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Assisting decisions in Inventive Design of complex engineering systems

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Abstract

Adopting relevant decisions in engineering design of multidisciplinary problematic is often perceived as a critical issue in industry. This situation becomes even more critical when in inventive design context since decisions lead R&D teams towards unusual directions that, by nature, expose the company to risky investments. IDM-TRIZ is an advanced framework proposed to address the issue of representing multidisciplinary and complex situations to facilitate TRIZ use in inventive design projects. One of its tool "problem graph" has been designed to link expert knowledge representations and automatic extraction of populations of contradictions. This first step nevertheless presents a limitation; it doesn't help project leaders to properly estimate the incidences of their decisions when engaging inventive activities to solve a specific problem. This paper addresses this issue and proposes an enhanced methodological process that is handling dynamic multiple graphical representations based on computed project data's exploitation. It provides relevant proofs that, in comparison with a traditional TRIZ approach, we have significantly improved the robustness of R&D decisions. In addition, we illustrate our methodology using a case study conducted in airspace industry (helicopter assembly complexity) to present and validate our hypothesis.

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1. Introduction

Managing the increasing complexity of technical artefacts has always been a matter of interest in research [1][2]. This is mostly due to the necessity to escape from the vagueness of intuitive decisions based on personal perceptions of apparently complex realities [3][4]. If we were once able to cope with hazardous decisions, nowadays world can't

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support anymore any losses of value due to weak decisions [5]. Does this mean that the entire world should be putted into equations? Certainly not [6], we are here more in line with a lean process that can't afford losing time and money from wrong directions, bad decisions based on a weak understanding of a given situation.

Major abbreviations or acronyms used:
- TRIZ: Theory of Inventive Problem Solving
- IDM: Inventive Design Method
- OTSM: General Theory for Strong (powerful) Thinking
- PB: Problem
- PS: Partial solution
- SC: Solution Concept
- EP: Evaluation Parameter
- AP: Action Parameter.

Complexity is also a topic in itself that has attracted many researches. We are considering for this contribution complexity as the result of a multidisciplinary situation that engender a sum of parameters that escapes from the mastery of humans [7]. Once a problem can't be understood only by human understanding due to the complexity of the situation, we consider it as a target for our research. We therefore base our research on the statement that we are nowadays facing with industrial situations that even if they escape to humans, company responsible (R&D heads) do need to take decisions that might engender losses of all kind for the company. This is mostly due to a lack of existing tools to cope with this difficulty in today's world.

In TRIZ world, when undertaking inventive problem solving activities, we have observed similar situations. R&D deciders (or simply project leaders) base their TRIZ-related activities on either expert (internal or external) that themselves base their understanding about the situation on intuition (even after questioning and observing facts). As an example, the targeted contradiction to be solved is often the result of a non-robust process [8]. Past researches have demonstrated that for the same problem, classical TRIZ might lead to solve different contradictions each being intuitively disclosed by different groups leading to results of all kind [5][9]. Consequently classical TRIZ can be qualified as producing inventive ideas systematically but without any guaranties about their positive impact on the complex equilibrium of consequences their development will lead to [10][11]. We would like in this paper to put forward that, first IDM-TRIZ was a framework of research dedicated to avoid such situations, second that based on the limitations of IDM- TRIZ, it is possible to propose improvements leading to more robust-ness in the process. The proposed contribution is the result of a research program that starts with a common statement in industry: how to better master the way decisions are taken at the early stage of an innovation process?

We have elaborated a methodology dedicated to multidisciplinary problematic mapping through data gathering so as their consignation into an ontological template for further graphical representations. In this paper we postulate that providing in advance to decision makers, graphical representation of their decision's impact on the system from various perspectives, can lead to more robust decisions. Thanks to an already defined IDM-TRIZ framework [12], we added the notion of multi-categorization of problems and made possible the visualization of hypothetic propagation of decisions into problem graphs [13]. As a result, before taking any decisions, managers are conscious about potential consequences of undertaking a direction or another. The paper is divided in 5 parts, after this introduction (first section) a state of the art of existing research in decision assistance will be exposed in a second. The methodology will be described in a third one, so as its differences in comparison to existing contributions. A fourth section presents a case study to illustrate our process in a real industrial situation. It aims to initiate a discussion about our claims and validate partially our initial hypothesis. Finally a section that will include both discussions and conclusions will end our paper.

