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COMPUTER AIDED INNOVATION

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Abstract

Innovation plays a crucial role in the development and the sustainability of the economy. Regardless its importance and the numerous national and international programs to promote and support innovation, it still remains an ad-hoc process based on hand-shaking and brainstorming. It is expected that Computer Aided Innovation (CAI) will have an impact similar to the one that Computer Aided Design and Computer Aided Engineering had to Manufacturing.

In thesis we investigate the notion of CAI and try to collect the essential elements that might lead to a systematic approach for innovation. Specifically we first review the available theories and frameworks that have the potential to provide the necessary background for future CAI systems. Specifically we consider TRIZ, ARIZ, QFD, SIX SIGMA and few others which they surely have a common objective but so far they seem to be unrelated from most other aspects. We compare them and try to identify their conceptual similarities and their common components at the semantic level.

Furthermore, we have systematically collected the available software systems for Innovation and interrelated them to our theoretical review. We conclude by proposing a semantic based software platform for CAI and investigate the critical issues concerning its implementation.

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1 Introduction

1.1 Objective

Innovation is not simply an economic mechanism or a technical process; it is a social phenomenon through which individuals express their needs and creativity. It has become a key to improved global competitiveness for many business sectors. Technological change strongly influences economic growth. Investments in research and development are closely linked to rising productivity levels, which have helped improve living standards in many advanced economies. Innovative economies typically exhibit how to increase the rates of economic growth and productivity; they want to invest in people and especially in highly qualified people.

Innovation plays a crucial role in the development and the sustainability of the economy. Because of its importance, researchers along the years tried to formulate a method or an algorithm that would make the innovation process more focused and, efficient and even automated. While examining the Innovation process we came across several methods that help with the innovation process. The aim of this thesis is to analyze these methods and tools and organize the knowledge of the innovation process. In the computer aided innovation approach we examined all the computer software tools that can be used to create an innovation.

1.2 Thesis outline

The thesis is organized as follows:

In the Second Chapter we give the definitions of Innovation that are found in the literature. Moreover we examine the aspects of innovation, how it is originated and the goals of the innovation process. There is also an analysis of how the patents and the patent analysis are connected to the innovation process.

In the third chapter there is an extended analysis of the Theoretical Framework of the Innovation Process. After many years of innovating the researchers came up with many methods that helped them organize their knowledge and do better innovative products. The method that is widely known and well established is the TRIZ inventive problem solving method. Apart from TRIZ we examine the Axiomatic Design method and the Quality Function Deployment (QFD) method. Along with these methods we examine methods that help the user analyze the problem and state it properly to be able to solve it.

In the fourth chapter there is an analysis of the software tools that are developed to help with the Innovation process. We see the Pro/Innovator software tool, the Innovation Suite and some other software tools for Innovation. What these tools have in common is the implementation of the TRIZ method.

In the fifth chapter we give the semantic analysis of the theoretical framework that was previously examined. In this chapter we examine closely the work that has been done in the computer aided innovation process. We examine already published papers from various researchers, projects and software tools with a semantic analysis view. Furthermore we give a proposal of a semantic based system that can be developed in the future.

2 An Introduction to Innovation

2.1 Definitions

The classic definitions of innovation in the dictionaries are almost all about introducing something new. According to the American Heritage Dictionary innovation is

"the act of introducing something new, something newly introduced"

while according to US Department of Health and Human Services[1] it is

"something new or improved, including research for development of new technologies, refinement of existing technologies, or development of new applications for existing technologies".

In Wikipedia the term innovation is referred to

"both radical and incremental changes in thinking, in things, in processes or in services"

This can has been also expressed in a similar way by Smart State Strategy Queensland Glossary[2], which consider innovation to be

"the process of converting knowledge and ideas into better ways of doing business or into new or improved products and services that are valued by the community".

To complement the above definitions it is worth to make the following statements. The innovation process incorporates research and development, commercialization and technology diffusion. Innovation is the invention that gets out in the world. Something to be innovative has to be substantially different and not have an insignificant change.

Innovation is very closely related to the notion of invention. Invention is the mother of necessity but according to Thorstein Velben, innovation is not invention, even if these two

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[1] http://www.hhs.gov
[2] http://www.smartstate.qld.gov.au

terms are confused. Invention might be something big and important, but if no one produces it then it remains undiscovered to the world. As it was mentioned above innovation is the invention that gets out in the world. As William Gibson claims that

"The future is already here. It is just not uniformly distributed. It is very important to focus on extracting value from the creative understanding of what is already known and stop obsessing about inventing something unique".

Innovation is also strongly related to creativity. These two terms don't actually refer to the same thing. According to Wikipedia

"Creativity is typically used to refer to the act of producing new ideas, approaches or actions, while innovation is the process of both generating and applying such creative ideas in some specific context."

In an organization or a company there is the distinction between innovation and creativity. Usually Innovation is considered as the extensive process of generating, creating and implementing innovative ideas. The term creativity is limited to the generation of the ideas within the innovation process. Innovation is actually the implementation of creative thinking when creativity means original thinking. The connections and relativity of the terms is very well stated by Amabile (Amabile, Conti, Coon, Lazenby, & Herron, 1996)

"Innovation begins with creative ideas, but creativity is a starting point for innovation; the first is a necessary but not sufficient condition for the second."

Innovation is not necessarily based on new, complicated and advanced technology. It could be just a simple realization of customers' needs at a particular time. For example the mobile phone was surely an innovation that required high technology solutions, several in fact, while at the same time the packaging of fresh, washed and ready to serve vegetables was also a great innovative success that required absolutely no new or high technology.

Innovation can happen after a lot of careful research and work on the subject of it. Apart from that innovation can arise after studying scientific facts and trying to emphasize on a technical system. This innovation is called *technical innovation*. Technical innovation is innovation that combines major scientific facts, discoveries and very important scientific rules and principles. For example, the mobile phone was an amazing innovation. Mobile phone technology was innovative because it combined knowledge from many scientific fields such as signal processing, wireless technology, electronics and especially microchips technology. It was an innovative that was widely known from its birth. The mobile phone was a technological innovation due to the knowledge that was used and the product that was developed.

When an innovative thing comes out, it is most often a technological achievement. A very innovative idea that was not at all technological was "the salad in a plastic bag ready to serve". This is an innovative non-technological achievement that impressed the world with the simplicity of the idea, and yet not-technological. It is important to understand that innovation has differences from the technological innovation only in the resources that are used and that technological innovation is highly scientific.

2.2 Where Innovation is originated from?

There are many sources of innovation. A commonly recognized source is manufacturer innovation. This is when a person or a business innovates in order to sell the innovation. Another source which is now becoming recognized and is in fact considered to be the most important and critical is the end-user innovation. This innovation happens when a person or a company develops an innovation for their own use (von Hippel, 1988).

A lot of attention is given by businesses in researching and innovating. However, innovation can be developed from alterations in existing systems and combination of knowledge and experience that has been already gained. Innovative work cannot be developed in just one company alone. Cooperation of many different parts (end users, developers, consultancies and standard bodies) is needed in order for innovation to emerge. When this cooperation exists in a social network level and involves organizations, companies and industries where user demands and needs meet with technologies and creative processes then the most innovative ideas are likely to develop.

Innovation is nowadays dramatically different than it used to be. There has been a drastic change over the last forty years in the conception of innovation. Inventors and researchers used to be completely isolated and so was their knowledge. It has been now accepted that innovation is a result of interaction and constant exchange of knowledge. Recent theories of innovation emphasize on the collaboration and on the importance of relationships rather than technical tools.

The question is "Who can do Innovation?" Innovative people, people with ideas for great innovations, are not born, just like in our days Olympic winners are not. There are people gifted who can create very important innovations, but with hard and focused work anyone can do innovation. With the appropriate management the levels of creativity and innovation in a company or in an organization can be improved (Buxton, 2005). This explains the existence of many courses in very important institutions about innovation. There are number of academic programs that aim to teach innovation such as programs in the School of Business in New York University of Leonard N. Stern, the Institute for Innovation and Entrepreneurship at Dallas[3], the MIT Sloan School of Management[4], Purdue University Innovations[5] and in many others.

2.3 The goals of innovation, the evaluation of its success and the impact of its failures.

When a company or an organization as a hospital, local government or manufacturing facility pays an agent (person or company) to do innovation, it is driven by many demands with most important the improved quality of products and the creation of a new market. The goal of innovation is not mainly the development of a new product but the improvement of many factors such as the production process. An important goal is also considered to be the extension of the product range. Another goal is usually reducing costs,

[3] http://innovation.utdallas.edu/
[4] http://mitsloan.mit.edu/
[5] http://www.purdue-innovations.com/i/

energy, or environmental damage. The goals may vary between improvements of products, processes and services regarding the person in demand with the invention.

The success of an innovation cannot be measured and therefore there are no distinctive metrics for it. The most common metrics are patent creation and Research and Development. If someone wants to evaluate the innovation he or she has to consider many things. For example one might investigate if a particular innovative product is a commercial success and if it is useful inside and outside of the company. It is also possible that an innovation will enable other innovative products.
The person who does the innovation has to consider what its costs are for the company or the organization. Moreover very good criteria for measuring innovation could be the costs for the company if innovation fails. In summary we could say that the evaluation criteria for an innovative product could be the benefits and the costs of it in a company, regarding the user's experience of it.

Failure is inevitable in the innovation process and an appropriate level of risk should always be considered. Innovations fail and according to a survey regarding product innovation from three thousand good ideas only one comes out in the world and the market. Failure should be identified early in the process of innovation in order to avoid the waste of resources that could be used elsewhere. The causes of failure are widely researched and vary. They can be internal to the organization or external and so cannot be controlled. Internal causes are usually in the organizations' control and some could be identified such as poor knowledge management, poor leadership or communication.
There are many reasons that can cause innovation failure. It is important that the goals are very well defined. As we will see later in the thesis, team work not only between the members of the innovation team but also with the members of all scientific fields is something that can prevent failing. The tasks of every member of the team have to be explicitly defined in order to help the team work and avoid failing the goals of the project.

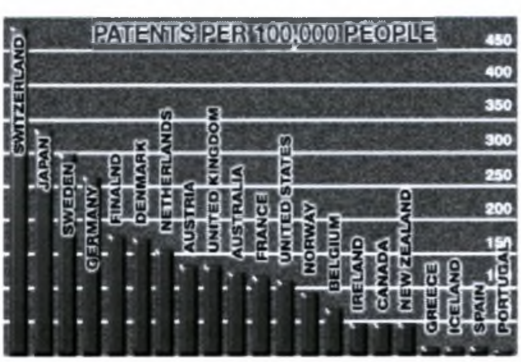
In Theory of Inventive Problem Solving, known as TRIZ (see in 3.3 for a detailed analysis), an important aspect of not failing when trying to do innovation is to monitor the results at every step. This helps us to predict how the system will evolve and avoid mistakes that have been done before.

2.4 Innovation and patents

It is of obvious high importance to protect your innovative work. Patents consist a way of protecting innovation and they seem to increase in numbers (see Figure 1). Patent offices around the world provide with patent certificates various innovations and inventions. The offices for certifying patents in an effort of keeping very high standards for the products that are patented, the products that are certified have to be innovative and of really high quality.

As we see in Figure 1 below patented work is very popular in Europe and Greece has a good appearance in the patent system. It is interesting to note that Japan stands very high.

The patents and the analysis of how the patents are created are the main source of information for the creator of the Inventive Problem Solving Method (TRIZ). He actually tried to analyze the solutions that the inventors used for the patents and later he tried to put them into certain categories. The concluding results of this research are very important and will be analyzed later on the thesis (See more in section for TRIZ in 3.3). Furthermore, as we will also see later in the thesis, the knowledge space of patents is of importance to software systems and in fact great efforts are devoted into utilizing this knowledge through the software.



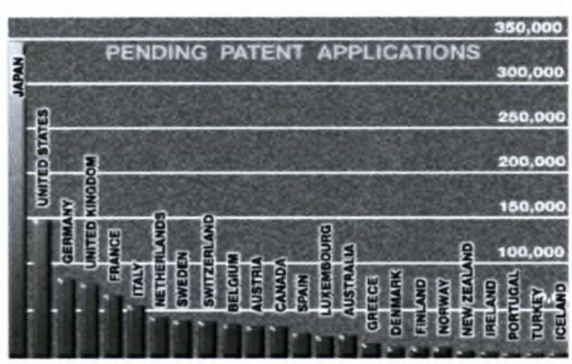


Figure 1: Patents per country.

3 Theoretical Frameworks for Innovation

How does Innovation actually take place? Many companies have been innovating for decades, so there must be identifiable methodologies in place (Gupta, 2007). Several known methodologies currently taught and used include creativity methods such as Brainstorming, Benchmarking, Complexity Theory, Axiomatic Design, QFD, Six Sigma, DFSS, TRIZ and many others.

All known such frameworks are listed below, several of them are briefly presented and the three most important analyzed and compared with each other. Specifically we consider the methods of the *Axiomatic Design* and the *Quality Function Deployment* (QFD) and the theoretical methodology of *TRIZ.*
The detail in the description and the depth in the analysis of each method are analogous to their importance.

3.1 Axiomatic Design

The Axiomatic Design framework is essentially a methodology designed to help with the decision making process. It is an axiom driven method which decomposes the customer requirements into functional requirements, design parameters, and process variables in order to achieve highly competitive results and fulfill the customers' needs. It is applicable in many design processes such as manufacturing, materials, and software and hardware designs.

Axiomatic Design is developed on top of three basic concepts; the *Four Design Domains*, the *Mapping Requirements* and the *Two Design Axioms* which are defined as follows:

Four Design Domains: There are four basic domains in the design world (Yang & Zhang, 2000)

- Customer Domain where the needs of the customer are identified.
- Functional Domain where the needs that are identified in the customer domain are stated in a way which explains the required functionality of the product.
- Physical Domain where the design parameters that match with the required functionality are identified.
- Process Domain where all the process variables are analyzed and the result is the way that the product will be produced.

Mapping Requirements: Solution alternatives are created by mapping the requirements in one domain onto a set of parameters in the corresponding domain.

The mapping between the customer and the functional domain is concept design, the mapping between the functional and the physical domain is product design and the mapping between the physical and the process domain is process design.

The mapping process is expressed in terms of characteristic vectors that are the goals and the solutions of the design process. Each domain has an output that includes very detailed information. The mapping between the corresponding domains is called *zigzagging*.

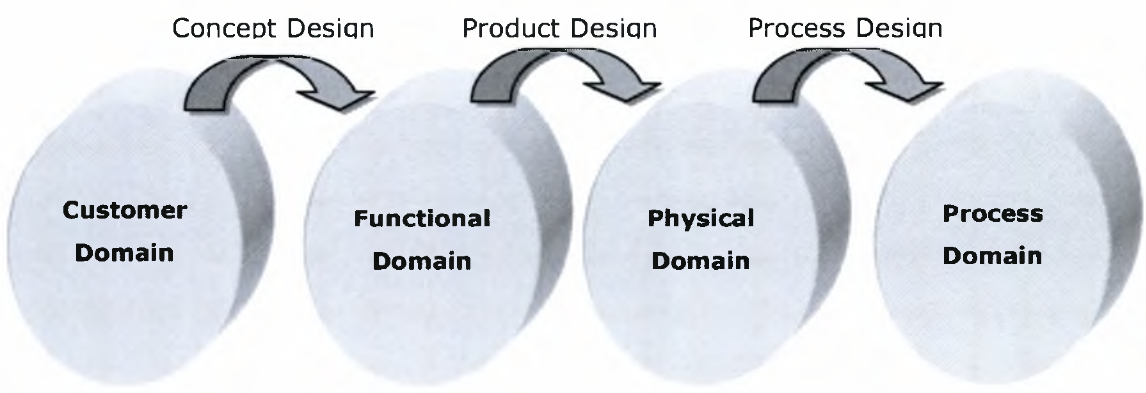


Figure 2: The four domains and the mapping process.

Two Design Axioms: Axioms are accepted without proof and are considered to be the foundations of a theory. The following two design axioms help with the evaluation of the proposed solution alternatives and the subsequence selection of the best alternatives.

