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The TRIZ-CBR synergy: a knowledge based innovation process

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Abstract: Today innovation is recognised as the main driving force in the market. This complex process involves several intangible dimensions, such as creativity, knowledge and social interactions among others. Creativity is the starting point of the process, and knowledge is the force that transforms and materialises creativity in new products, services and processes. In this document a synergy that aims to assists the innovation process is presented. The synergy combines several concepts and tools of the theory of inventive problem solving (TRIZ) and the case-based reasoning (CBR) process. The main objective of this synergy is to support creative engineering design and problem solving. This synergy is based on the strong link between knowledge and action. In this link, TRIZ offers several concepts and tools to facilitate concept creation and to solve problems, and the CBR process offers a framework capable of storing and reusing knowledge with the aim of accelerating the innovation process.

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1 Introduction

According to Smith (2005), the outcome of innovation depends only on two factors:

1 creativity and knowledge of talented employees

2 the effectiveness of methods and processes that support their work.

This paper proposes a synergy that aims to support both dimensions: creativity and knowledge. The first element in the synergy is the case-based reasoning (CBR) process, useful to store and share knowledge. With regard to creativity, an approach capable of supporting idea generation for systematically solving problems is needed. Recently, an approach that conceives innovation as the result of systematic patterns in the systems evolution has emerged in the industrial world: the theory of inventive problem solving (TRIZ) theory or TRIZ, the second element in the synergy. The following sections briefly present this synergy.

This document is organised as follows: Sections 2 and 3 briefly introduce the two main elements in the synergy (the TRIZ and the CBR approach). In Section 4 the synergy is presented. Section 5 analyses an example of its application.

2 TRIZ: the theory of inventive problem solving

The TRIZ theory appeared in the 40's when Genrich Altshuller, a patent expert serving in the soviet navy, decided to find some fundamental principles to invent. While working as a patent expert, Altshuller realised that even the more creative inventions had common basis. The evidences that supported this observation were the multiple inventions that shared the same problem (described as a contradiction) and the same solution in unrelated industries. Even more important was the fact that periodically a significant time gap between similar solutions was present. Consequently, if those known solutions were available to inventors in other domains, the innovation process would be more efficient (Terninko et al., 1998). Thus Altshuller and colleagues created an interdisciplinary knowledge capitalisation process with a difference: the knowledge synthesised was transformed with the aim to make it reusable in several domains.

The TRIZ theory is a well accepted approach for solving problems. This theory states that even if apparently the evolution of technology seems to follow unpredictable stages, in the long term it follows well identified and repeatable patterns. Thus, knowledge of these patterns could be applied to propose a framework where the systematic development of technologies is possible (Fey et al., 2005). Knowledge about these evolution patterns also facilitate the solving problem process in new product design, production systems, improvement of products, services and processes.

In the present context TRIZ theory consents several advantages over traditional methods for product design, particularly when applied in the early design stages. The main advantages are:

- TRIZ offers an ample collection of knowledge extracted from several domains. This capacity produces an environment where knowledge can be used in a transversal way. As a consequence, the application of TRIZ is not restricted to a single technical domain. This advantage is inherent to TRIZ tools for modelling and solving problems. Those tools had been conceived like vectors or pointers to guide creativity towards solutions that had proved its efficiency in the technological world. The TRIZ capacity to reuse solutions from a huge diversity of domains does not ensure a successful solution to a problem, but radically increases the probability of success and reduces time and effort while developing solutions.

- TRIZ is an equilibrated approach that combines, in the same environment, psychological and technical creativity. This capacity lying in its basis and structure. TRIZ is based on four essential areas:
  1 a statistical patent analysis (more than three million) to derive some general solving strategies
  2 a synthesis of the main advantages extracted from numerous techniques for problem solving
  3 an analysis of the inventor's creative thinking patterns, with the aim of producing a set of strategies to model and to solve problems

4   a capitalisation knowledge process in scientific literature.

Analysis of these areas leads to create some tools that make a tangible link between knowledge and action (Cavallucci, 1999).

The process deployed by Altshuller revealed the TRIZ cornerstones:

1   All technological systems evolve according to well-defined regularities acting as models or patterns of evolution. These models are useful for analysing the future development of a product, system or technology. Among these evolutions patterns, one has a crucial role: ideality. This concept (which is not exclusive to TRIZ), announces that all systems evolve towards the increase in their degree of ideality. In the evolution process, a system searches to increase its performance with no additional resources nor harmful secondary effects, producing a TRIZ capital concept which reveals solutions directions usually not considered. Several TRIZ tools have been conceived to find a way of improving a system through innovation, especially through the transformation of its available resources in solutions that add value to the system.