2. State of the art

Among many existing relevant works in decision science, we have mainly observed methods aiming at deciding which solution to develop (or accept) [14]. This abundant literature displays many contributions in assisting decision makers in design projects but is poorly investigating decisions in this direction: which problem to choose for moving ahead in the appropriate direction. As an example, if we would like to invent a new hammer, do we need in priority to lower its weight, to build it cheaper or to find a new way of hitting the nail systematically in its center? Each of these directions is relevant, and probably necessary within a given context of the company. Nevertheless if you ask the R&D director, you might not get the same answer as if you question the manager or the dean of marketing department.

Table 1 TRIZ, OTSM and IDM major differences

TRIZ [1946-1985 by Altshuller & beyond by others]	**OTSM [1985-2009 by Khomenko & beyond by others]**	**IDM [starts in 2006 at INSA Strasbourg]**
Intuitive human expertise estimates the problematic situation.	Notion of Network of problems Notion of Problem Notion of Partial Solution Notion of core problem (intuitive) Notion of Network of	Problem graph Problem + Accuracy of the syntax Eligibility of a Partial Solution Core problem automatic – graph theory Automatic derivation of a problem graph Into a set of contradictions
Human skills-based theory (unachieved)	Contradictions Expert-based theory	Ontology-based theory
Laws are described	Laws exists	Laws are connected to contradictions
Validation of the solution if no compromise is made	No Solution Concept Impact measurements	Solution Concepts are ranked according to their capacity to shrink the graph
No differences between parameters	Control Parameter	Action Parameter (ontology consistency)
Dedicated to solve engineering problems.	Dedicated for developing thinking skills	Dedicated for becoming an industrial practice

Depending on viewpoints, endorsing a direction in Design will unavoidably engender important consequences on expenses, human efforts and time consuming. Therefore, it arise a problematic of choosing the best potential direction for the company and it is easily understandable that the most promising one is the one that will reach the largest quantity of issues while not provoking the rise of unexpected new problems. This creates a challenge of building hypothetic scenarios based on existing facts and representation. These multi-objective scenarios are subjected to later be accurately calculated on further stages in the pipeline of innovation [15]. But here again, if there is significant literature in representation means, these representations are always designed for a better understanding, increasing clarity, enabling complex representation or easing computation for solving [16]. What we need in Inventive Design, is a way to represent realities for both moving ahead in the most promising direction and easing TRIZ tool use in providing to problem formulation the appropriate set of contradictory parameters so as to ease Contradiction formulation [17].

While we already provided contributions in the direction of complex problems representations and its link with contradictions in previous work [13], we still did not properly manage the use of this representation in order to ease decisions of solving processes. We decided to use the computations aspects if IDM-TRIZ (due to its ontology) and graph theory propagation of constrains in order to automate hypothetic solving scenarios. In order to ease viewpoint representation we adopt a categorization strategy by tagging each graph component (Problems and Partial solutions) when appropriate, to associate it to one or several categories. This categorization helped us to navigate in complex graphs and facilitate decisions. After several experiments, we can now observe, analyze and discuss these first results for moving ahead in systematic innovation.

3. Methodology and results

3.1. IDM-TRIZ basics

IDM breaks down into four stages here briefly described:

Step 1: Initial situation analysis: This phase consists of investigating all knowledge having to do with the initial unsatisfactory situation and transposing this tacit and explicit knowledge [18], which may exist either in textual documents or in the minds of experts, into an exploitable mathematical model in order to determine by which means to enter into a more detailed or parameterized description of the problem. The objective here is to build a "problems graph" resulting from this transposition in order to develop from a situation that is fuzzy, often resulting from an empirical heaping of studies experiences, toward an exploitable graphic model that uses rules and algorithms of the Graph theory [19]. The problem graph is made up of elements of a simple symbolic graph, which rapidly facilitates clarification and recording of tacit knowledge bits gleaned from questioning. It is proposing a graphic model in which two knowledge categories coexist: knowledge representing problems as yet unresolved from the initial situation and knowledge representing known partial solutions in the same domain.