1. Independence Axiom: Maintain the independence of the Functional Requirements.
2. Information Axiom: Minimize the information content of the design.

The general meaning of the first axiom is that a good design of a system is independent of the requirements. It is actually the mapping between the Functional Requirements (What needs to be done?) and the Design Parameters (How is it going to be done?). Designs which do not satisfy the Independence Axiom are called coupled while ones that satisfy the first axiom are called uncoupled or decoupled. In an uncoupled design the Design Parameters are completely independent.
An everyday example that we came across is a typical water faucet. The Functional Requirements are "control temperature" and "control water flow". The design parameters are hot and cold water handles. In the left image in Figure 3 the design is coupled while in the right one the design is decoupled (Axiomatic Design Technology). "Designs that satisfy the independence axiom are called uncoupled or decoupled," as Robert Powers said, president of Axiomatic Design Software, Inc[6].

Figure 3 Water faucet: An Axiomatic Design example

The second axiom is about minimizing the information about the design. Here information about the system is the key. The second axiom says that when two or more alternative

[6] http://www.axiomaticdesign.com/

designs satisfy the first axiom, the best design is the one with the least information. That is, when a design is good, information content is zero.

In general the main idea of this axiom is minimize the information content: Among alternative designs which satisfy Axiom 1, the best has the minimum information content which means the maximum probability of success.

There are many theorems and corollaries that derive from these two axioms. These will be discussed in 3.5.2 in contrast with TRIZ.

3.2 Quality Function Deployment (QFD)

Quality Function Deployment (QFD) is a method that helps us to understand the needs of the customer in order to plan and produce a product. It was originally designed in 1966 by Yoji Akao which described QFD as a "*method to transform user demands into design quality, to deploy the functions forming quality, and to deploy methods for achieving the design quality into subsystems and component parts, ultimately to specific elements of the manufacturing process*". (Akao, 1994)

QFD is a structured method which uses several types of matrices in order to define customer requirements and to translate them into plans to make a product which fulfills these needs. (Crow, Customer Focused Development with QFD, 2002)

QFD is nowadays accepted to be a widely used method in large companies and organizations. Really impressive applications are found in the design of huge projects such as the F-35 Joint Strike Fighter and in many organizations. Specifically, QFD and its techniques is used in big car companies like GM, Ford, Daimler, Chrysler, and others like IBM, Raytheon, General Electric, Boeing, Lockheed, Martin and many others.
Furthermore, QFD is a basic method that is used in *Design for Six Sigma* (DFSS) which we briefly present in section 3.4.2 below.

3.2.1 The QFD methodology

In QFD there are some basic general steps that one needs to follow in order to complete the method successfully. These are:

(a) *Gather Customer Needs:* In QFD it is important to gather the customers' needs and organize them in the right way. It is called the Voice of Customer. In order to collect all the needs and requirements the researcher can use surveys, questionnaires, interviews and anything that will help him or her to understand the problem and the user requirements. The organizing part of the information can be done with ranking methods and also gathering information from other sources. After this step is completed the first matrix of QFD appears. It is the House of Quality (see below).

(b) *Product Planning Matrix:* It consists of several steps and its main objective is to distinguish which of the selected customer needs are important. In the Product Planning Matrix all the customer needs are organized.

(c) *Concept Selection Matrix and Development:* In this step the concept alternatives are discussed and evaluated.

(d) *Assembly/Part Deployment Matrix*: This matrix helps us to develop a design layout and determine the critical subsystems and parts of the solution. A fact that this matrix is useful is that the designer develops the connections and relationships between the customer needs and the parts of the designed system. Moreover it helps determine the potential interactions between the technical part characteristics. Importance rating is essential in this matrix as to analyze and finalize it and determine the required actions to be followed (Crow, Performing Qfd Step By Step, 2002).

The basic methodology involves 4 stages and phases of the development of the system (Crow, Customer Focused Development with QFD, 2002) as they are depicted in Figure 4. The first Phase is the Product Planning phase where, as we can see in the figure below, the important thing is to define and prioritize the customer needs. This phase includes the planning of the product that responds to and fulfills those needs. The outcomes of this phase are the Technical Requirements of the new product. These requirements feature the input of the next phase, the Product Design or Part Deployment Design. In this phase the inventors identify the critical parts of the new product and translate them into Part Characteristics. In the Process Planning Phase after analyzing the Critical Characteristics, we establish the critical processes of the product. The final phase is important in order to Control the quality of the Parts and the Processes of the new product.

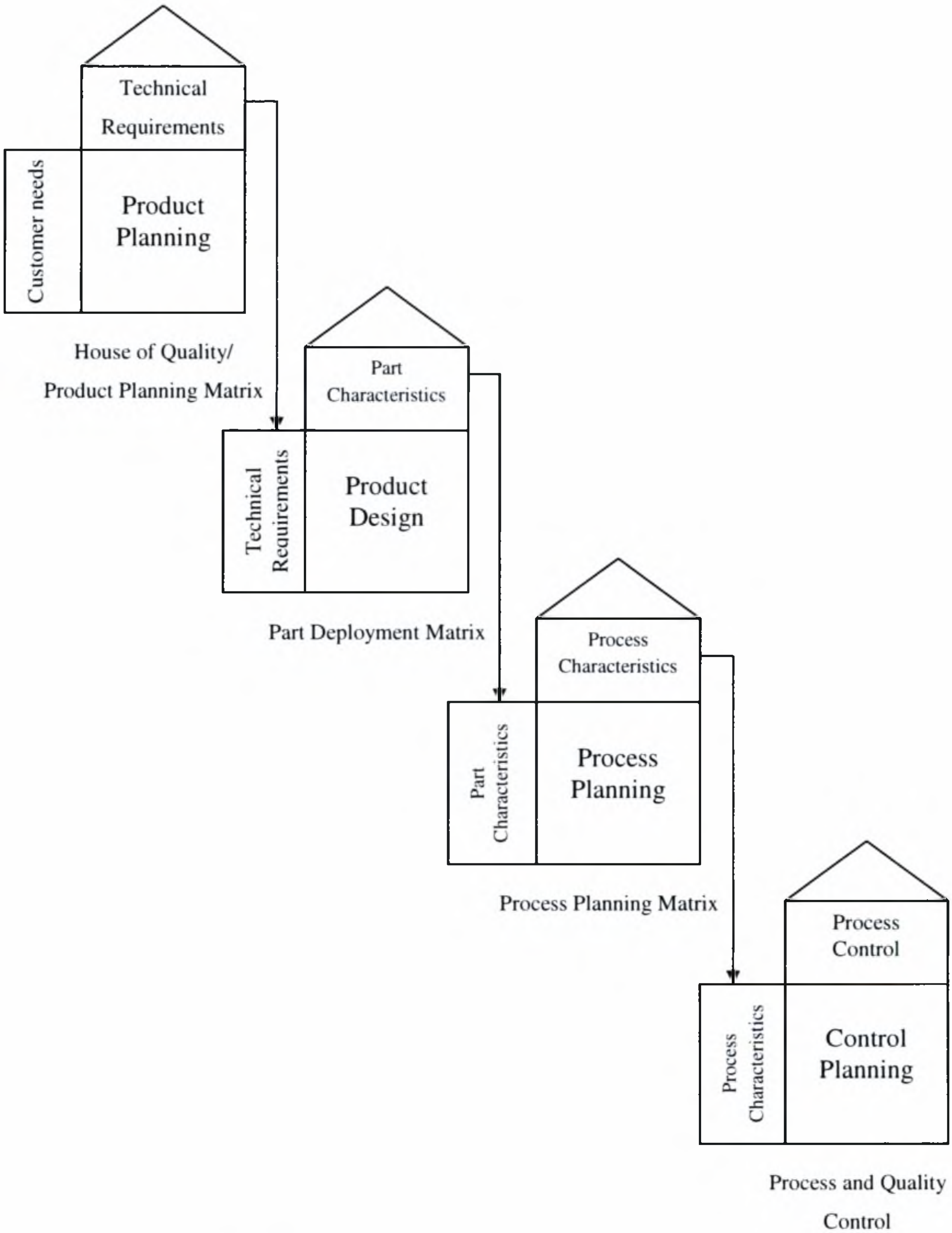


Figure 4 The Four Phases of QFD

It is interesting to mention that the House of Quality was introduced in 1972 in the design of an oil tanker by Mitsubishi Heavy Industries. There is a lot of work done around the House of Quality. There are even software tools to help people design it. Nevertheless, bedsides its impact Akao stated that the House of Quality is not QFD but rather an example of one tool. It is called "House" because it looks like a house with correlation matrix as its roof, customer needs with product features as the main part and evaluation as the porch. It mainly explains how the needs of the customer will meet the product that is going to be produced. We give an overview of the House of Quality in the following Figure 5 House of Quality.

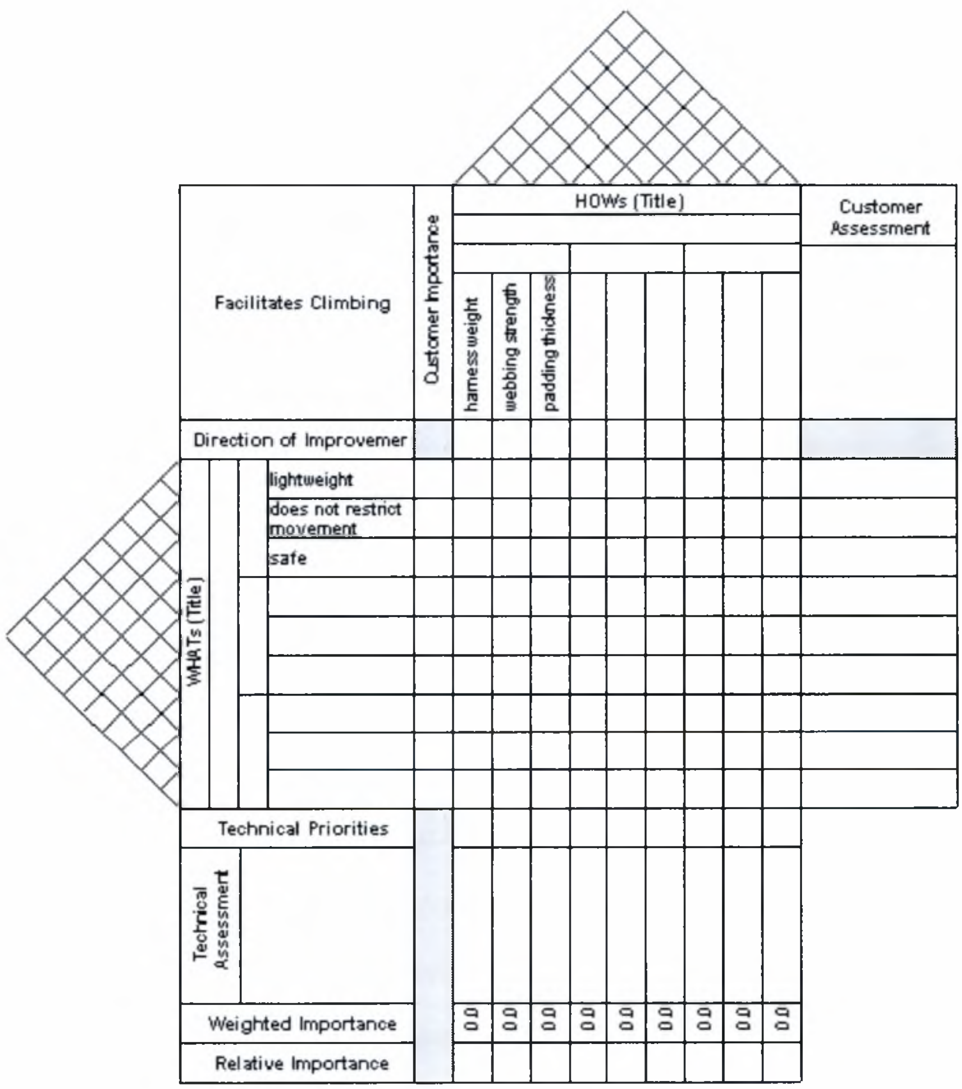


Figure 5 House of Quality

3.3 What is TRIZ?

TRIZ is a *Methodology of Inventive Problem Solving* or *Theory of Inventive Problem Solving*. It was developed in 1950's by Genrich Saulovich Altshuller and his colleagues. A short biography of Altshuller is given in Annex I: **Altshuller - A short biography**.

Altshuller was originally trying to find a way to exclude the subject of the innovation, separate innovations from the subject that each one concerned. While he was researching, he noticed that researchers that were doing innovations of similar fields and used similar knowledge didn't share any of that knowledge and were not aware of anything else but their knowledge. After researching over 400.000 patents he tried to find a way to overcome the subject of the Innovation and unite the way that the Innovations are created. After a systematic and in depth analysis of his collected data, he came to the conclusion that very often the processes to solve different problems from diverse technological fields follow certain common basic rules. He collected these basic rules and separated them from any subject. These are now known as the 40 *Inventive Principles* and are used for solving inventive problems. Based on these principles, Altshuller tried to avoid all the problems that arise from the method with psychological inertia. Overcoming this factor the solutions are of higher level. This method, which was developed by Altshuller and his team, doesn't have as an intention to simulate the way the inventor thinks. The purpose is that when someone uses it, the solutions will be of the same type. In the figure below we see the general theme of TRIZ (on the left) with the problem of finding the roots of a polynomial of degree 2 (on the right). If someone decides to use TRIZ it means that there is a problem to be solved. After using TRIZ and its tools he or she will come up with the general problem, the pattern of the original problem. TRIZ and its knowledge base help the researcher to find the general solution to the general problem, and this comes from Altshuller's belief that *"someone else has already solved a similar problem to yours"*. TRIZ helps find the general solution and with the appropriate analogical tools the specific solution can be reached.

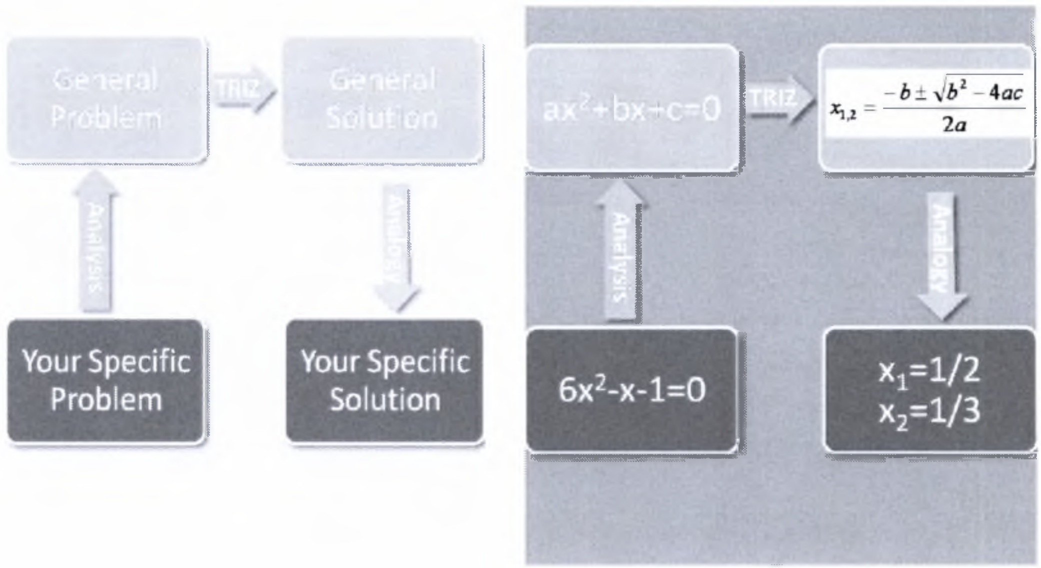


Figure 6 TRIZ abstraction and an example.

Apart from the 40 Inventive Principles, Altshuller stated that the problem can be analyzed in what he defined as the 39 Parameters. Based on the same philosophy as the one used for the identification of the 40 Inventive Principles, these parameters are far from any technological field. The 39 Parameters are part of the Contradiction Matrix, the tool that uses the 40 Inventive Principles in order to solve the technological problem.