2   The concept of inventive problem and contradiction is an effective way to solve problems. An inventive problem is one that contains at least one contradiction. A contradiction materialises when a useful action simultaneously causes a harmful effect/action or when the introduction, improvement, intensification of the useful action or the elimination of the harmful effect/action causes inadequacy, or an unacceptable complication of either one part or on the whole system (Fey et al., 2005).

Thus an inventive solution is one which surmounts total or partially a contradiction. As an element of the synergy introduced further in this document, a particular kind of contradiction has capital importance: the technical contradiction. This kind of conflict appears when any attempt to improve one useful system parameter or characteristic has an unacceptable impact in another useful feature. Usually these kinds of problem are solved with trade-off solutions. Altshuller found that several methods or strategies to satisfy contradictions were available and easily exploitable. Hence those strategies were arranged to accomplish this objective.

3   The innovative process can be systematically structured. Altshuller found several common patterns in the patents database that have been proved its efficacy in different technological disciplines. TRIZ uses these successful solutions or strategies to solve new problems (Terninko et al., 1998).

Like any other approach, TRIZ has several limitations. Some of the most important in the present context are:

1   TRIZ does not deal with real and specific processes, machines or object but with models or abstractions. The main TRIZ concepts and tools are not attached to specific objects and subsequently, can be applied in several domains. Even if this capacity is in fact an advantage, TRIZ is without an explicit structure or tool to play the role of a memory. Consequently, TRIZ can not remember specific past solutions while solving problems. This procedural knowledge is unavailable for other persons facing similar problems.

2   TRIZ uses general knowledge and, accordingly to (Kolodner, 1993), the application of this kind of knowledge in a particular situation could be extremely difficult.

3   The solving process of technical problems …"depends on how often the solver has faced similar problems and on the solver's ability to recognise the similarity" (Savransky, 2000). A framework to develop this capacity is therefore required.

The limitations presented above demand a tool or methodology capable of storing and reusing knowledge: central capacities of the CBR process. The following section offers a succinct description of this AI tool.

3   The CBR process

In the CBR process, problems are solved by reusing earlier experiences. In this process, a target problem is compared with a set of specific solved problems encountered in the past (called cases), to establish if one of the earlier experiences can provide a solution. If a similar case or set of cases exists, their associated solutions must be evaluated and adapted to find a new one. This approach has proved its utility to support design activities, equipment selection, knowledge management activities among others (Avramenko et al., 2004).

The CBR as a methodology for problem solving encompasses four essential activities: retrieve, reuse, revise and retain. In this process, the problem solving process starts with an input problem description or target problem. This description is used to -*retrieve*- a problem or set of previous solved problems (cases), stored and indexed in the memory. Then if one or various stored cases match with the target problem, the most similar case is selected to -*reuse*- its solution. Subsequently, the derived solution must be -*revised*- tested and repaired if necessary in order to obtain a satisfactory result. Finally the new experiences which comprise failure or success, but also the strategies to repair and implement the final solutions (among other particular features), are -*retained*- for further utilisation and the previous case memory is updated. A CBR system has several advantages such as:

1   Learning is a very important product of the CBR process, perhaps the most important. López de Mántaras and Plaza (1997) emphasise: "Learning is in fact inherent to any case-based reasoner not only because it induces generalisations based on the detected similarities between cases but mostly because it accumulates and indexes cases in a case memory for later use".

2   According to Leake (1996), the retain phase or memorisation stage within the CBR process is an excellent support for acquiring and sharing knowledge. This capacity is a consequence of the strong connection between reasoning and learning.

3   The CBR process is based on the analogical thinking process, which it is the most utilised human process for problem solving (Terninko et al., 1998). Consequently, the solutions available in a CBR system are easier for users to understand and apply than a rule- or model-based approach (Limam et al., 2003). This characteristic consents benefits such as: large volumes of information can be managed (more than in a rule-based approach) and the knowledge as case memory can be maintained and

updated automatically with the use of the system. Another determining factor is time impact. Users of this kind of computational tools become more competent over time.