Step 2: Formulating contradictions: With Stage 1 decision making conventions in place, what appears as a key issue in the study is subsequently used as a departure point for producing a detailed formalization of a range of polycontradictions, from which the contradictions of the area being examined will be extracted and ranked. These contradictions are the technical and physical issues to resolve in order to have an impact on root problems that render the initial situation unsatisfactory. The following phases are found within this stage:

- Formulating polycontradictions
- Extracting contradictions
- Creating a priority-based hierarchy of each contradiction depending on a given scenario

Step 3: Generation of Solutions Concepts: Each contradiction stated as a priority in the previous stage then becomes an entry point for implementing TRIZ techniques and tools to achieve a resolution without trade-offs. The problem resolution processes are used for each of the priority contradictions and may be successive or iterative. They exploit the technical contradictions resolution matrix related to inventive principles, the Substances-Field modelling related to the Inventive Standards system and the ARIZ-85C algorithm [20]. This stage produces a limited number of solution concepts that are pertinent to the initial situation and exhibit full traceability.

Step 4: Selection of solution concepts: In this stage, the hypothetical impact of each solution concept is weighed against the problems graph created in Stage 1. The purpose of this is to evaluate the impact of each of the solution concepts on the initial unsatisfactory situation and to choose which one or ones among them to develop more in detail. These stages were detailed in a previous publication [21].

The closest set of procedure, methods and tools to IDM is OTSM. Nevertheless, even if we found many advanced definitions in OTSM that were appropriately moving in the right direction, we could not clearly define a coherent corpus of components useful for fully operating OTSM both in education and research [11][7][22]. In table 1, we summarize the major components of TRIZ and OTSM and how have they been either replaced or reconstructed in order to fit with the overall ontology of IDM.

3.2. Anticipating decision's consequences

Based on the STEP 1 of IDM-TRIZ, we obtain a problem graph on which (since all of its components are numerically stored into an XML file) one could associate each problem and partial solution to a set of categories that will enable later on filtering data's.

Figure 2 provides a generic example of an averagely complex graph that displays components in Fig 2 belonging to all categories and in Fig 3 only to the categories having been asked to be displayed by user.

Propagation scenario is an easy step to organize in a graph; therefore, we implement an "outgoing" function that features a scenario of hypothetical propagation of a decision to solve a given problem. Consequently, we can ask the computer to collect and display all impacts of a decision assuming that all links are there and true after having being defined by experts. Next section provides an application of this new functionality in order to evaluate its impact on a study.

Figure 1: 3 Illustrations of the problematic situation of cables in helicopters

4. Case study

4.1. Introduction to the overall problematic

Like in Automotive sector helicopter is a system that integrates an increasing quantity of electrical equipment (through cables) having an ever increasing impact on many different critical functions (flight commands, engine controls). In addition this increasing quantity of embarked systems and their evolution towards being electrically powered causes weight and safety problems. This raises new problems, risks or additional constrains at several levels:

- New certification constrains on cabling or installing systems;
- The increasing importance of failure risks on electrical stripes, in particular chafing of stripes (due to friction with other items embarked on in helicopter and its structure or body).
- Installation difficulties related to increasing complexity of internal sub-systems, space roominess, and evolution from mechanically to electrically powered brakes and flight commands.

It has been noted these last years that several aerospace programs undergoes dramatic difficulties and delivery delays partially due to the difficulties these evolutions have brought to cabling activity in assembly lines (amongst others Airbus A380 and Boeing B787). The goal of this study was to develop a new and inventive strategy that would lower these cabling installation difficulties in addressing the situation using IDM-TRIZ tools.

4.2. Problem graph

Based on experts questioning (interviews) we apply problem graph construction rules and obtain the following graph (illustrated in figure 2).