After the research on the patents Altshuller categorized the solution of the patents into the following 5 levels:

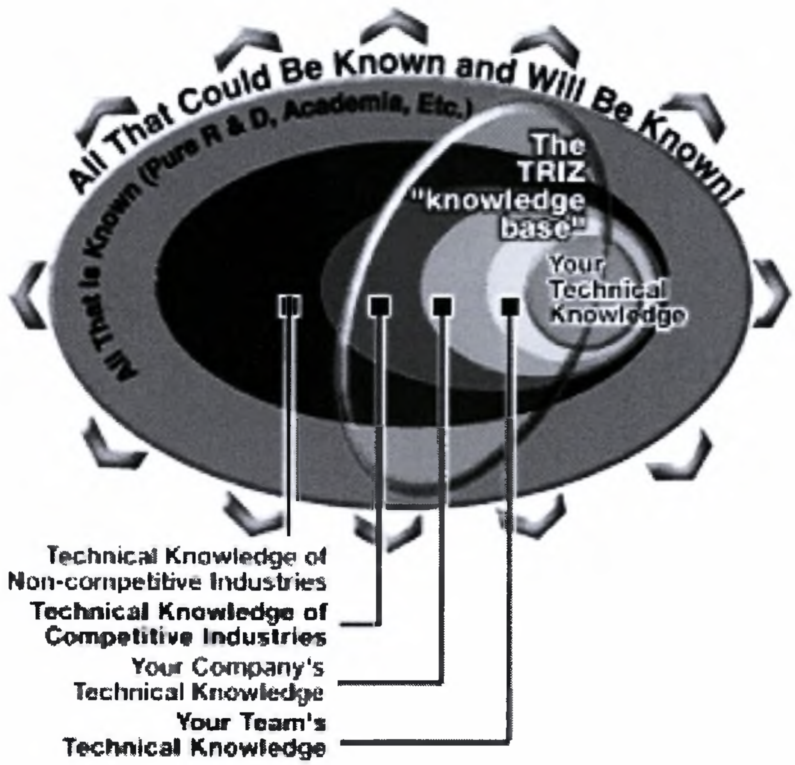


Figure 7 The TRIZ Knowledge (Theory of Inventive Problem solving (TRIZ))

Level 1: Routine design problems that are solved by methods known within the specialty of the company or the organization. (He claims that 32% of the solutions occurred at this level.)

Level 2: Minor corrections to a system with knowledge found within the company itself. (45%)

Level 3: Fundamental improvements to an already existing system with methods known outside of the company are needed. (18%)

Level 4: New generations using a new scientific principle, rather than technological to perform the primary functions of the system. Introduction of a new principle in an existing system is required (4%).

Level 5: Rare scientific discoveries and inventions of a new system are necessary (less than 1%). For example inventions such as x-rays and laser (Savransky, 1996).

3.3.1 TRIZ characteristics

When all the analysis of the problems is done in a project, the inventors and the developers have to decide what the next steps for finding the solution will be. They have to choose among several creativity tools to find help with their invention. Brainstorming, synectics and other similar approaches are limited in capabilities and creativity because of their dependence on the intuition of the team. If the methods used are physiologically based, the results will probably be unpredictable and unrepeatable. TRIZ is a method for problem solving based on logic and data. It can provide repeatability and predictability due to its structure and basically due to its algorithmic approach. (Savransky, 1996). The above discussion is nicely depicted in Figure 8 below.

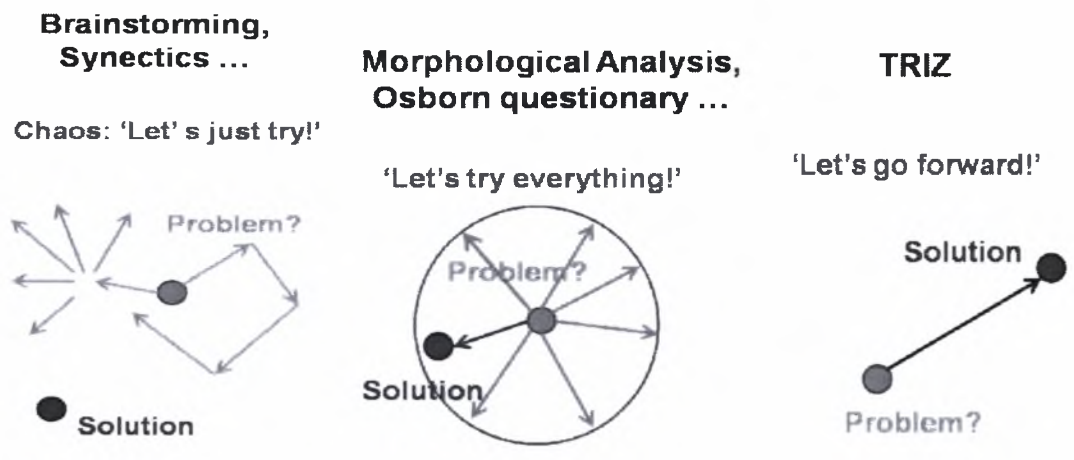


Figure 8 TRIZ as an effective roadmap.

TRIZ includes many theoretical foundations, but as a theory from a philosophical point of view it is incomplete. Efforts are still been made for more studies and research in order to make it complete and consistent as a theory (Souckov, 2006).

Modern TRIZ is a large knowledge base, which includes several methods and techniques. According to (Souckov, 2006) "*TRIZ is an evolving science of creativity and innovation which has already been used to build a number of practical and working tools and techniques*".

TRIZ can sometimes lead the inventor to a solution directly but the case is to fertilize generic and abstract thinking, creative thinking, to be able to translate the ideas and the solutions. As Altshuller used to say about TRIZ "*It is not a system of powerful concept generating tools. It is a way of developing skills for what called strong thinking*".

3.3.2 TRIZ basic principles

TRIZ method is based on three major principles (Savransky, 1996):

(a) The resolution of Technical and Physical Contradictions.

(b) The Evolution of the Systems.

(c) The Ideal System and the Ideal Solution.

The basic concept of TRIZ is the resolution of a Contradiction. As stated by Altshuller "*emergence of a contradiction is the main feature that distinguishes an ordinary problem from an inventive problem*". In order to obtain innovation the contradiction has to be eliminated rather than optimized (Souckov, 2006).

There are two kinds of contradictions; the "Physical" and the "Technical" contradictions (Domb, Contradictions: Air Bag Applications, 1997).

Technical contradictions are the engineering "trade-offs". The desired state cannot be reached because something else in the system prevents it. When something gets better, something else gets worse. It represents a conflict between two parts of a system (Savransky, 1996). For example, the bandwidth increases (the parameter that gets better) but more power is required (the parameter that gets worse).

Physical contradictions exist when an object has opposite requirements (Domb, Contradictions: Air Bag Applications, 1997). The physical contradictions result from incompatible requirements on the physical condition of the same element (Savransky, 1996). For example the software should be easy to use but at the same time should have many complex features and options.

3.3.3 Background theory: Theory of Technical Systems Evolution and Trends and the Laws of Evolution

Technical Systems Evolution is the main theoretical foundation of TRIZ (Souchkov, 2006). Every product which is designed for certain functionality, tends to evolve in a systematic way according to some generic patterns and trends of evolution. In other words "Technical Systems Evolve". The TRIZ Laws of Evolution are claimed to be independent of any technological area. These laws of evolution are powerful knowledge which helps the inventor to predict the evolution of the system.

The most important trend of technology evolution is the trend of ideality growth. This trend indicates that a system has to be designed and produced to do every required function with the highest performance and the minimum amount of cost.

The other laws of evolution are listed below, grouped into three categories:

Statics:

- Law of system completeness: a technical system tends to complete its material-energy structure to deliver the required function.
- Law of energy bypass: a necessary condition of functioning of a system is to provide effective energy flows through all parts of the system. Accordingly the trend of ideality growth, systems tend to minimize amount of types of energy used as well as to minimize a number of energy transformations within a system.
- Law of irregularity of system's parts evolution: the more complex a system becomes during the evolution the more irregularly its parts evolve. As a result, further development of the system becomes more difficult due to contradictions arising between system's parts.

Kinematics:

- Law of increasing a number of material-energy interactions: a system tends to increase the degree of interacting material-energy components to provide a higher degree of performance and controllability.
- Law of frequency and form adjustment: During evolution, a system tends to adjust frequencies and forms of interacting components.
- Law of dynamics growth: A system tends to replace existing designs of its movable parts or working tools with structures which have a higher degree of freedom.

Dynamics:

- Law of transition to microlevel: A system tends to replace a physical principle behind its component delivering a main function with a new physical principle which utilizes properties of more fragmented materials, particles or physical fields.
- Law of transition to macrolevel: A system which has approached its limits of evolution can further evolve through merging with other systems (that produces a new function); or it can be eliminated if its function might be delivered by other systems.

3.3.4 The TRIZ *classical* Method

TRIZ as a detailed algorithm of problem solving can be summarized in the basic following steps. Furthermore, there are many tools and methods that are part of the TRIZ knowledge base (Savransky, 1996) and they we will be presented and analyzed later in this chapter.

i. Select the technical problem. When the inventor defines the problem, TRIZ will help formulate the technical contradiction of the problem. Making the right choice of the contradiction the problem passes to the state of problem solving. If the contradiction is a part of the Contradiction Matrix a lot of time will be spared and the solution process will be faster.

ii. Formulate a physical contradiction. The technical contradiction should be replaced with a physical one. An element of the system should have a property A for executing a function and also an "anti-A" property for other conditions of the problem.

iii. Formulate an Ideal Solution. According to TRIZ philosophy the Ideal System and is a system with no harmful factors and only with beneficial ones. The Ideal Solution is analogous to the mathematics definition of the limit, the unrealizable system.

iv. Find resources for the solution making use of the TRIZ knowledge base.

v. Determine the strength of the solutions and choose the best one. Here comes the comparison of each solution with the Ideal Solution that was formulated in (iii) above. The evaluation of the result and the solution is for high importance for the outcome of the invention.

vi. Predict the development of the system considered within the problem. TRIZ supports this step with Laws of Evolution and with several forecasting techniques. At this point the inventor can predict potential future problems of the system.

vii. Analyze the solution process in order to prevent similar problems.

3.3.5 Solving a Problem with Classical TRIZ

The classical TRIZ method is resolving technical contradictions using the Contradiction Matrix and the 40 Inventive Principles. It is the first and most popular TRIZ technique.
Once a contradiction is expressed in the technical contradiction the next step is to locate the features of the contradiction in the Contradiction matrix. We will use a simple example of a technical problem that is analyzed as a contradiction.
Consider that the problem is the proposal to change the speed of the inflation of the airbag, to reduce injuries in small occupants. The contradiction here is that injuries increase in high speed accidents. The translation in the TRIZ features is:

Improving parameter: Duration of moving object
Worsening parameter: Object generated harmful effects.

	Worsening Feature → / Improving Feature ↓	Volume of moving object	Speed	Force (Intensity)	Stress or pressure	Shape	Reliability	Object-generated harmful factors	Ease of operation	Ease of repair	Device complexity	Difficulty of detecting and measuring
		7	9	10	11	12	27	31	33	34	36	37
9	Speed	7, 29, 34	+	13, 28, 15, 19	6, 18, 38, 40	35, 15, 18, 34	11, 35, 27, 28	2, 24, 35, 21	32, 28, 13, 12	34, 2, 28, 27	10, 28, 4, 34	3, 34, 27, 16
10	Force (Intensity)	15, 9, 12, 37	13, 28, 15, 12	+	18, 21, 11	10, 35, 40, 34	3, 35, 13, 21	13, 3, 36, 24	1, 28, 3, 25	15, 1, 11	26, 35, 10, 18	36, 37, 10, 19
11	Stress or pressure	6, 35, 10	6, 35, 36	36, 35, 21	+	35, 4, 15, 10	10, 13, 19, 35	2, 33, 27, 18	11	2	19, 1, 35	2, 36, 37
12	Shape	14, 4, 15, 22	35, 15, 34, 18	35, 10, 37, 40	34, 15, 10, 14	+	10, 40, 16	35, 1	32, 15, 26	2, 13, 1	16, 29, 1, 28	15, 13, 39
15	Duration of action of moving object	10, 2, 19, 30	3, 35, 5	19, 2, 16	19, 3, 27	14, 26, 28, 25	11, 2, 13	21, 39, 16, 22	12, 27	29, 10, 27	10, 4, 29, 15	19, 29, 39, 35
33	Ease of operation	1, 16, 35, 15	18, 13, 34	28, 13 35	2, 32, 12	15, 34, 29, 28	17, 27, 8, 40		+	12, 26, 1, 32	32, 26, 12, 17	

Figure 9 Extract of the Contradiction Matrix (Domb, Contradictions: Air Bag Applications, 1997)

The actual contradiction exists from the beginning and what is of high importance is to form the trade-off, the contradiction the actual problem in the right way.

If we look up the Contradiction Matrix the parameters that we came up in the previous step we will find that the intersection of those two identifies, of the 40 Inventive Principles of TRIZ, Principles "21, 39, 16, 22".

The complete list of the 40 Inventive Principles can be found in Annex II **The 40 Inventive Principles** while the Contradiction Matrix along with the 39 parameters can be found in **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**.

Next follows the analysis of the Principles that the Contradiction Matrix suggests for this technical contradiction.

Principle 21. Skipping

A. Conduct a process, or certain stages at high speed.

Inflate the air bag faster, so that it is fully inflated when the small person impacts it.

Principle 39. Inert atmosphere

A. Replace a normal environment with an inert one.

B. Add neutral parts, or inert additives to an object.

The bag acts "hard" because of its motion. So something that would "soften" the surface would be the equivalent of an "inert" material-it does not prevent the original purpose but it cushions the blow from the bag itself. Change the structure of the bag-make it corrugated, or make it of filaments, or use multiple crushable layers. Change the "hardness" without changing the structure.

Principle 16. Partial or excessive actions

A. If 100% of an object is hard to achieve using a given solution method then, by using "slightly less" or "slightly more" of the same method, the problem may be considerably easier to solve.

The de-powered air bag has been proposed as a solution of this type. By using less power, the acceleration of the bag is less, and injuries will be reduced.
Conversely, smaller bags with higher power would reach full inflation sooner, so that the passenger would be protected from the accident and not injured by the air bag.

Principle 22. "Blessing in disguise" or "Turn Lemons into Lemonade"
A. Use harmful factors to achieve a positive effect.
Use the relative motion of the person and the vehicle as part of the protection. Design other parts of the system (seat, dash, side panels) to redirect the moving person to be properly placed for best air-bag protection.
B. Eliminate the primary harmful action by adding it to another harmful action to resolve the problem.
Add a buffering material to a corrosive solution.
Use a helium-oxygen mix for diving, to eliminate both nitrogen narcosis and oxygen poisoning from air and other nitrox mixes.
C. Amplify a harmful factor to such a degree that it is no longer harmful.
Use a backfire to eliminate the fuel from a forest fire
This again suggests inflating the air bag faster, so that it is no longer harmful by the time the person reaches it.

For a detail presentation of the above example the reader is referred to (Domb, Contradictions: Air Bag Applications, 1997)

Physical contradictions are the case where two mutually opposite requirements to one aspect of a technical system need to be fulfilled at the same time. Situations like this are impossible to solve with the common ordinary sense. TRIZ advises to formulate situations like this into the physical contradiction form and to resolve such contradictions the following *separation principles* are recommended:

1. Separation in space
2. Separation in time

3. Separation between the whole system and its parts
4. Separation based on different conditions

If we examine closely the physical contradictions, the requirements to solve the contradictions may be found separable in time, in space, or in some other conditions. Then under the separation the system can satisfy the contradictory conditions separately (Nakagawa, 2001).

3.3.6 The evolution of TRIZ: ARIZ and the Substance- field analysis

Over the years the research of Altshuller and his team continued, many articles and books have been published and major international conferences have been devoted to. But most important TRIZ tried to catch all the types of problems in order to help and be effective. Two of the most important techniques that were developed are ARIZ and Substance- field analysis.

ARIZ is one of the most powerful and complex TRIZ technique which helps to solve the problem that cannot be solved with any other TRIZ tool. ARIZ is the acronym for the Russian phrase "Algorithm for Inventive Problem Solving". (Marconi, 1998). It is a structured process that makes a complex problem to evolve to a point where it is just a simple enough problem to solve.