The CBR process has limitations such as:

1   The case-memory store cases for a single domain. In other words, the case-memory contains only problems in a well defined context. This is in fact one of the most important advantages of CBR, but applying this specific knowledge-base to innovation projects could be an obstacle to creativity. This phenomenon occurs because single domain solutions conserve a well defined reflection vector, which is difficult to surmount. This vector is called psychological inertia in TRIZ (Altshuller, 1999).

2   Another consequence of the above mentioned limit is that creative solutions available in others domains can not be considered while solving problems. Nevertheless, the quantity of sources and domains utilised when solving problems has a positive impact over obtained solutions (Sifonis et al., 2003).

3   An important CBR drawback is revealed when for a new problem to solve, there is not a similar case in memory. If this condition occurs, the solver has to face this problem by using less performance techniques like brainstorming or the trial and error process.

Based on the intrinsic limitations and advantages inherent to both approaches, it is possible to state that TRIZ needs an element capable to storing and reusing knowledge, and the CBR process needs a structure that facilitates the access to solutions obtained in other domains and also a general knowledge structure to index cases in the case-memory. Next section briefly describes the combined approach TRIZ-CBR, satisfying both requirements.

4   The TRIZ-CBR synergy

While analysing the world patent databases, Altshuller and his research team realised that identical problems have been solved in different domains. They also observed that even the most creative solutions described in a patent could be derived from some general principles. This observation led Altshuller to deploy a knowledge capitalisation process to extract and synthesise those original strategies or methods for problem solving (Altshuller, 1999).

Consequently, Altshuller proved that knowledge from patent databases could be extracted, transformed and arranged in such a way that its reutilisation was accessible to any person in any domain. TRIZ can, therefore, be considered as the first innovation knowledge base (Zotlin and Zusman, 1999), which offers the organisation "the ability to strip away all barriers between different industry sectors" and to gain access to "the best practices of the world's best inventive minds" (Mann, 2003).

Nowadays, TRIZ users "continually demonstrate that applying common solutions for the resolution of contradictions, identified as effective when applied to parallel problems in the world patent base, radically improves the design of systems and products" (Terninko et al., 1998). This TRIZ capacity had been exploited for the most important companies in today's industrial sector.

This reflection and knowledge capitalisation process also establishes the foundation of several TRIZ tools. One has a crucial role in the synergy of such tool, the contradiction matrix acts as a memory for indexing and retrieving similar problems. Analysis in the patent database, also revealed that an inventive problem (one that could be formulated as a contradiction), can be formalised with a reduced number of parameters. This observation led to formalise 39 generic parameters and 40 inventive principles (Altshuller, 1999). Both elements were organised in a 39 × 39 matrix named contradiction matrix (Figure 1). This matrix had been updated in a 48 × 48 matrix (Mann et al., 2003).

Figure 1   Fragment of the contradiction matrix

1	2	3	4	5	6	7	8
+	-	15, 8, 29,34	-	29, 17, 38, 34	-	29, 2, 40, 28	-
-	+	-	10, 1, 29, 35	-	35, 30, 13, 2	-	5, 35, 14, 2
8, 15, 29, 34	-	+	-	15, 17, 4	-	7, 17, 4, 35	-
	35, 28, 40, 29	-	+	-	17, 7, 10, 40	-	35, 8, 2,14
2, 17, 29, 4	-	14, 15, 18, 4	-	+	-	7, 14, 17, 4	
-	30, 2, 14, 18	-	26, 7, 9, 39	-	+	-	
2, 26, 29, 40	-	1, 7, 4, 35	-	1, 7, 4, 17	-	+	-
-	35, 10, 19, 14	19, 14	35, 8, 2, 14	-		-	+

Hence, the contradiction matrix is useful to solve inventive problems. An inventive problem is defined as:

- A problem that contains at least one contradiction.

- A contradiction exists when any attempt to improve one useful system parameter or characteristic has an unacceptable impact in another useful parameter. This is denominated a technical contradiction.

- An inventive solution, which surmounts one contradiction totally or partially.

This kind of problems is usually solved with trade-off solutions. TRIZ philosophy is to solve contradictions with a premise: to avoid compromise. Altshuller found that several methods to satisfy contradictions were available and easily exploitable. Hence, these strategies were arranged to accomplish this objective inside the contradictions matrix.

