and the Evaluation of the Maintainability in Preliminary Design Phase

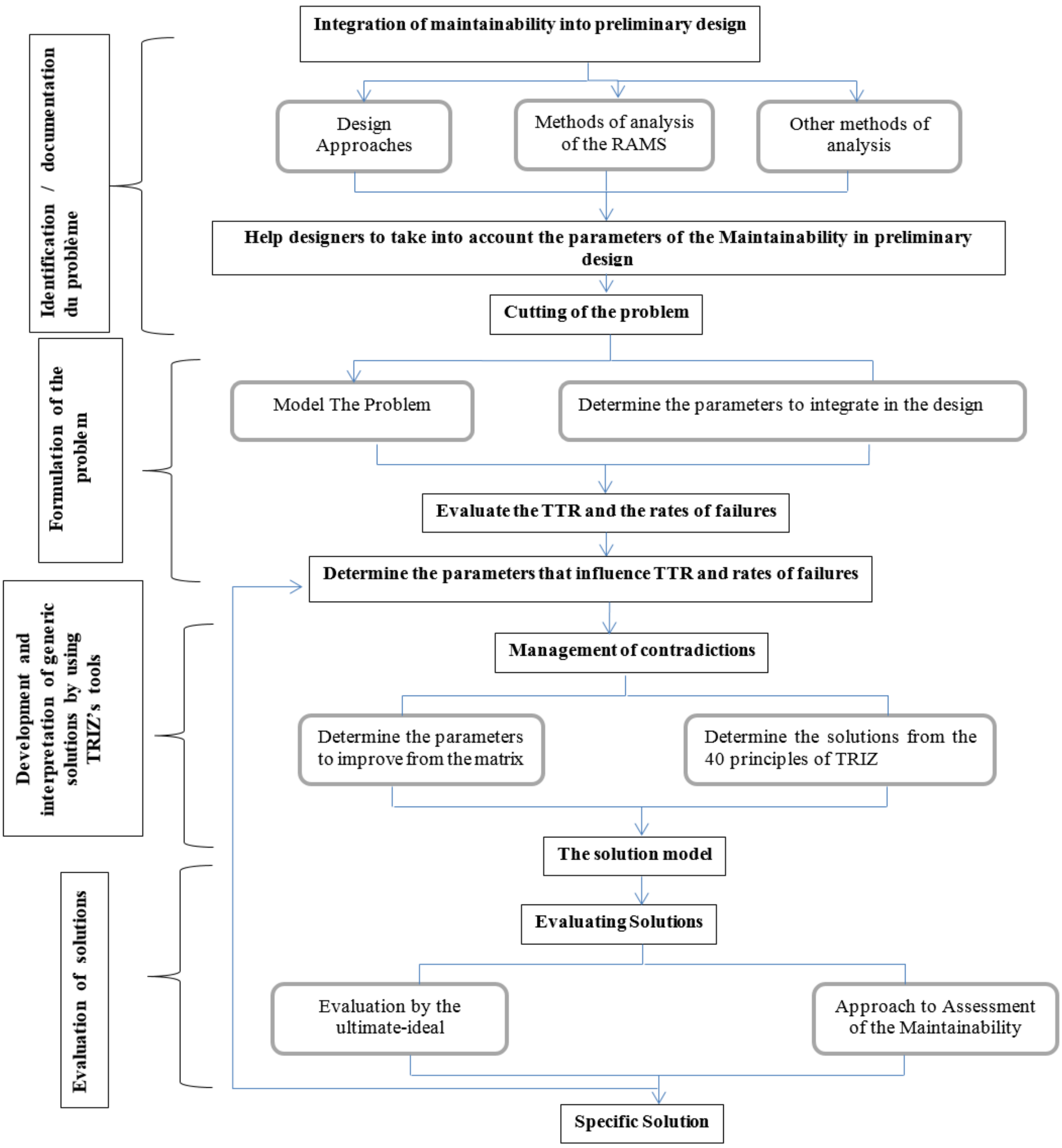

Fig. 8. Model for the resolution of the problematic of the integration and the evaluation of the Maintainability in preliminary design phase.

4. Conclusion

It can be concluded that the TRIZ method aims to bring out inventive solutions. Large groups adhere to it discreetly but surely. It tends to define creativity, as an exact science. This is going to hurt more than one, to shake up more than one idea. But this is one of the ambitions of the TRIZ theory, to break the psychological inertia that holds so many inventors in their same impasses. Theory for some, method for others, it is in any case an idea of genius that can "boost creativity".

Its application requires more rigor and training. It is defined as an "experimental science" whose objective is to help inventors and more generally all engineers to methodically solve technological problems.

According to its designers, TRIZ may apply:

- In research and development of new generations of products, proposing a set of laws of evolution.
- In the resolution of complex problems, with a methodology and tools based on the resolution of conflicts inherent to all technical systems.
- To solve complex problems, with a methodology and tools based on the resolution of conflicts inherent to all technical systems.
- In the identification and treatment of failures of all industrial products, it is an application that could be related to risk analysis.

In this context, we have presented in the said work a conceptual model for the integration of the Maintainability in preliminary design phase in the case of Innovative design based on the approach TRIZ. In effect, the departure of the approach is the problem to take into consideration the maintainability in the preliminary phase of design, and then with the help of a functional analysis and a FMEA study (what we have noted the methods of analysis of the RAMS) we can determine the generic problem in order to help designers to model the problem and to determine the parameters that will integrate in preliminary design, in a goal to evaluate these parameters and to use the tools of TRIZ who have allowed us to manage the contradictions and generate innovative solutions for each situation. To finish by the evaluation of the solution generated by two tools proposed: by the ultimate-ideal for assess the ideality of the solution, and the approach for the evaluation of the Maintainability presented in one of our previous work to determine the components which penalizes the solution.

We envisage as perspective of this work, apply this conceptual model for a wind power system, in order to determine the parameters to improve to optimize the maintainability and availability in generating an optimal solution based on the approach TRIZ.

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