ARIZ is a step-by-step program for the analysis and solution of the inventive problems (Petrov, 2004). It is not always easy to analyze and formulate a problem effectively and ARIZ has the method of the comprehensive analysis, a very heavy and difficult process. According to Altshuller there is only one difference between TRIZ and ARIZ. The letter "T" stands for Theory and the letter "A" for Algorithm. Algorithm means a sequence of mathematical operations and a clear program of actions. Which came first? Because ARIZ is part of the original TRIZ Problem Solving Procedure we cannot answer clearly this question. ARIZ as an algorithm that established TRIZ as a problem solving method and this is why it is an important part of TRIZ. (Soderlin, 2002).

There are several version of ARIZ as it has been developed by the years. The first ARIZ version appeared in 1959 (ARIZ-59). Other modifications are ARIZ-61, ARIZ-71, ARIZ-77, ARIZ-85, ARIZ-85C (Petrov, 2004). The later modification is most commonly used.

Substance-Field (Su-field) Analysis (Slocum) is a TRIZ analytical tool for modeling problems related to existing technological systems. It provides a fast, simple model to use for considering different ideas drawn from a knowledge base. According to Su-field Analysis any given system can be presented as an interaction of 2 *substances* with each other, over a *field*. More specifically, it considers that the desired function of a system is the output from an object or substance (**S1**) which can be caused by another object (**S2**) with the help of some types of energy (**F**). Substances can be single items or complex systems. The action or means of accomplishing the action is called a field. Fields can be considered mechanical, electric, magnetic etc.

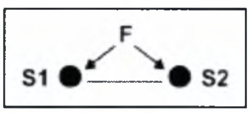


Figure 10 Su-Field Modeling

Substance field analysis is used for problem formulating and the problem can be solved with the 76 inventive standards.

There are four steps to follow in developing the Su-field Model (Terninko):

1. Identify the elements.
2. Construct the model.
3. Consider solutions from the 76 Standard Solutions.
4. Develop a concept to support the solution.

Below we give a diagram that shows how the Su-Field analysis can be applied.

The process iterates between steps 1 and 2 until there is the right formulation of a problem and the triplet is identified. The solution is structured in step 3 and in step 4 it is developed.

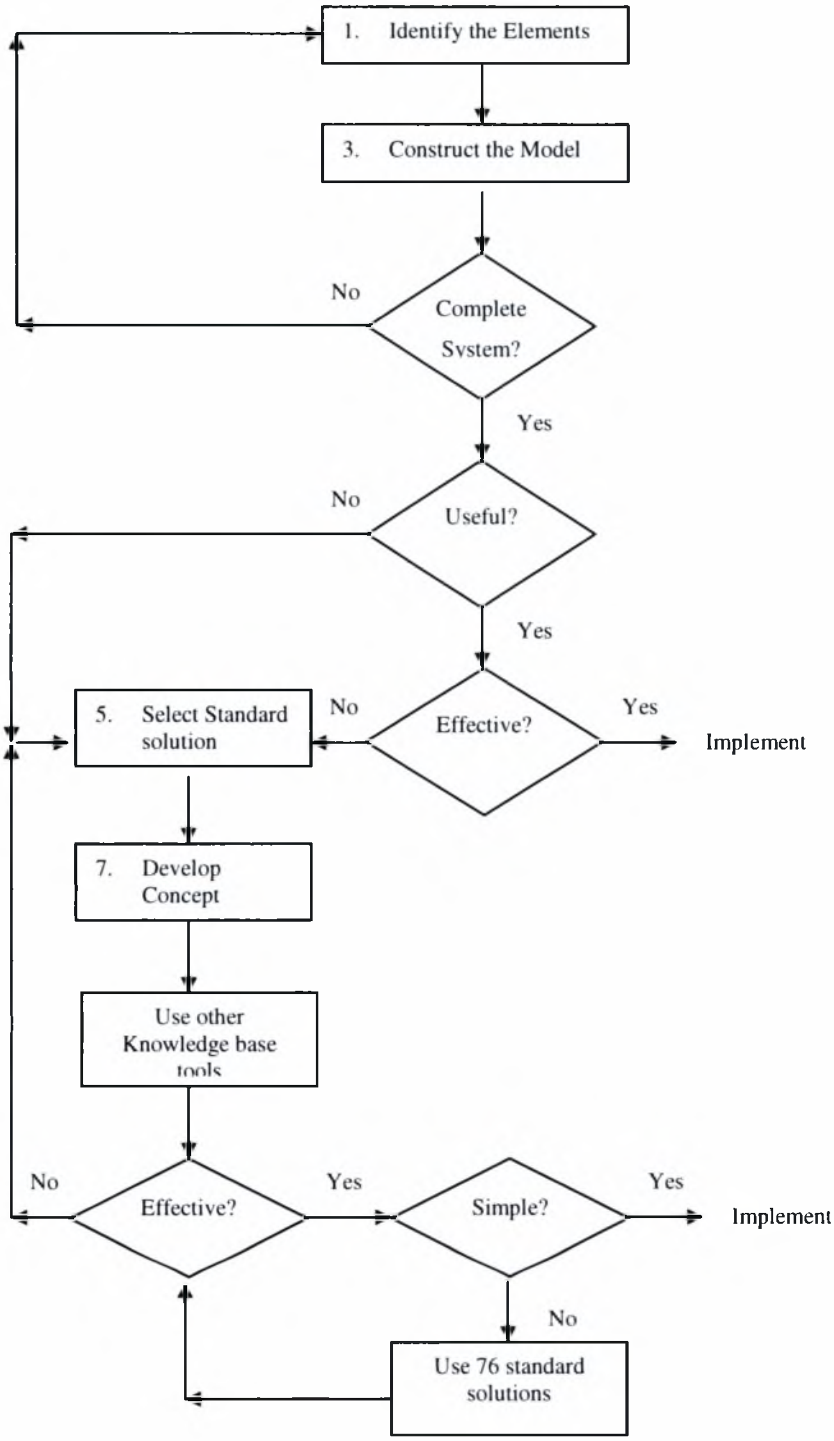


Figure 11 Su-field Analysis flow

3.3.7 The TRIZ landscape.

It is important to have a clear view of the whole TRIZ "landscape". For that, we note that TRIZ consists of number of tools. These tools form a sequence of a process and follow a certain philosophy (Sheu, 2007). In the figure below we see the hierarchical view of TRIZ and its tools.

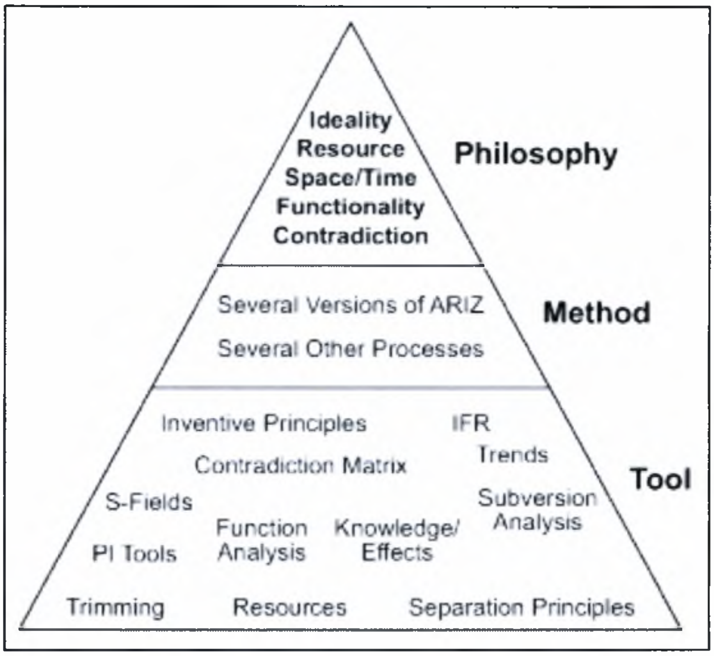


Figure 12 The TRIZ hierarchical view (Sheu, 2007)

When using TRIZ there is a certain sequence of tools that are going to be used. The process starts with specifying a problem. The next step is to analyze the problem using problem analysis methods. After that, the problem is solved using one of the TRIZ tools.

In the following figure (Figure 14) we show the General TRIZ flow and the many components that someone that practices TRIZ can use. We will refer to this figure in the next section too when we will consider software issues for TRIZ.

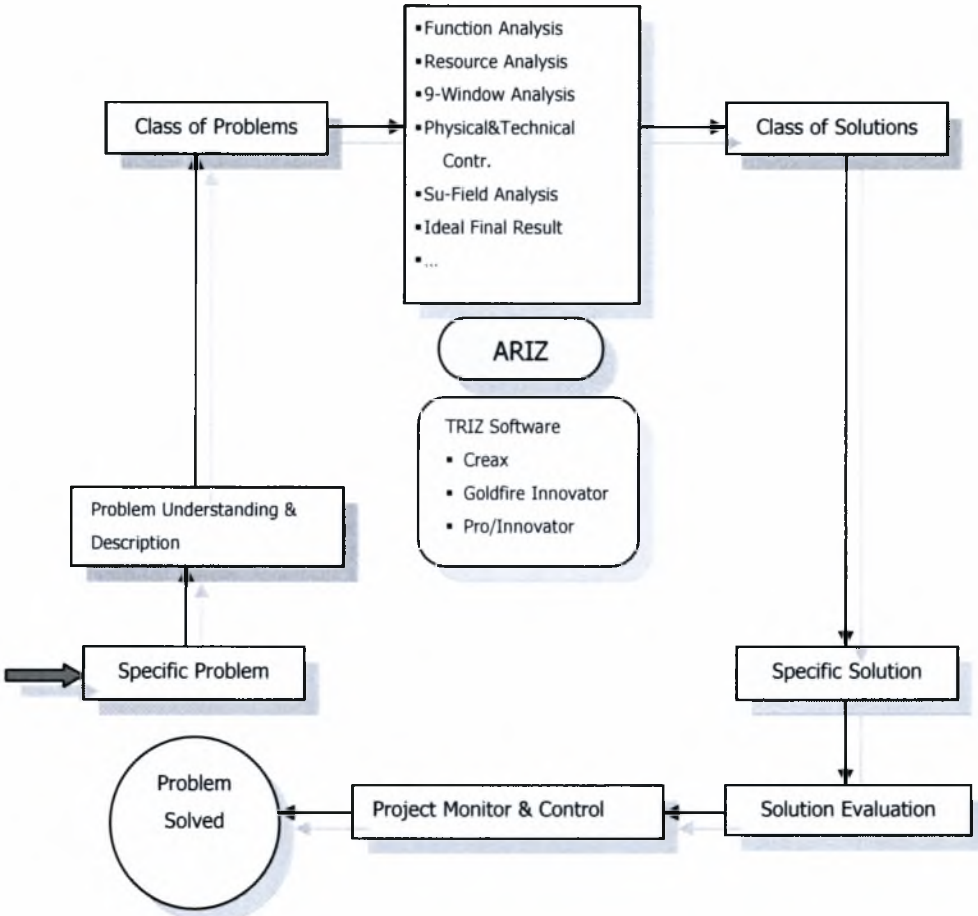


Figure 14 TRIZ flowchart

3.3.8 System Analysis Methods

Along with TRIZ, many other methods for system analysis and problem formulation have been developed and are currently in use. It is a very important factor of Inventive problem solving to analyze the system and the problem of the system properly. The system analysis methods help the researcher or the inventor to analyze the problem, identify the contradiction of the problem and formulate it properly. The system analysis methods are not an explicit part of TRIZ. These methods are developed from many laboratories and teams. The TRIZ innovation process benefits from the system analysis methods, because there is a useful and well formulated outcome of them. Out of these methods we comment below on five of them.

Multi-Screen diagram of thinking, also known as the *9-window diagram*, is a tool for system analysis and forecast. With this method every system is viewed in three layers: the system itself, with all its boundaries and limits, the subsystems and the supersystem. Moreover with the layers, there is analysis in time, with the present, the past and the future as it is depicted in Figure 15. This makes easier for us to understand the evolution of the system. According to Altshuller "*This way of thinking is a feature of outstanding inventors, artists, musicians-those who used to create new breakthrough ideas by seeing the world through the prism of system thinking*". (Souchkov, 2006)

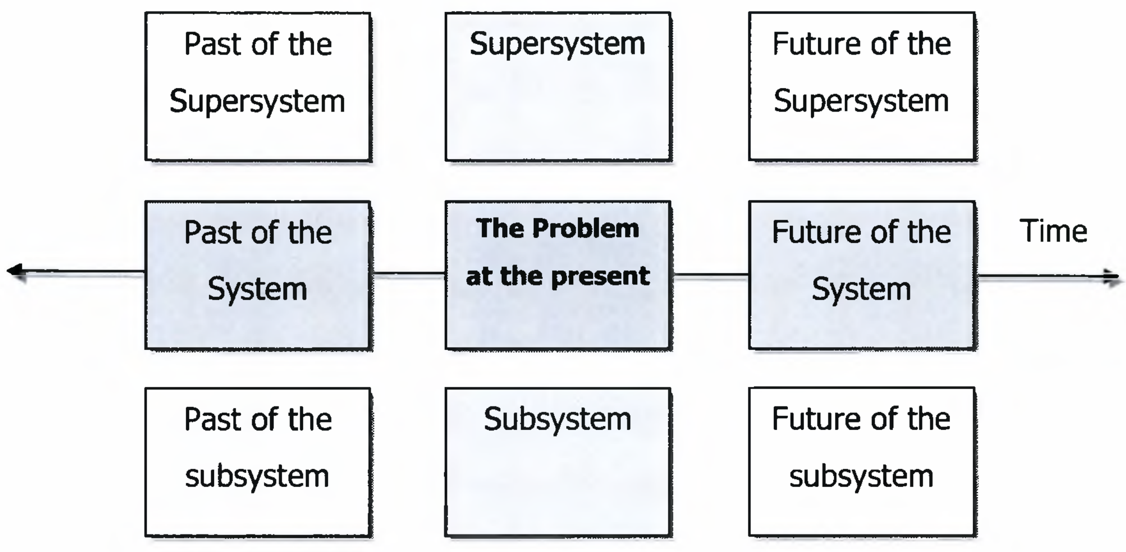


Figure 15 - The Multi-Screen Diagram

Function analysis is a systematic analysis of products and it is used to formulate a problem in terms of the TRIZ problem solving method.

Function is defined as *an effect of a physical interaction between two system components.* Function analysis is used to model the existing products and the functions that derive from them. It is commonly used in Su-field analysis modeling process of the problem (Souchkov, 2006).

Resource Analysis: Resources play a major role in TRIZ and the proper use of resources helps to introduce the ideal solutions without complicating the system. Analyzing the resources helps obtaining more cost-effective solutions. Originally Resource analysis was part of ARIZ, but because of its strong effect and its efficiency it is used with other TRIZ methods as well (Souchkov, 2006).

Root Cause Analysis is a method used for analyzing a problem and formulating technical contradictions. The first step is to define the initial problem and then try to find what is causing this problem. There are four general steps: data collection, causal factor charting, root cause identification and recommendation generation and implementation (Jung, Bae, Suh, & Yi, 2006). The inventor finds the causes of the initial problem. The causes can be analyzed to more detailed ones that derive from the initial cause. After charting the causes the contradictions arise. Careful evaluation has to be done to choose the most important contradiction to proceed with the solution of the problem.

Root Conflict Analysis (RCA+) is a method developed by ICG Training & Consulting[7]. When referring to conflicts in RCA+ we mean contradictions, causing conflicts (Souchkov, 2006). It is based on the similar approach of Root Cause Analysis and it focuses on revealing conflicts. It is used to analyze very complex problems and especially innovation situations.

3.4 Other innovation theories

Apart from the theories mentioned above there are many others that are used from researchers and inventors. There is in general a continuing effort to integrate TRIZ with other methods so that are more efficient. Below we briefly present few of them.