The contradiction matrix plays the role of memory in the TRIZ-CBR synergy because it can be easily adapted to different contexts and domains. This matrix contains the statistical analysis of over three million patents. One of the most important conclusions of this work is the statement: "if two problems share the same contradiction, then their nature it's similar and consequently, the associated solution of the first one could be applied on the second" (Altshuller, 1999) and (Mann, 2003). Thus, this initial similarity between two problems can be exploited in the TRIZ-CBR synergy. In order to explain the

problem solving process in the synergy, the application methodology of the contradiction matrix must be presented. The following section describes this logical sequence.

4.1 Deploying contradiction matrix

The simplicity of applying the contradiction matrix has made it one of the most utilised TRIZ tools. The methodology of this tool is broken up into five stages:

1   To state the initial problem as a conflict between two characteristics or useful parameters of the system (sub-system or component) where the problem has been identified.

2   To correlate both parameters with two parameters among the 48 generic parameters.

3   To utilise the contradiction matrix; the first column identify the parameter that needs to be improved and in the first line, the damaged parameter or that which impedes improvement of the system. The intersection between line and column isolates the successful inventive principles used to remove or minimise similar contradictions across domains.

4   To analyse the proposed principles.

5   To derive an operational solution from those principles. If during stage 4, any of the proposed principles offer a potential concept solution, it is recommended to re-formulate the initial contradiction or to explore the ensemble of principles.

4.2 Example

Chromatographic separations are unit operation techniques used to continuously separate a multi component mixture. One of the possible technological starting points of this unit separation is the true moving bed (TMB), for which a simplified version is illustrated in Figure 2. For the TMB separation technique, the component mixture is applied in a column where the liquid and solid phases flow in counter current directions. The liquid outlet of zone 4 is recycled to the zone 1 inlet, and conversely for the solid, the zone 1 outlet is redirected to the inlet of zone 4. Moreover this apparatus has one feed (with the mixture to separate) and two outlets to withdraw products: extract (rich in the component as it became more retained, preferentially in the solid phase) and raffinate (rich as the component became less retained, preferentially in the liquid phase). The principle disadvantage of this technique is the flow of the solid phase, which is a complex task. Applying the five steps mentioned above:

Step 1   Formulate the problem as a conflict. Reduce the solid phase flow without reducing the global efficiency of the separation process.

Step 2   Correlate with two generic parameters. In this case, the contradiction can be formulated in the following fashion:

- improved parameter: the flow of the solid phase implies difficulty of use; consequently the parameter 33 ('convenience of use' or 'ease of operation') is chosen
- damaged parameter: parameter 19 ('use of energy by moving object').

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Step 3 Utilise the contradiction matrix. For convenience a standard 39 × 39 matrix was utilised in this example. An electronic version of this matrix is available at www.triz-journal.com. The intersection of line 33 and column 19 of the matrix stress the followings principles: 1 (segmentation), 13 (inverse or inversion) and 24 (intermediary).

Step 4 Analyse the proposed principles. The first principle specifies that the object or process can be fragmented into independent zones. Consequently the first idea is to divide the system in such an independent zone. A sub-principle of principle 13 is to 'make movable parts fixed and fixed parts movable'. Having in mind that the circulation of the solid must be reduced, it can be fixed. Consequently if the solid becomes static, we have to perform the inlets and outlets ('fixed parts movable') through rotation in order to simulate fluid flows. A combination of both principles 1 and 13 gives the solution (SMB).

Step 5 Derive from those principles an operational solution. As it is clearly explained by Pais et al. (1998), the counter-current flow of fluid and solid is simulated. The absorbent bed is divided into a number of fixed beds. The inlet and outlet lines move one fixed bed simultaneously at fixed time intervals towards the liquid direction (Figure 3). This is the operational principle of the simulated moving bed (Cortes Robles et al., 2006).

Figure 2 The TMB (see online version for colours)
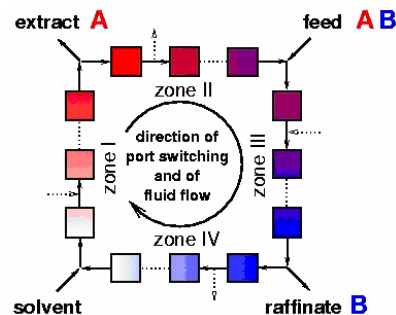
Figure 3 The simulation moving bed (see online version for colours)
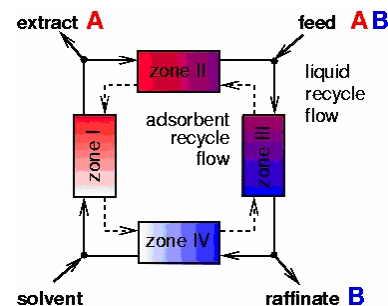
The 40 inventive principles have been adapted in several technical and non technical domains. Among those are: education, industrial engineering, process engineering, microelectronics and architecture. The knowledge transfer capacity of the contradiction matrix is essential to conceive the case-memory because the CBR process requires an abstract generalisation that will be utilised to store and index problems in the memory; consequently an extremely flexible structure is desirable.