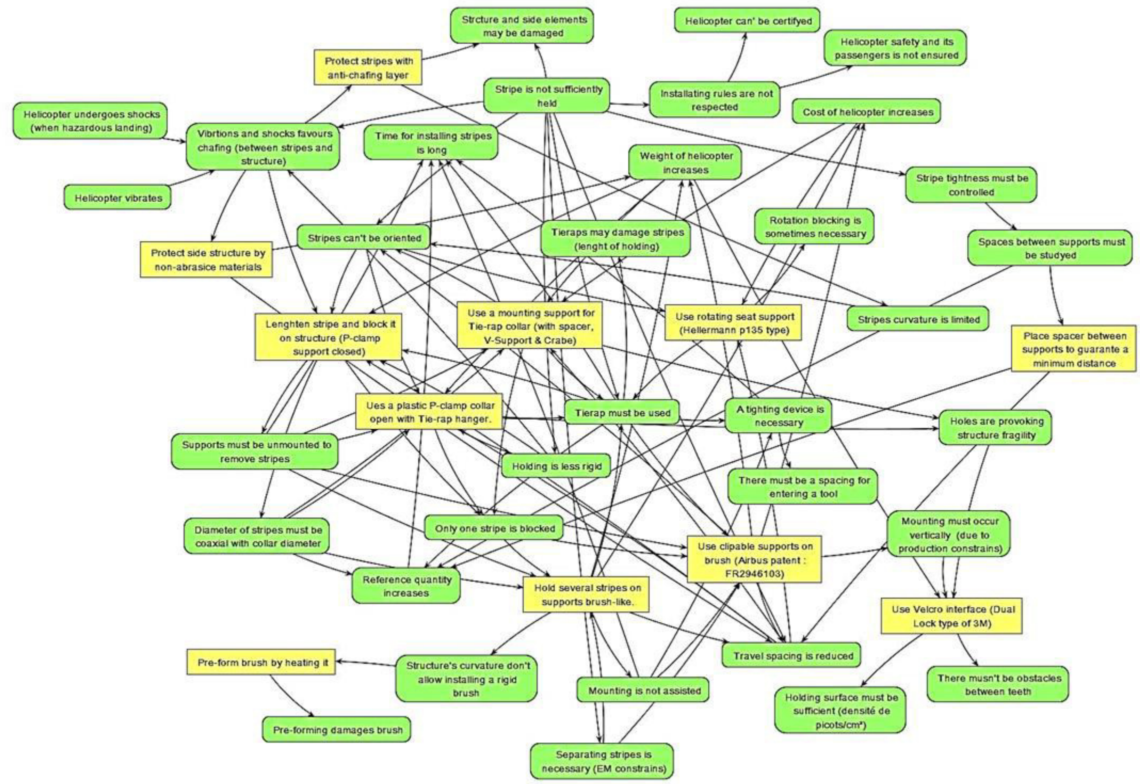

Figure 2: Problem Graph obtained from Expert's questioning

4.3. Extracting R&D orientations (decisions) from problem graph's interpretation

We are now facing with the problem of interpreting such a complex graph, assuming that what is expected from company's R&D manager is to orient the solving phase in a relevant direction. We therefore focused on providing him with useful information such as: which is the longest chain of problems likely to be solved and to provoke its solving, which is the most relevant problem to consider in priority? Classically, graph theory or other graph tool proposes at this stage to highlight origins (problems at the origins of the chain). Such considerations are not valid when the graph is constituted by 2 different types of entities (in our case PB & PS). Our methodology is to consider that all assumptions of cause and effect chains be-tween PB to PS; or SP to PB; or PB to PB are all potentially exhaustive. Consequently, if PBn is to be solved then PBm will also automatically be solved if this latter is not involved into another chain (otherwise its solving will become doubtful or conditional). The fact that we translated experts' knowledge in such a shape favors the automatic extraction of useful information since we have now a mathematical or numerical model (easy to compute with).

Manually, it is also easy to tag components (PB & PS) in categories (one or several) and decide to concentrate on a specific one more than on another (therefore apply the same algorithm on a single category of problems) and display to decision makers the "potential" consequences of a decision on not only the considered category but also on others.

On this particular category, our algorithm suggested to concentrate on PB09 "Tierap is necessary" since it will provoke the most important quantity of solved consequences. We can therefore propose to decision makers the following argument for the robustness of his decisions:

If you engage an inventive problem solving activity on [removing tierap necessity]; you may expect that [No tightening device will be necessary] AND [no spacing between structure and mounting device for entering a tool will be necessary]. You may also positively affect [Time for installing stripes] AND [quantity of references]. This assumption is not evident at all when considering the overall description of the problematic. A first “classical” TRIZ activity led the group towards a totally different direction and as a result obtained totally different new product development orientations.