3.4.1 Six Sigma

Pure quality costs because of lost sales and business opportunities. Improving quality leads to customer satisfaction. Six Sigma is a structured methodology for improving quality, increasing "The Degree of Quality". It was developed in 1980s by statisticians in Motorola that they realized the usefulness in having a specific metric to measure the quality improvement. It uses the Sigma metrics, which refers to measure of variations. It is as

[7] http://www.xtriz.com/

statistical measurement of the capability of a process to meet customer satisfaction (Kumar, 2005).

Typically Six-Sigma follows a five–step methodology known as DMAIC (Define, Measure, Analyze, Improve and Control (Kermani, 2003).

- *Define*. In this phase the critical-to-quality (CTQ) variables should be defined. The customer satisfaction goals are what need to be defined. It is the voice-of-customer and in other words the reasons that cause and generate the problem.
- *Measure*: This phase includes information review and data collection of how the system currently works. It is important to quantify every factor that measures the CTQ variables.
- *Analyze:* This phase is a statistical analysis of the data to understand the relationships of the variable and how they affect the quality.
- *Improve:* A creative phase, where one is aware of the problem and the cause. The cause needs to be eliminated through developing the solutions. The important part on this phase is creativity.
- *Control* phase maintains quality. Here we give answers as what needs to be done to keeps the process working in the same quality. This phase is important to avoid falling back in quality.

3.4.2 Design for Six Sigma (DFSS)

DFSS is an approach for designing or re-constructing from the begging a product or a new service (Simon). DFSS is not actually a methodology. It is, as just mentioned, an approach towards new products and services with high performance (What is DFSS?).In Six Sigma as we mentioned above the methodology that is used is DMAIC. In DFSS the researcher can utilize many other possible methodologies. One popular DFSS methodology is called DMADV after the words

- *Define* the customers' needs and the moreover the goals of the project.
- *Measure* the specifications of the customers' needs.
- *Analyze* the process options to meet customers' needs.

- *Design* the process.
- *Verify* the design and the performance according to the customers' needs.

Since DFSS focuses on the design of a new product or service, it is important to have modeling and simulation tools for measuring and evaluating in advance the performance of the new system. The main tools include, Quality Function Deployment (QFD) that we already present in 3.2, Function analysis etc.

DFSS and Six Sigma seems to be closely related sharing common objectives. Six Sigma is an improvement process, philosophy and methodology. It is used to improve a product or process within the company that no longer meets the customers' needs. DFSS focuses in designing new products and services. The projects that use DFSS are larger and last longer and don't have the goal to fix a customer problem (What is DFSS?).

3.5 Comparison of the Methods

3.5.1 TRIZ and QFD

The techniques and methods of TRIZ are already discussed in a previous chapter of this thesis (3.2). Here we will see how each one of the major tools provided by TRIZ can be used in a variety of stages of QFD. There is an attempt from TRIZ and QFD experts to enhance QFD with TRIZ as the next step in innovation methods.

The first step in this kind of methods is to analyze what the user wants. This is known in QFD as Customers needs. The researcher collects the customers' needs and then organizes them and starts the product planning by analyzing these needs. The system analysis in TRIZ can be done with many methods such as Function Analysis (see more in 3.3.8).

The Ideal Final Result or the Ideal Solution is known to QFD users as customers' demanded quality. This explains why this innovation is needed. The quality improvement can be achieved by identifying why the system is non-ideal at the moment.

The contradictions of TRIZ are as we said before the classical engineering trade-offs. TRIZ guides the developer to design the principles that resolve the contradiction. This TRIZ technique can be used in all the steps of QFD.

When the developer reaches the stage of evaluating the solution, it has to be compared to the Ideal Final Result; to be sure that it meets the customers' she needs and that there is actual improvement in the new system. The evaluation process is a part of the whole QFD method.

The enhancement of QFD with TRIZ and the use of TRIZ tools in each step of QFD is a new field of research. The objective is to integrate these methods to help all product and process developers create innovations that win the market by solving customers' problems. (Domb, QFD and TIPS/TRIZ, 1997).

3.5.2 TRIZ and Axiomatic Design

TRIZ and Axiomatic Design can be compared because of the nature of these two theories (Yang & Zhang, 2000). Axiomatic Design has the two main axioms from which, as we said before (3.1), many corollaries can be derived. In this section two selected corollaries which have been derived from the two main axioms are compared with TRIZ fundamental tools.

Corollary 1: Decoupling of Coupled Design. Decouple or separate parts or aspects of a solution if Functional Requirements are coupled or become interdependent in the proposed design. This corollary is similar to the TRIZ contradiction analysis.

Its relation to TRIZ is easily seen. Solving a contradiction in TRIZ means the removal of functional coupling in Axiomatic Design. That leads us to our second Corollary.

Corollary 2: Minimization of Functional Requirements corresponds to the Ideal Final Result (IFR) philosophy.

This corollary recommends that the designer strives for maximum simplicity in overall design or the utmost simplicity in physical and functional characteristics. Also in TRIZ the IFR helps an engineer to focus on concepts that minimize requirements in substance, energy and complexity of engineering product and process.

We should mention though that not all corollaries can be compared with a TRIZ tool. For example, the corollary named "use of Standardization" states the rule "use of standard methods, operations and routines. TRIZ does not use standardization of the physical components. TRIZ focuses on the inventive problem solving.

Apart from the corollaries, form the two basic design axioms, theorems can be derived as well. Here we compare with TRIZ the theorem that states:" Coupling Due to Insufficient Number of DPs". When the number of Design Processes is less than the Functional Requirements then the solution is couple the functional requirements or the problem cannot be solved. Su-field analysis has a very similar approach. Any functioning system can be modeled in a triangle. Any missing part of this triangle reflects the problem.

There are also fundamental differences between these two theories. One of the 40 inventive principles of TRIZ is Asymmetry (Principle 4). In Axiomatic Design a corollary that derives is "Use of Symmetry".

4 Software and Practical Considerations

There are no software tools that can replace thinking skills and abstract thinking. TRIZ software tools basically provide a vast collection of TRIZ concepts, techniques and examples and problem modeling means (Fey, 2001). In other words, TRIZ related software packages provide some tools to help the user practice TRIZ. They are mainly tools for problem formulation, problem and system analysis and databases with all the principles of TRIZ and many of the TRIZ components. It is important to repeat here that TRIZ is not just a simple process and not a database of methods. If someone wants to use TRIZ should have combinational thinking skills (Souckov, 2006). Nevertheless, TRIZ-based software may be helpful if it's used to support the thinking process, not replace it. If someone wants to use the TRIZ software tools effectively he should know how to use TRIZ first. It is important to state here that all the above statements hold for all other similar to TRIZ systems and platforms that seem to lead to the notion of Computer Aided Innovation.

We next briefly describe the most important tools that we found during our research. We will focus on two of them which we believe that are the most important and powerful.

4.1 Pro-Innovator (IWINT[8])

Pro/Innovator[9] is to our opinion one of the most important tools for Computer Aided Innovation (CAI). It is a very satisfying software platform for the Innovation process and very good tool to practice TRIZ and its components.

It consists of five main functions as those are depicted together with their interdependencies in Figure 16 and briefly described below:

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[8] http://www.iwint.com/

[9] http://www.iwint.com/products/product1/proi.html

Figure 16 Main functions of Pro/Innovator

Problem Description: With the *reFormulator* tool the researcher can analyze the problem. The method that is used for the reformulation of the problem is Multi Screen Diagram (see more in 3.3.8). Below we can see a diagram of the multi-screen diagram method outline that describes how the method works in the Pro/Innovator. It is basically the analysis of the system, the upper-systems and the subsystem in time. With this method the user has the problem analyzed with many details and in a form that is very close to a contradiction.

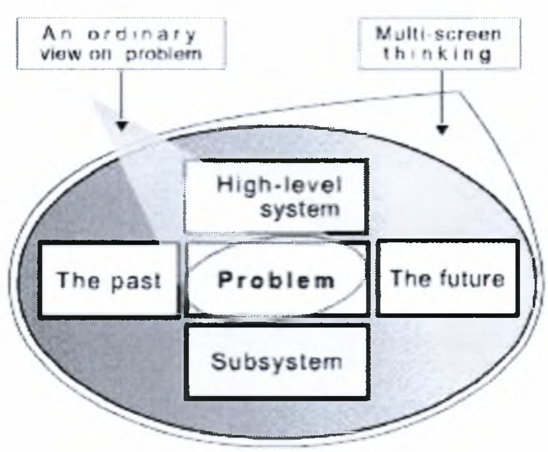

Figure 17 Multi-Screen Diagram in Pro/Innovator (Iwint, Inc. Computer Aided Innovation Solutions)

As already mentioned and as we can also see in Figure 17, the general philosophy of the method is mainly used to show how the resources, the interactions with the high level systems and the subsystems, help solve the problem, help define the root cause of the problem. With the *reFormulator* the researcher takes as a result alternative views of the original problem. After identifying all these, the researcher can try eliminating one of the problem causes.

The above defined methodology is very common in the software packages for TRIZ.

Here follows a picture of the *reFormulator* tool. As we can see, the user can describe the initial problem and then can add sypersystems, subsystems, and previous operations of the system, consequences and causes, all in relation with time.

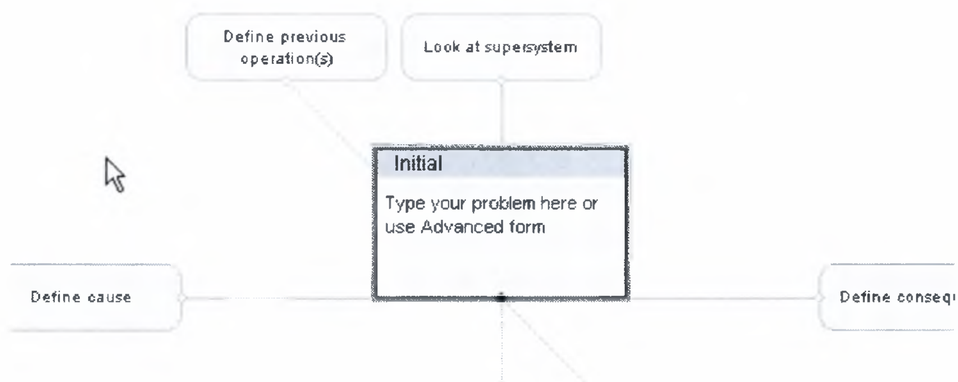

Figure 18 The reFormulator tool of Pro/Innovator (Iwint, Inc. Computer Aided Innovation Solutions)

Solutions Generation: In this tool there are animated examples of the TRIZ's 40 inventive principles. Here the user has the problem formulated in a contradiction, has all the analysis about the causes and the consequences and is ready to start solving the problem. In order to solve a contradiction the TRIZ's inventive principles are presented with examples. The important part in the solution generator, as it seems from the description of the software, is that there are actual solutions presented. Every solution that is shown is from a similar field. Here the user can find the patent search engine that is, according to the description of the software, semantic-driven. Unfortunately, no additional information is available on this subject.

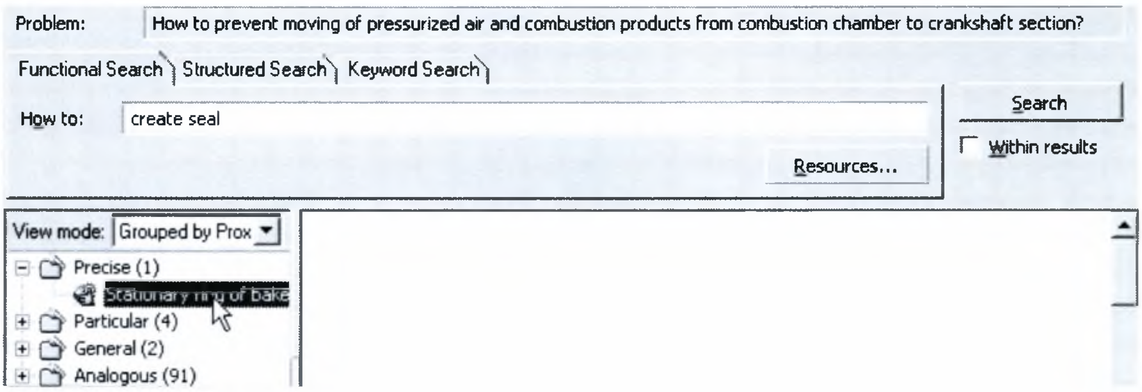

Figure 19 Solution Module of Pro/Innovator

The inventor can use the report that is generated from the system for writing a patent application in order to protect the invention, using the *Invention Protection*.

Solution evaluation: Evaluates solutions based on the statistic result of more than 9 million worldwide patents.

Intellectual assets Management: the basic knowledge base editor. Here the user can input many user defined solutions, using general templates.

Our comments on the Pro/Innovator are very positive. It is a very well organized tool, well structured, very useful and quite important for a TRIZ practitioner.

4.2 Innovation Suite (CREAX)

Innovation Suite[10] is one of the most respected software that support Innovation using TRIZ. It is created and published by CREAX[11] and has many tools that help the user with the innovation process. We analyze the most important ones that use TRIZ methods.

The *Problem Description* tool helps us to describe the original problem. The main idea is that the user creates a project, defines the details, the resources, the constraints and many other aspects of the problem. Here follows an example of a problem that is described in the Problem Description tool.

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[10] http://www.creaxinnovationsuite.com/

[11] http://www.creax.com/index.htm

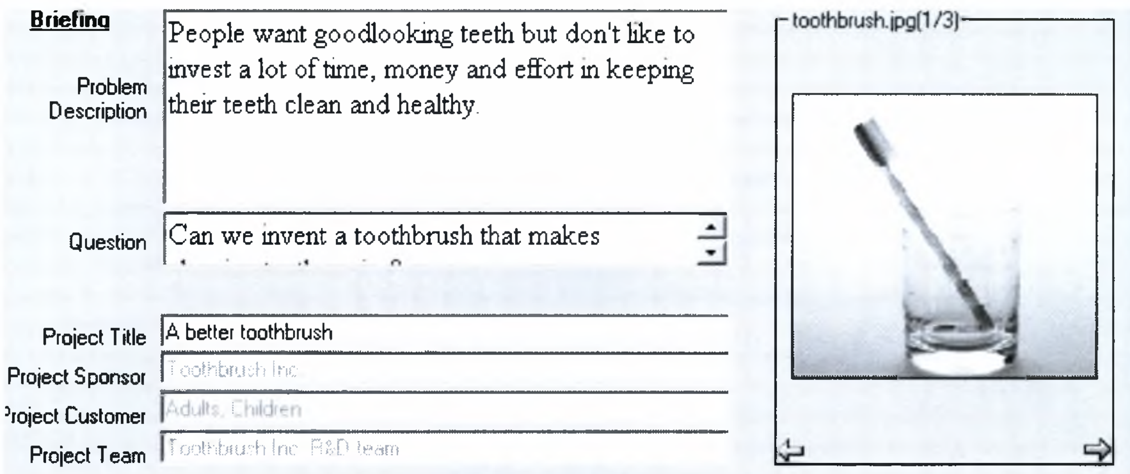

Figure 20 Problem Description Module of Innovation Suite (CREAX Innovation Suite)

reDefinition is a tool that actually uses the root cause analysis that we described in 3.3.8 This tool is a way of clarifying the original problem that was defined in the Problem description module. With root cause analysis the researcher can identify the roots of the problem and specify what is causing the problem. The tool is described in the picture below.