4.3 The ideal final result (IFR)

According to TRIZ, all systems evolve towards the increase of degree of ideality. This concept is employed in the synergy. A TRIZ tool based on this concept is IFR. This tool helps solvers to explore the solution space and to support concept generation. The IFR is a solution that:

1 eliminates the deficiencies of the original system

2 preserves the advantages of the original system

3 does not further complicate the system (uses free or available resources)

4 does not induce new disadvantages.

The IFR will define a perfect system that opens a solution space which is rarely considered in a problem solving process.

Once the key concepts of both approaches are defined, it is possible to present the process at the synergy's core (Figure 4).

Figure 4 The TRIZ-CBR synergy
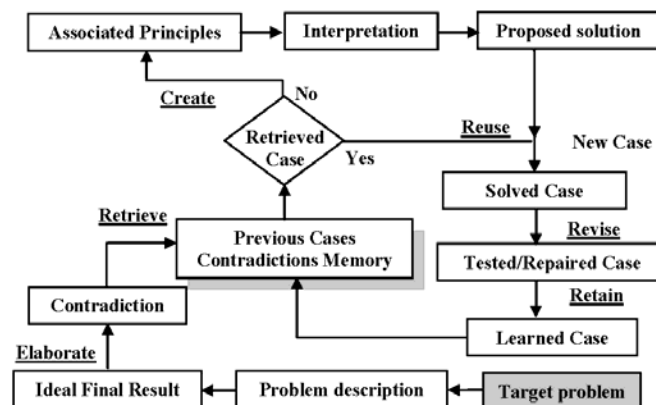
In the process outlined in Figure 4, the target problem is described and modelled as a contradiction. Hence, this contradiction and some other elements derived from the problem description (available resources, objective, sub-systems, among of others) are used to retrieve a similar case in the memory. This search might or might not offer a similar case. This condition generates two separate sub-processes:

1 A similar case is retrieved; hence its associated solution is evaluated to decide if such initial solution will be reuse.

2 No similar cases are stored in the memory. Thus, the system will propose at least one inventive principle (and no more than six between the 40 that already exist) that has been successfully used in the past. This will be used for the purpose of solving this particular contradiction in some other domains. Afterwards, the inventive principles (standard solutions or strategies to solve problems) must be interpreted to propose a potential solution.

Subsequently, both sub-processes converge and the proposed solution is then verified and repaired if necessary in order to obtain a satisfactory result. Finally the new experiences which comprise failure or success (and occasionally the strategy to repair or to implement solution) are retained to reuse it in the future, and the case memory is subsequently updated. The TRIZ-CBR synergy was tested in 100 cases (derived from patents) with excellent results (Cortes Robles, 2006).

5 Example

This example shows how a problem was stated and solved. The problem is to maximise the available space in vehicles when transporting purified water in 19 lts containers (Figure 5).

Figure 5 The water container (see online version for colours)


This problem generates numerous conditions:

1 Containers can not be placed vertically (one upon the other). This condition causes reduction of the batch size in a vehicle and also the delivery rate.

2 If they are placed vertically and side by side, it is difficult for operators to lift the container, resulting in a risk of injury.

3 Necessity of adapting a structure to transport containers leading enterprises to spend money on vehicle adaptation.

4 Difficulty in moving containers for clients.

5 Occurrence of frequent accidents for transportation of the container, resulting in the need for a new container. As a result, a new container is needed, one that maximises space, reduces difficulty associated to transport and minimises the risk of injury.

6   In addition, an excellent transparency level is a priority. The following scheme
     shows how this problem was solved.

The solutions present themselves:

• First, suggests transforming the container in such a way that one could be placed one
  upon the other by retracting and extracting the container water inlet. This solution
  can solve partially the transport problem.