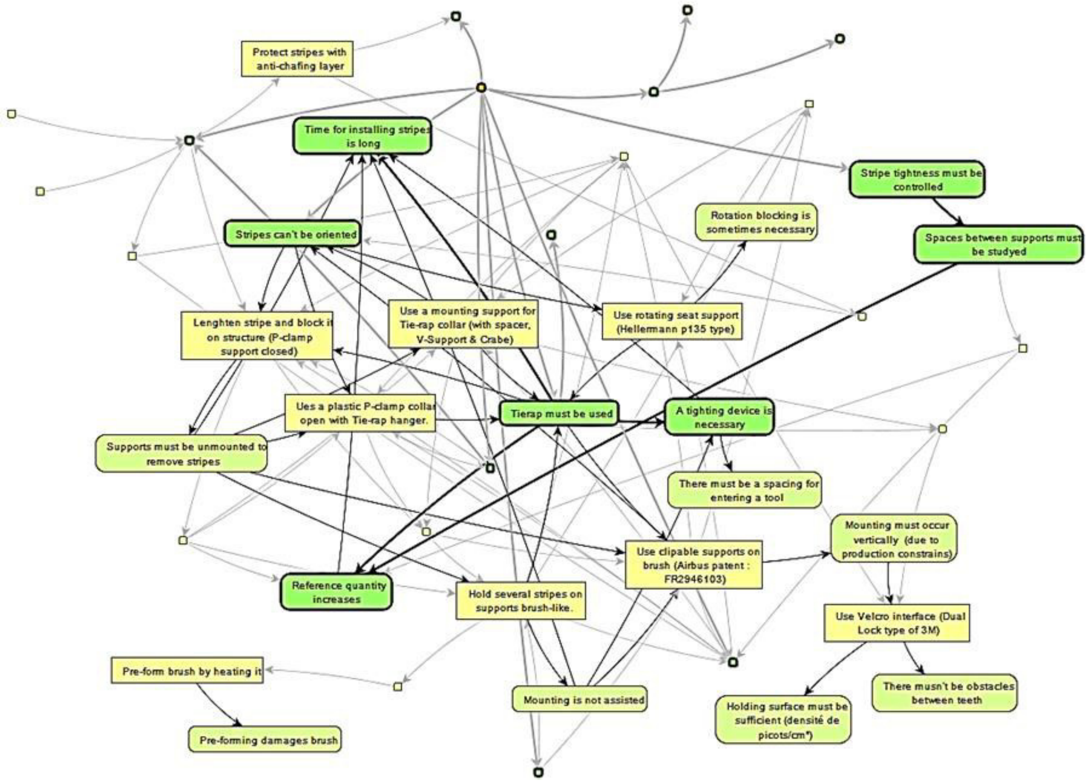

Figure 3 Highlighted longest chain of Mounting category

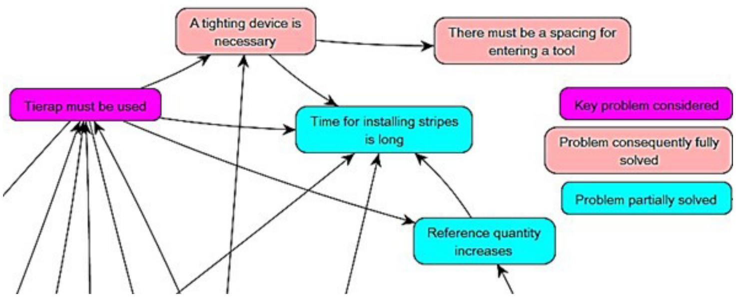

Figure 4: Excerpt of Problem Graph limited to the consequent chain of problems totally or partially touched

5. Results and Discussion

Through this paper, we reminded that early decisions are mainly based on intuition and past experiences. Consequently it provokes high risks for the budget of a company to undertake a weak direction on which one did not anticipate its consequences. We have addressed the question of anticipating decision's consequences beyond what human can do in using IDM-TRIZ problem graph and modifying it to provide decision makers with hypothetical chains of consequences. We added several ways of organizing this display so that different angles involved in a project could individually and collectively anticipate decision consequences. We tested our methodology on an industrial case study having been also treated using TRIZ and have obtained results that differentiate our methodology results from those obtained with classical TRIZ. We remarked that the addressed contradiction was not the same so as the problem to be solved in priority. Consequently the finally chosen solution concept is different and of a higher level of ideality when possessing a more robust anticipation strategy.

The limitation of our work is twofold. First, we postulate that investigating only one propagation algorithm is not exhaustive and with further investigation, we could build new ways of manipulating problem graphs, bringing new results. This paper is therefore the first milestone of this research orientation. Second, the proposed solution concept by our enhanced IDM-TRIZ is theoretically calculated, but not yet under the hand of people involved in the company at the assembly line. It is therefore difficult to perceive if our methodology has fully combined both computer-assisted inventive decisions and a real-life positive consequence according to what was expected.

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