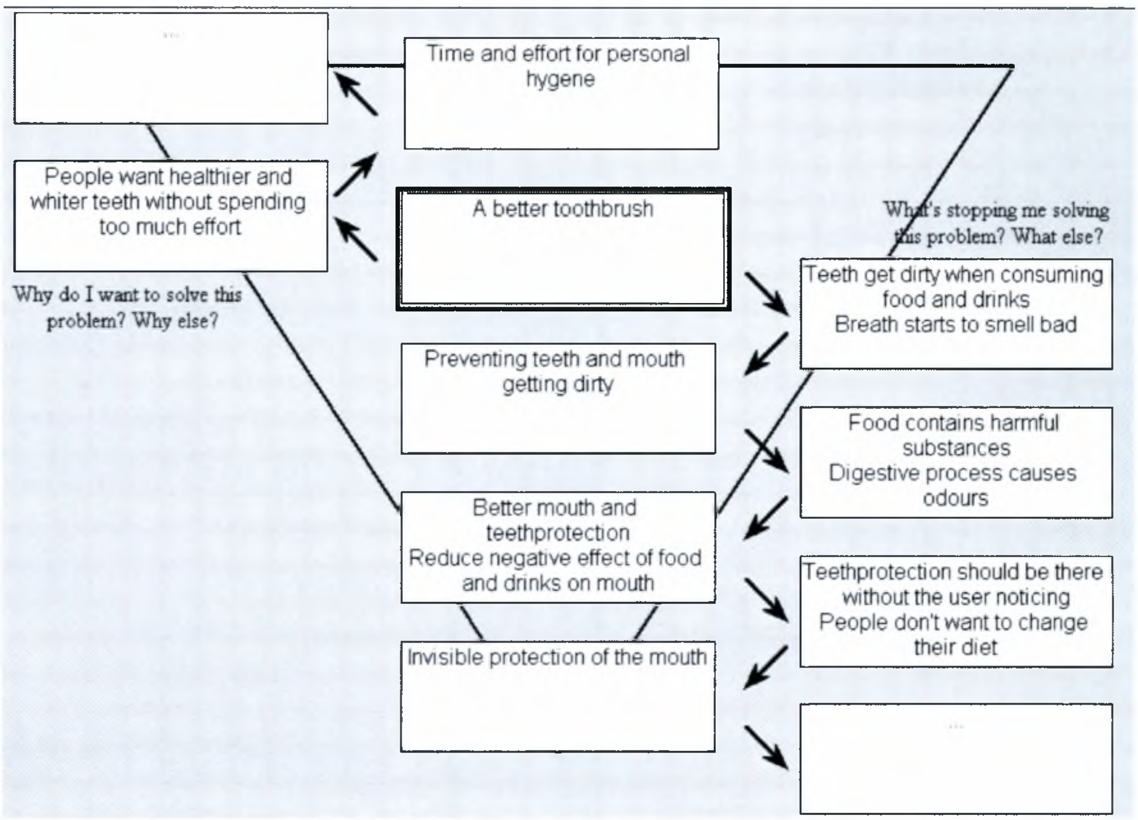

Figure 21 reDefinition Tool of Innovation Suite (CREAX Innovation Suite)

System Model is used to describe the functional relationships between the various components of the system such as effective, insufficient or harmful and some other types. In the figure bellow we see the example of this tool given by Creax. The inter-relationships in the example are stated with the arrows.

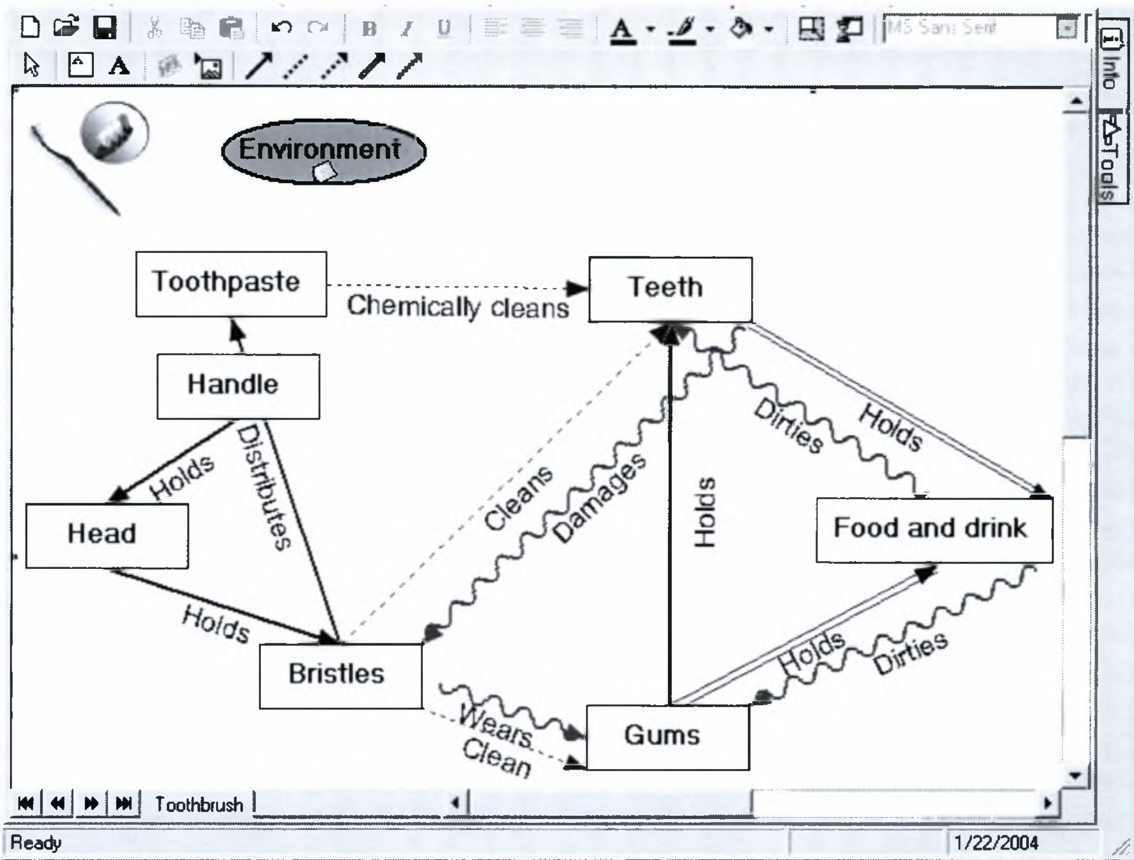

Figure 22 System Module of Innovation Suite with an example (CREAX Innovation Suite)

The following figure shows the explanation of the relationship arrows in the system tool.

Figure 23 Functional relationship between the components of the System (CREAX Innovation Suite)

In the *Ideality* tool the user defines the Ideal Final Result (IFR) from the TRIZ method. Here the user can work backwards by stating the current situation, the IFR and all the obstacles that prevent from reaching the IFR.

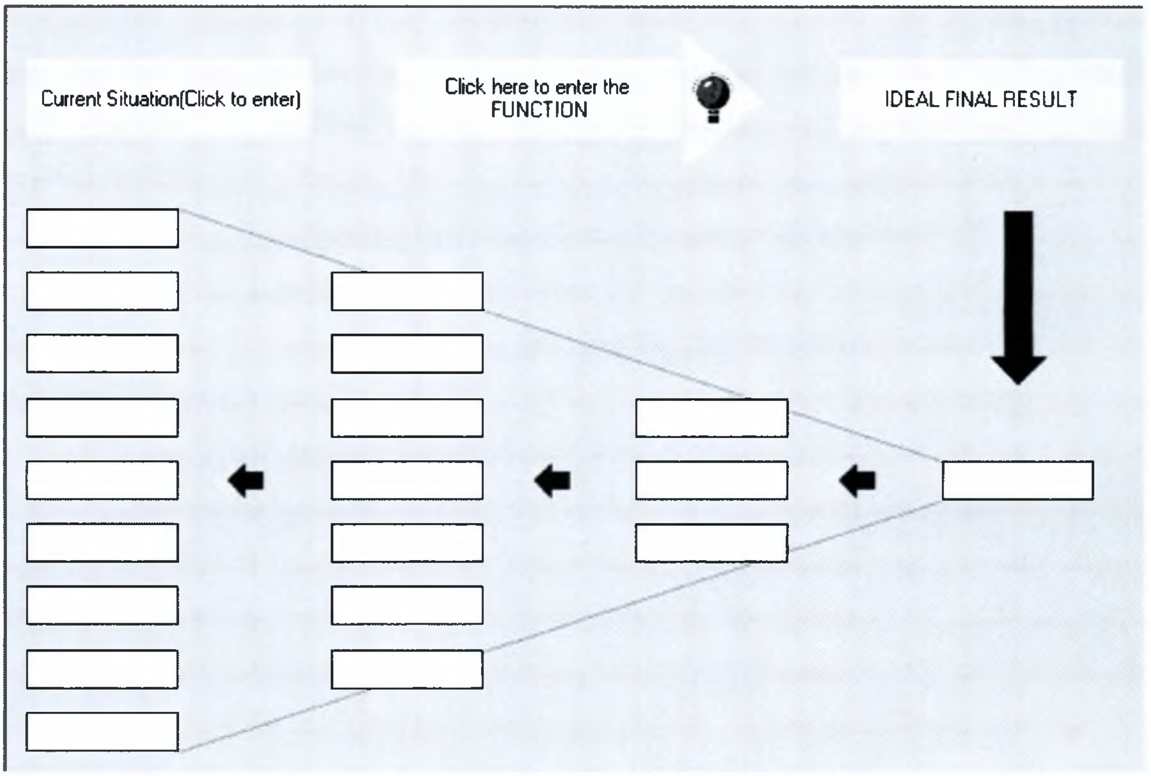

Figure 24 Ideality tool of Innovation Suite (CREAX Innovation Suite)

The Contradiction Matrix and the 40 Inventive Principles are shown in a nice graphical interface with additional examples and references.

S-fields is the tool for modeling the Su-field analysis, a very useful tool of TRIZ (see more about Su-field analysis in 3.3.6).

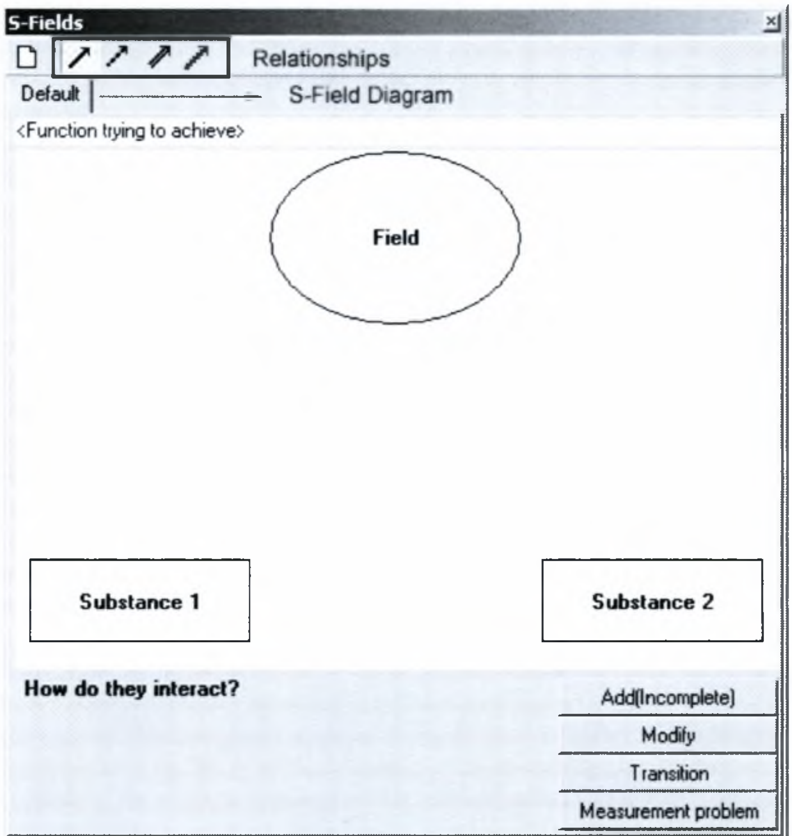

Figure 25 S-fields Tool of Innovation Suite (CREAX Innovation Suite)

A similar tool of the *reFormulator* tool of Pro/Innovator is found here with the names *Resources* and *Constraints*. These two tools use the 9-window analysis (or multi-screen diagram as it was also mentioned earlier). Every problem has constraints and these have to be stated properly so that the user can analyze them and solve the problem. This tool helps the user to think in Time and Space as the 9-window analysis states.

In the figure bellow we see the example of the *Resources* that is given by CREAX.

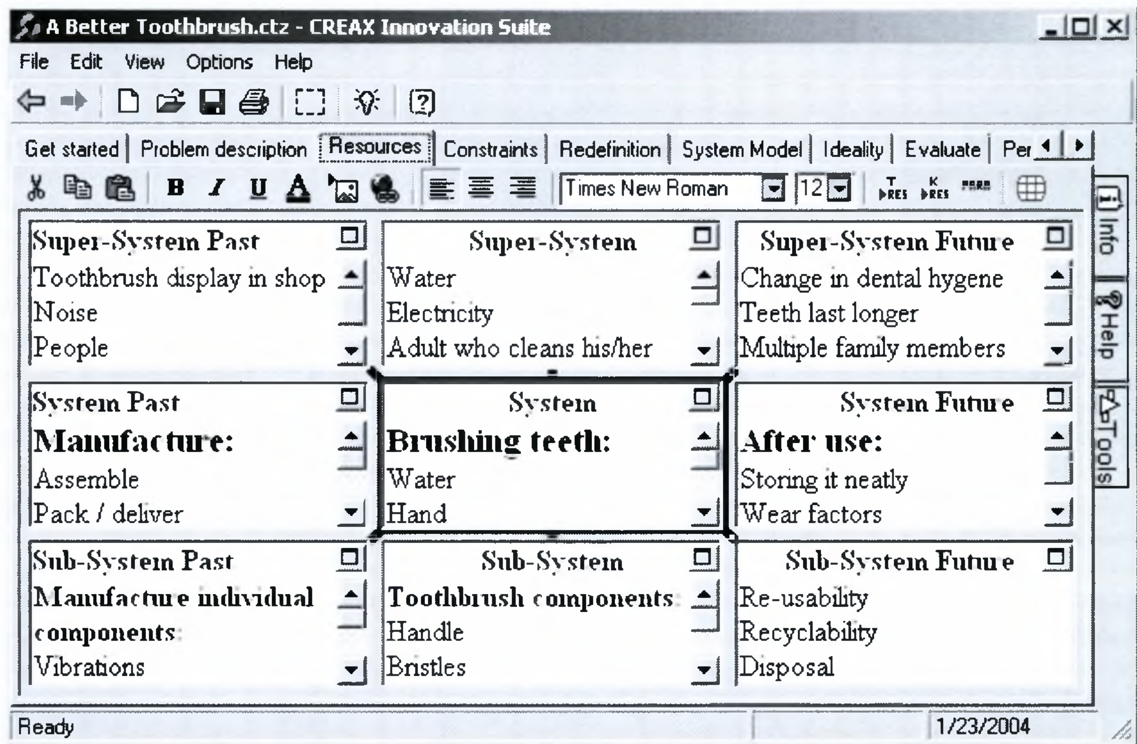

Figure 26 Resources tool of Innovation Suite (CREAX Innovation Suite)

The software package includes many other tools that help with the process of the inventive problem solving. TRIZ is based on the idea of the use of the already known, the use of resources and solutions that are already known as patents. For this purpose there is the *Knowledge* tool that contains a search machine-tool connected to many world known search engines for patents.

For all the software tools that we describe in this thesis we consider that this is a very important tool for the TRIZ innovation process. Uses many methods and guides the user through the innovation process. It is not stated anywhere that TRIZ is what the user actually practices, but it important that there is previous knowledge of this kind of problem solving. All the tools help the user analyze the problem, the resources, the constraints, the Ideal Final Result and everything else that can use to solve the original problem.

4.3 Other tools

Apart from the two important software tools that were analyzed above there are many others that try to help the invention process, using some TRIZ tools.

Goldfire Innovator[12] is the software package for helping with the innovation process offered by Invention Machine. This package is a very popular one in the TRIZ community. It is tool that offers all the TRIZ components and features with examples, even real life analogies, and also provides with a wizard for the Su-field analysis. It is supposed to have a semantic-based search engine to search among patent libraries. Goldfire Innovator is comprised of Innovator's Workbench, the tool that includes the TRIZ and other innovation features; the Researcher, the semantic search engine tool and Goldfire Intelligence, the tools with a large scientific database and access to other patent content.
The above tool seems to be very important, but due to lack of information we are unable to review it any further. We kindly asked the company for a demo tool but there was none available.

Tech Optimizer is an old software also by Invention Machine. It is supposed to be the older version of Goldfire Innovator and its tools are now part of this new product. It used to be a very user friendly environment that actually helped with the exercise of the TRIZ method. It is one of the first tools that were actually useful to TRIZ practitioners.