• Second, one proposes to completely change the actual system. IFR suggests
  recommends to describe the ideal system, which in this case, is a container that does
  not have any physical dimension (weight, volume, etc.) but which accomplishes its
  useful function. The most similar system is a water bag developed in the aerospace
  industry. This option is actually under analysis to propose a new way to distribute
  water. Clients have manifested an initial and natural opposition to this project, but
  nowadays, they see the project from a different perspective. This project also
  involves other industries such as: recycling industries, services, communication,
  among others.

Figure 6   The design tree (see online version for colours)
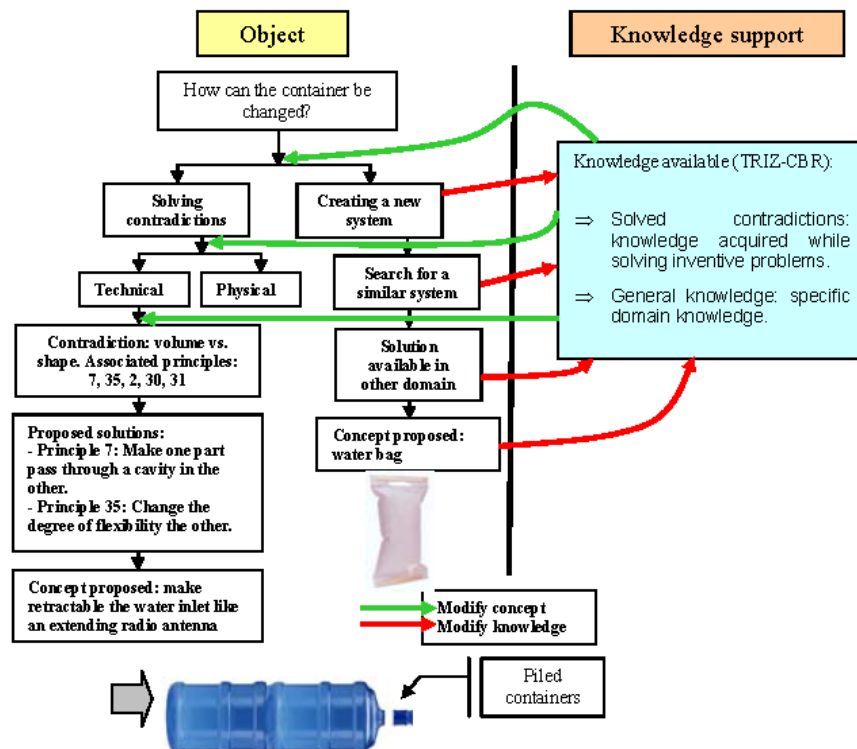
6 Conclusions

The TRIZ-CBR approach combines the TRIZ ability to propose creative solving strategies applicable across-domains, and the CBR memory, creating a framework that closely relates knowledge and action. Besides, the process schematised in Figure 4 encloses a process where knowledge is applied in a very dynamic way. The problem faced modifies the available knowledge and knowledge impact the design process.

The synergy has another capital advantage: the TRIZ-CBR synergy has the capacity to offer solutions even if a problem had never been faced in the past, and also to remember how a solution was obtained. The contradictions based memory, allows prevention where a solution had failed or to increase success possibilities when a successful solution was created. This capacity reduces effort in problem solving activities, accelerating the innovation process.

As showed, the tools and concepts developed in TRIZ are valuable in knowledge creation. Ideality has the power to polarise the individual's mental models in the same direction and the synergy IFR-contradiction, the capacity to guide creative effort for developing solution close to ideality. Furthermore, contradictions generate a creative chaos where new concepts are created (Nonaka and Takeuchi, 1995). All those stages are lastly supported by a system capable to capture, store and make available the produced experiences while solving contradictions.

The associated disadvantages to this model are principally:

Human factors: emotions like fear, insecurity (the conviction that innovation requires some birth qualities or to lose a position within the organisation), among others; make really hard knowledge exchange.

The efficacy of the TRIZ-CBR memory is intrinsically related to its content. Thus to store cases in an initial empty memory is time consuming. The TRIZ-CBR synergy was verified with 100 patents (Cortes, 2006). Nevertheless, this kind of systems becomes more efficient over time and the contradiction memory can be maintained and updated automatically with the use of the system.

The process to store solved contradictions in the memory is generally made a posteriori and therefore, users can't remember all developed stages while solving problems, generating valuable information lost.

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