TRISolver[13] is a software tool by TriSolver GmbH & Co. This software package is a web-based tool over a company's intranet to make its usage easier. It provides with a guide through TRIZ methodology and a database of the TRIZ components such as the 40 Inventive Principles with animated examples. The amount of examples is limited to the most common TRIZ features.

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[12] http://invention-machine.com/GoldfireInnovator.htm
[13] http://trisolver.com.ua/en/software/innovationssoftware.htm

TRIZ Explorer Software[14] is a tool published by Insytec B.V.[15]. It is a TRIZ reference tool according to (Domb, Review:TRIZ Explorer Software, 2000). The whole software uses a knowledge management system, the *nuComposer*. The user can add examples if wanted and there are web links to major TRIZ references provided. The Su-field analysis is practiced with animated examples. TRIZ explorer is not a very appropriate tool for a beginner with the TRIZ method, but it is a satisfying tool for the TRIZ reference library (Domb, Review:TRIZ Explorer Software, 2000).

Innovation Workbench is a software tool that is published by Ideation International[16]. We cannot actually make any comments on this tool because of lack of information.

While researching for TRIZ tools and software we came across a tool[17] that is actually the Contradiction Matrix in an excel spreadsheet. It is a commercial tool that we found no significant use of it.

4.4 Summary

In this chapter we have briefly described the software tools that may someone use when practicing TRIZ. There are many very competent and considerable software tools that a researcher can find to support with the innovation process. The important thing to say is that the user has to be careful and actually have a previous knowledge of TRIZ for the desirable solutions and results. The most important software tools are the Pro/Innovator (4.1) and the Innovation Suite (4.2). These two software packages have a lot of tools that represent and try to simulate the TRIZ innovation process. There are powerful tools for formulating a problem and analyzing the causes of the system. Although we did not see any solutions being generated of course, the tools that represent the 40 inventive principles and the Contradiction Matrix are not as significant as we would expect. These tools don't actually decide on behalf of the user but show him the way to the solution. As a conclusion

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[14] http://www.insytec.com/trizexplorer.htm
[15] http://www.insytec.com/
[16] http://www.ideationtriz.com/
[17] http://www.lugerresearch.com/index.html

we can say that despite the important tools, there is place for a lot of work to be done in the area of the TRIZ software.

5 Semantic Support for CAI

5.1 Background and motivation

As it is easily apparent from all the above sections, knowledge management plays a central and crucial role in Computer Aided Innovation. It seems advanced techniques of knowledge management are expected to significantly assist practitioners in many aspects during the whole CAI lifecycle and therefore it is worth to investigate how modern and emerging knowledge representation and management technology may assist the further development of theoretical background and significantly improve their software implementations.

5.1.1 The motivation

It is important to realize that TRIZ, and other similar theories, enhances creativity by introducing knowledge-based and systematic approaches to understanding problems and defining the best strategies to search for a solution (Souckov, 2006). The TRIZ method and as well as the other similar methods presented in chapter 0, examine and analyze the problem no matter the subject it refers to. The first and important step is to analyze it properly. This approaches the semantic analysis of system. After reasoning through for example the "TRIZ knowledge base" the innovator tries to find a solution as closer as possible to the Ideal Solution. All this approach leads us to study a way of connecting the TRIZ methodology and ontologies, ontology-based knowledge management systems, ontology based reasoning and make use to all the tools.

5.1.2 Theoretical background

A *knowledge base* is a collection of data along with facts, relationships and procedures that constitute the knowledge of a domain, a database of related information about a particular subject. In computer science terms, a knowledge base is expresses using some formal knowledge representation language in order to be in a machine readable form.

The definition of Knowledge base in the ICH glossary[18] is

"a store of knowledge about a domain represented in machine-processable form, which may be rules, facts, or other representations."

The *knowledge base* is also compared with the notion of the *repository*. The repository is a store of items with relationship information among them that typically are fetched in order to perform some tasks (Lombardi, 2003).

We next turn our attention to ways that we can use for *knowledge representation* in general and the notion of *Ontology* in particular.

One of the most detailed and elaborate definition of the term Ontology given below is from Wikipedia:

"Ontology is a term that originates in philosophy and means "theory of existence". The core meaning in computer science is a model for describing the world that consists of a set of types, properties, and relationship types. What ontology has in common in both computer science and philosophy is the representation of entities, ideas, and events, along with their properties and relations, according to a system of categories"

An alternative definition, probably the most popular among computer scientists, of the term ontology was proposed by Thomas R. Gruber in 1992 (Gruber, 1993)

"An ontology is a specification of a conceptualization."

Sometimes, ontology is defined as a body of knowledge describing some domain.

Ontology very commonly deals with the representation and retrieval of data. A potential but limited scoped ontology specification is a *glossary* (a list of terms and meanings). Another one of the simplest notions of a possible ontology may be a *controlled vocabulary*. A Controlled Vocabulary is considered as a collection of preferred terms that are used to

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[18] http://www.ichnet.org/glossary.htm

assist in retrieval of content. A set of hierarchical controlled vocabularies is taxonomy, and a *thesaurus* includes taxonomy with associated and related terms (Lombardi, 2003). A thesaurus provides additional semantics in the relations between terms.

Individuals or *instances* of an ontology are also basic components of an ontology. The combination of an ontology with associated instances is what is known as a knowledge base, in other words a knowledge base is an ontology populated with data.

Ontologies are used for knowledge representation because of the accuracy of the information retrieved. If the ontology is well designed and has all the relationships well defined the answers when querying an ontology-based knowledge representation system are very accurate.

Basically, the role of ontology in the knowledge management process is to facilitate the construction of a domain model. It provides a vocabulary of terms and relations in a specific domain. In building a knowledge management system, two types of knowledge are essential:

Domain knowledge: Knowledge about the objective realities in the domain of interest

Problem-solving knowledge: Knowledge about how to use the domain knowledge to achieve various goals. This knowledge is often in the form of a problem-solving method (PSM) that can help achieve the goals in a different domain (Sureephong, Chakpitak, Ouzrout, & Bouras, 2007).

Knowledge Management System refers to a system for managing knowledge in organizations, supporting creation, capture, storage and dissemination of information. Such a Knowledge-management system usually incorporates a search engine, data-mining tools and facilities.

An integrated part of a knowledge management system is the Reasoner. A reasoner, according to Wikipedia, a reasoned, a semantic reasoner, reasoning engine or rules engine is a piece of software able to infer logical consequences from a set of asserted facts or axioms. The notion of a semantic reasoner generalizes that of an inference engine, by providing a richer set of mechanisms to work with. The inference rules are commonly specified by means of an ontology language, and often a description language.

5.2 Review of Existing work

5.2.1 Review of Scientific Literature

For a long time Innovation and more precisely the TRIZ Innovation process was connected to the Artificial Intelligence. There is some literature on this subject that try to describe the TRIZ method and the process of finding innovative solutions with description logic. TRIZ from the point of view of the Artificial Intelligence provides the user with heuristic knowledge which leads into the search for a solution. (Zanni & Rousselot, 2006).

One of the first scientists that published their work about TRIZ and AI is I. Boyko. The idea of the work that has been done in (Boyko, 2001) was to make the knowledge base development and the search process automated by intellectual computer systems. For this purpose he developed a theory for knowledge representation with the goal to automate in the future the innovating process. It is worth to mention here that at that time the notion and the use of ontology and ontological organization of the metadata were not wide spread.

A very interesting approach of integrating the TRIZ method was (Soo, Lin, Yang, Lin, & Cheng, 2005). The multi-agent platform that they designed integrates the patent document analysis with TRIZ and the agents can suggest directions for the solution of the invention based on heuristic methods and principles to resolve contradictions. There are six agents: *ontology agent, thesaurus agent, invention agent, coordination agent, domain agent and patent agent.*

We will see some of them more detailed. There is a natural language processor to get the semantic and syntactic information of the problem in *thesaurus agent* and then the agent classifies the information into the correct semantic hierarchical tree. The ontology agent corrects the thesaurus hierarchy that is generated from the thesaurus agent and structures it into an ontology format (using the OWL language). There is also the *invention agent* that is actually the TRIZ agent. It uses TRIZ to suggest principles to improve or solve the problem. The user expresses the technical contradiction and then the agent suggests the principles that according to TRIZ will solve the inventive problem.

The proposal of the agents did not actually have a TRIZ ontology. The first attempt to formulate a TRIZ ontology was made by Dubois S. in his PhD thesis (Dubois S. , 2004). He suggests the formalization of the TRIZ components and their interrelationships. It is of high importance to comment that this is a big problem in the TRIZ community and there have been efforts to design a TRIZ ontology within the European TRIZ Association[19].

The Dubois TRIZ ontology is presented in many papers that came before the PhD thesis. The main objective was to present a formalization of the problem formulation frames of TRIZ. This was mainly based on the semantic analysis of the corpus knowledge that would be analyzed to identify and represent the concepts which include ARIZ and the substance-field analysis. In the picture that follows Figure 27 we see the UML description of the proposed ontology.

[19] http://etria.net/

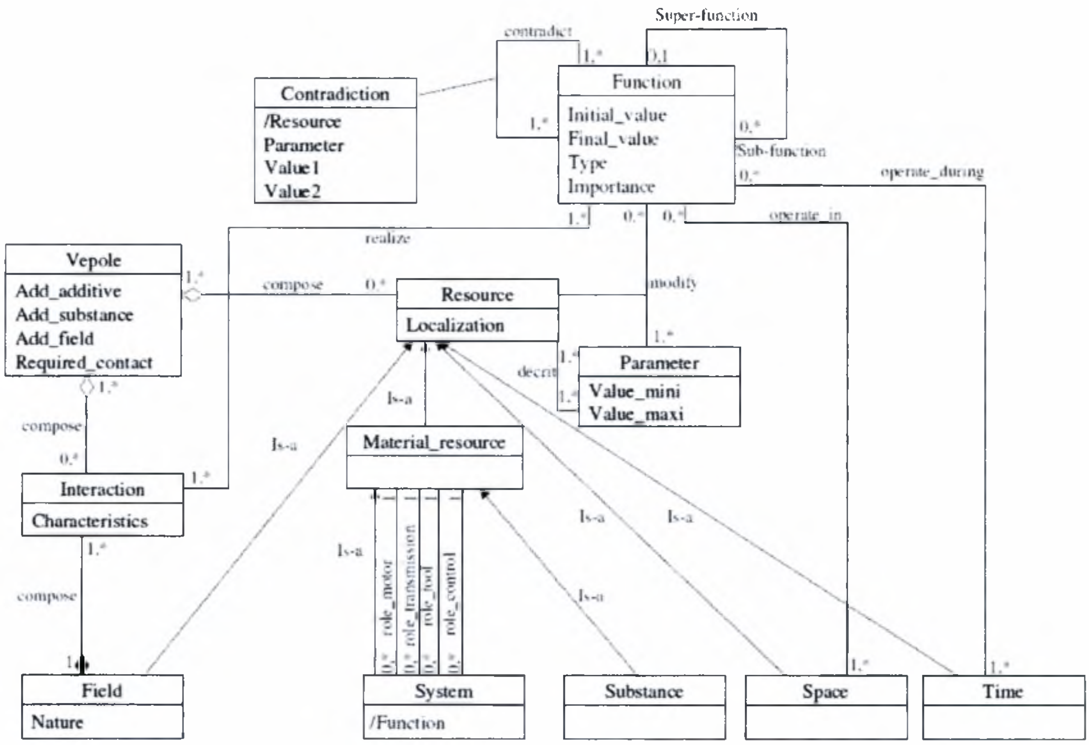

Figure 27 UML model of TRIZ frames (Dubois, Lutz, Rousselot, & Caillaud, 2005)

Dubois and the LGECO team of the Insa-Strasbourg[20] have been working on the formalization of the TRIZ components and the definition of the relationships that link the components for a long time. There is a lot to benefit from this formalization, starting from teaching the TRIZ method. There have been steps towards the formalization of the TRIZ method, but no one can say that a complete and full ontology exists. In (Zanni & Rousselot, 2006) there is the comment that we made earlier that there is not an ontology of the TRIZ concepts and this is the most important thing to focus on.

Another one of the LGECO work in this scientific area is a proposal of a substance -field ontology to support the TRIZ thinking process (Bultey, Beuvron, & Rousselot, 2007). Bultey introduces an ontological work based on the ontology that first appeared in (Dubois, 2004), improved by the concepts of substance-field analysis and description logic. Su-field

[20] http://www.insa-strasbourg.fr/

analysis is chosen because of the difficulties TRIZ shows, with most important the fact that most of the bibliography of TRIZ is in Russian and almost all of the TRIZ fundamental issues have suffered of the translators' interpretation due to their own knowledge (Cavalluci, Lutz, & Kucharavy, 2002). As we have already mentioned, Su-field analysis is the latest methodology that Altshuller developed. Moreover, it is crucial to point out that the reasoning included in Su-field analysis is closer to the common reasoning.

The goal of this proposal was to introduce a computer aided problem solving software for the substance field analysis method. This happens with the enrichment of the TRIZ ontology with the substance-field ontology and the physical action ontology. At this point this is all that has been done, the proposal of the software and the three ontologies.

As a conclusion we can say that so far there is very little work published in the area of using semantic-based technology to help with the innovation process of TRIZ. There are very important research findings that can give an important help for any further attempt to formulate the TRIZ method and organize the knowledge in an ontology.

5.2.2 Projects

Know-it project[21]

This project has as a main objective to support the innovation process development. The primary goal of the project is the support of the conceptual development of the innovation process in companies. It focuses on the new product development (NPD) as a core element of innovation in the company. The project is centered on the following steps (EU-Research Project KNOW-IT):

1. Outline the current technical system function in a systematic way with respect to technology and market development.
2. Use automatic analysis methods for the technical system.
3. Identify possible developments of the system using the Systematic Innovation approach with respect to the laws of evolution.

[21] http://www.know-it-project.eu/?language=en

4. Evaluate the possible development directions and choose the most appropriate ones.

In the project there is the prospect of developing a software tool to aid in every step of the analysis. The general outline of the tool is given by the following picture.

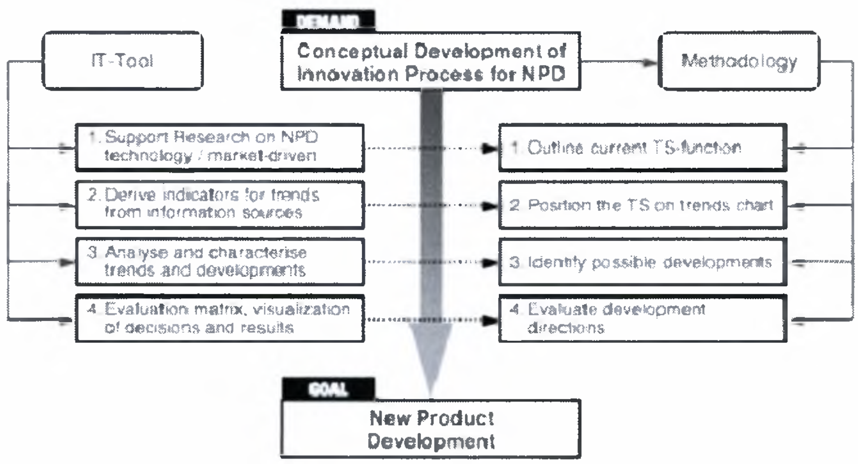

Figure 28 Know-IT software tool (EU-Research Project KNOW-IT)

The designed system's high level overview is shown in the following figure:

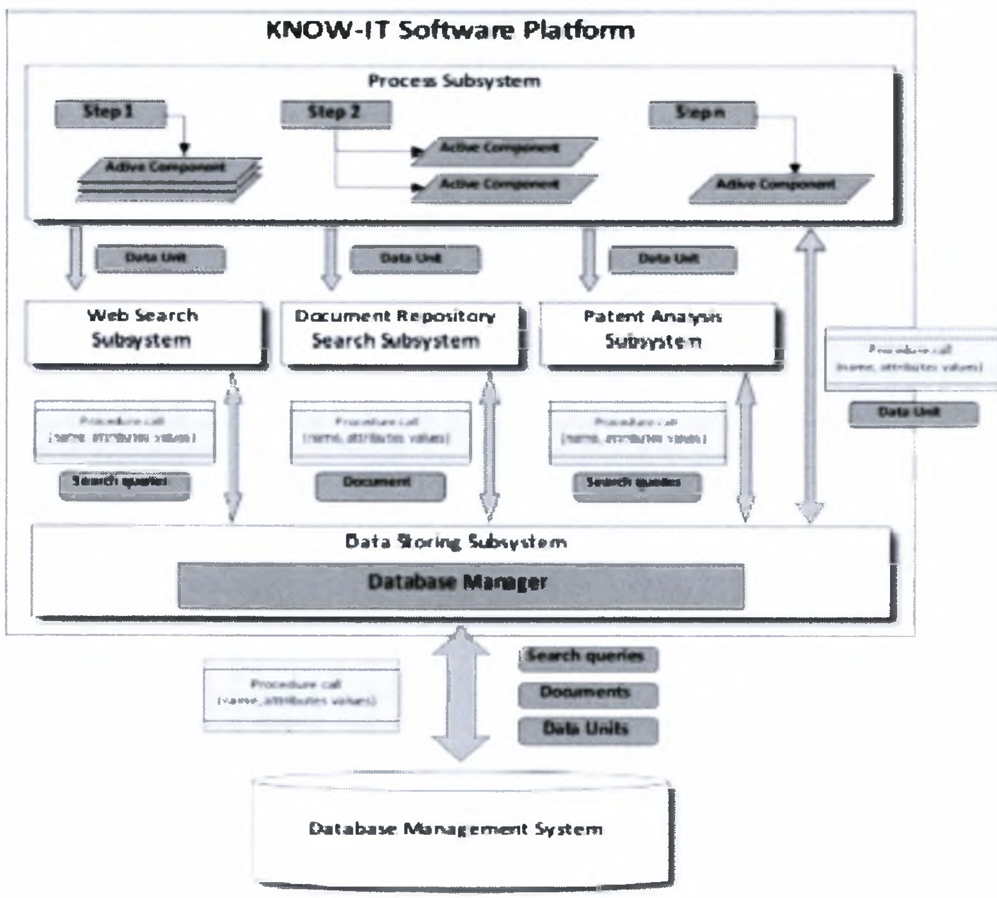

Figure 29 High-Level outline of the Know-IT Software Platform (EU-Research Project KNOW-IT)

WebTEXpert

The main objective of the project is to perform research on methodologies for integrated innovation management, to develop appropriate courseware and to establish web-based services on industrial associations' portals as learning and training platforms where SMEs can learn to apply knowledge based, integrated methodologies for innovation management.

The research activities of WebTEXpert aimed at sophisticated methods and tools for the innovation management adapted to the specific needs of SMEs in the textile and clothing sector. They concentrated on New Product Development (NPD), New Product Introduction (NPI) and Networking for NPD/NPI with a specific focus on integration of the life-cycle phases; value added stages and innovation processes. The research was performed in seven research groups covering all relevant textile applications and textile processes as well as European textile regions.

5.2.3 Semantic support in existing software

In the previous chapter (4) we examined the software tools that can be used to aid the Innovation process. Here we will examine closely those that try to use semantic-based tools.

Most of the systems use semantics technology to expand the queries in the patent search engines. It is a very common use of the semantic technology but it is not the one that we should be looking at.

The Pro/Innovator tool that we already analyzed (4.1) has the most interesting semantic support. In the picture below (Figure 30) we can see that the user query is expanded with a linguistic processor and follows an additional expansion with an ontology processor. The two processors give the semantic relations between the terms of the query and this helps with the searching process for relevant information in the Knowledge Base of technical solutions. The same semantic technique is applied to search for relevant patents in World Patent databases.

The Linguistic Processor performs general query formalization tasks, spell-checking, functional query understanding and keyword list generation. The Ontology Processor performs domain specific query expansion, expansion using direct synonyms and syntactic synonyms, hierarchical expansion and associative expansion.

In the figure below (Figure 30) we see the process of the 2 processors.

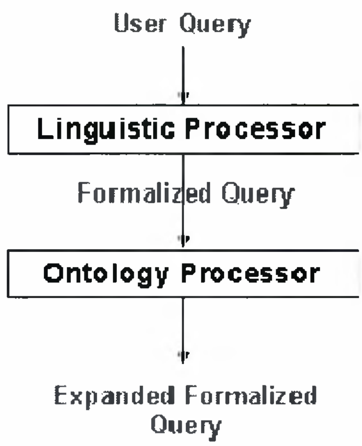

Figure 30 Pro/Innovator Ontology processor (Iwint, Inc. Computer Aided Innovation Solutions)

5.3 Synopsis

After examining the innovation process, we reviewed the work that has been towards Computer Aided Innovation; scientific papers, projects and commercial software tools.

We propose knowledge management system that uses TRIZ to be the next step in Computer Aided Innovation. The system is under careful consideration. There are many difficulties and a lot more work needs to be done in this area.

The basic TRIZ ontology only exists as a scheme and it is important to start from this.

The researcher needs to have an organized knowledge base formed in a way that can be used to give solution to real problems. As discussed previously in the thesis ontologies and the semantic representation of the knowledge base is the most appropriate form for this purpose.

We see the need for an organized knowledge representation of the tools that can be used and the methods for inventive problem solving such as TRIZ. What we know so far is the TRIZ ontology that was previously introduced in the literature and the representation of the TRIZ components organized with rules, relations, and instances. TRIZ and the components have to be organized and formulated the way that we already described. The main outcome of this would be an ontology that formulates all the TRIZ methods, tools and expands. This would help the TRIZ practitioner to choose the right tool that can help him with the Innovation process.

It is important to understand the TRIZ knowledge base and the reasoning mechanism. The basic reason that the already existing software failed is because there was no reasoning mechanism simulated and the user was responsible for the collection of the knowledge. In the future we will integrate the knowledge of the TRIZ into a semantic based system.

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Annex I: Altshuller - A short biography

Genrich Saulovich Altshuller, the creator of TRIZ was born on October 15, 1926 in Tashkent, Uzbekistan (former USSR) to a family of journalists. Later he moved and lived in Baku, Azerbaijan (USSR). When he was in school he was awarded with something equivalent to patent for a diving gear in the age of 16. He also built and tested a boat with a jet engine that used carbide as fuel.

After the World War 2 he assigned to the Commission on Innovation of the Caspian Navy Flotilla and he continued to invent.

In 1948 Altshuller and his associate, Rafail Shapiro, wrote a letter to the Soviet dictator Josef Stalin, suggesting to use TRIZ in order to help the country recover from the war. The reply was one year later when they were arrested and sent to Vorkuta Labor camp. After Stalin's death, Altshuller returned to Baku and started publishing articles about TRIZ. He became a science fiction writer because he couldn't find a job. He wrote under the pen name Altov and he quickly became popular.

In 1971 he founded the Public Institute for Inventive Creativity which became the first center for learning TRIZ. From 1974 to 1986 he published many tutorials and books on TRIZ. In 1989 he became the President of the International TRIZ Association, founded by his students. He died in September 24, 1998 form complications from the Parkinson's disease.

A recent, very detailed and interesting biography of Altshuller can be found in (Genrikh Altshuller – The Creator Of TRIZ, 2007)

Annex II The 40 Inventive Principles **(Tate & Domb, 1997)**

Principle 1. Segmentation

A. Divide an object into independent parts.
    - *Replace mainframe computer by personal computers.*
    - *Replace a large truck by a truck and trailer.*
    - *Use a work breakdown structure for a large project.*

B. Make an object easy to disassemble.
    - *Modular furniture*
    - *Quick disconnect joints in plumbing*

C. Increase the degree of fragmentation or segmentation.
    - *Replace solid shades with Venetian blinds.*
    - *Use powdered welding metal instead of foil or rod to get better penetration of the joint.*

Principle 2. Taking out

A. Separate an interfering part or property from an object, or single out the only necessary part (or property) of an object.
    - *Locate a noisy compressor outside the building where compressed air is used.*
    - *Use fiber optics or a light pipe to separate the hot light source from the location where light is needed.*
    - *Use the sound of a barking dog, without the dog, as a burglar alarm.*

Principle 3. Local quality

A. Change an object's structure from uniform to non-uniform, change an external environment (or external influence) from uniform to non-uniform.
    - *Use a temperature, density, or pressure gradient instead of constant temperature, density or pressure.*

B. Make each part of an object function in conditions most suitable for its operation.
    - *Lunch box with special compartments for hot and cold solid foods and for liquids*

(Part C continued on the next page.)

C. Make each part of an object fulfill a different and useful function.

- *Pencil with eraser*
- *Hammer with nail puller*
- *Multi-function tool that scales fish, acts as a pliers, a wire stripper, a flat-blade screwdriver, a Phillips screwdriver, manicure set, etc.*

Principle 4. Asymmetry

A. A. Change the shape of an object from symmetrical to asymmetrical.
   - *Asymmetrical mixing vessels or asymmetrical vanes in symmetrical vessels improve mixing (cement trucks, cake mixers, blenders).*
   - *Put a flat spot on a cylindrical shaft to attach a knob securely.*

B. If an object is asymmetrical, increase its degree of asymmetry.
   - *Change from circular O-rings to oval cross-section to specialized shapes to improve sealing.*
   - *Use astigmatic optics to merge colors.*

Principle 5. Merging

A. Bring closer together (or merge) identical or similar objects, assemble identical or similar parts to perform parallel operations.
   - *Personal computers in a network*
   - *Thousands of microprocessors in a parallel processor computer*
   - *Vanes in a ventilation system*
   - *Electronic chips mounted on both sides of a circuit board or subassembly*

B. Make operations contiguous or parallel; bring them together in time.
   - *Link slats together in Venetian or vertical blinds.*
   - *Medical diagnostic instruments that analyze multiple blood parameters simultaneously*
   - *Mulching lawnmower*

Principle 6. Universality

A. Make a part or object perform multiple functions; eliminate the need for other parts.
   - *Handle of a toothbrush contains toothpaste*
   - *Child's car safety seat converts to a stroller*
   - *Mulching lawnmower (Yes, it demonstrates both Principles 5 and 6, Merging and Universality.)*
   - *Team leader acts as recorder and timekeeper.*
   - *CCD (Charge coupled device) with micro-lenses formed on the surface*

Principle 7. "Nested doll"

A. Place one object inside another; place each object, in turn, inside the other.
   - *Measuring cups or spoons*
   - *Russian dolls*

- *Portable audio system (microphone fits inside transmitter, which fits inside amplifier case)*

B. Make one part pass through a cavity in the other.
  - *Extending radio antenna*
  - *Extending pointer*
  - *Zoom lens*
  - *Seat belt retraction mechanism*
  - *Retractable aircraft landing gear stow inside the fuselage (also demonstrates Principle 15, Dynamism).*

Principle 8. Anti-weight

A. To compensate for the weight of an object, merge it with other objects that provide lift.
  - *Inject foaming agent into a bundle of logs, to make it float better.*
  - *Use helium balloon to support advertising signs.*

B. To compensate for the weight of an object, make it interact with the environment (e.g. use aerodynamic, hydrodynamic, buoyancy and other forces).
  - *Aircraft wing shape reduces air density above the wing, increases density below wing, to create lift. (This also demonstrates Principle 4, Asymmetry.)*
  - *Vortex strips improve lift of aircraft wings.*
  - *Hydrofoils lift ship out of the water to reduce drag.*

Principle 9. Preliminary anti-action

A. If it will be necessary to do an action with both harmful and useful effects, this action should be replaced with anti-actions to control harmful effects.
  - *Buffer a solution to prevent harm from extremes of pH.*

B. Create beforehand stresses in an object that will oppose known undesirable working stresses later on.
  - *Pre-stress rebar before pouring concrete.*
  - *Masking anything before harmful exposure: Use a lead apron on parts of the body not being exposed to X-rays. Use masking tape to protect the part of an object not being painted*

Principle 10. Preliminary action

A. Perform, before it is needed, the required change of an object (either fully or partially).
  - *Pre-pasted wall paper*
  - *Sterilize all instruments needed for a surgical procedure on a sealed tray.*

B. Pre-arrange objects such that they can come into action from the most convenient place and without losing time for their delivery.
  - *Kanban arrangements in a Just-In-Time factory*
  - *Flexible manufacturing cell*

Principle 11. Beforehand cushioning

A. Prepare emergency means beforehand to compensate for the relatively low reliability of an object.
   - *Magnetic strip on photographic film that directs the developer to compensate for poor exposure*
   - *Back-up parachute*
   - *Alternate air system for aircraft instruments*

Principle 12. Equipotentiality

A. In a potential field, limit position changes (e.g. change operating conditions to eliminate the need to raise or lower objects in a gravity field).
   - *Spring loaded parts delivery system in a factory*
   - *Locks in a channel between 2 bodies of water (Panama Canal)*
   - *"Skillets" in an automobile plant that bring all tools to the right position (also demonstrates Principle 10, Preliminary Action)*

Principle 13. 'The other way round'

A. Invert the action(s) used to solve the problem (e.g. instead of cooling an object, heat it).
   - *To loosen stuck parts, cool the inner part instead of heating the outer part.*
   - *Bring the mountain to Mohammed, instead of bringing Mohammed to the mountain.*

(Part B continued on the next page.)

B. Make movable parts (or the external environment) fixed, and fixed parts movable).
   - *Rotate the part instead of the tool.*
   - *Moving sidewalk with standing people*
   - *Treadmill (for walking or running in place)*

C. Turn the object (or process) 'upside down'.
   - *Turn an assembly upside down to insert fasteners (especially screws).*
   - *Empty grain from containers (ship or railroad) by inverting them.*

Principle 14. Spheroidality - Curvature

A. Instead of using rectilinear parts, surfaces, or forms, use curvilinear ones; move from flat surfaces to spherical ones; from parts shaped as a cube (parallelepiped) to ball-shaped structures.
   - *Use arches and domes for strength in architecture.*

B. Use rollers, balls, spirals, domes.
   - *Spiral gear (Nautilus) produces continuous resistance for weight lifting.*
   - *Ball point and roller point pens for smooth ink distribution*

C. Go from linear to rotary motion, use centrifugal forces.
   - *Produce linear motion of the cursor on the computer screen using a mouse or a trackball.*
   - *Replace wringing clothes to remove water with spinning clothes in a washing machine.*
   - *Use spherical casters instead of cylindrical wheels to move furniture.*

Principle 15. Dynamics

A. Allow (or design) the characteristics of an object, external environment, or process to change to be optimal or to find an optimal operating condition.
   - *Adjustable steering wheel (or seat, or back support, or mirror position...)*

(Part B continued on the next page.)

B. Divide an object into parts capable of movement relative to each other.
   - *The "butterfly" computer keyboard, (also demonstrates Principle 7, "Nested doll".)*

C. If an object (or process) is rigid or inflexible, make it movable or adaptive.
   - *The flexible boroscope for examining engines*
   - *The flexible sigmoidoscope, for medical examination*

Principle 16. Partial or excessive actions

A. If 100 percent of an object is hard to achieve using a given solution method then, by using 'slightly less' or 'slightly more' of the same method, the problem may be considerably easier to solve.
   - *Over spray when painting, then remove excess. (Or, use a stencil--this is an application of Principle 3, Local Quality and Principle 9, Preliminary anti-action).*
   - *Fill, then "top off" when filling the gas tank of your car.*

Principle 17. Another dimension

A. To move an object in two- or three-dimensional space.
   - *Infrared computer mouse moves in space, instead of on a surface, for presentations.*
   - *Five-axis cutting tool can be positioned where needed.*

B. Use a multi-story arrangement of objects instead of a single-story arrangement.
   - *Cassette with 6 CD's to increase music time and variety*
   - *Electronic chips on both sides of a printed circuit board*
   - *Employees "disappear" from the customers in a theme park, descend into a tunnel, and walk to their next assignment, where they return to the surface and magically reappear.*

C. Tilt or re-orient the object, lay it on its side.

- *Dump truck*

D. Use 'another side' of a given area.
   - *Stack microelectronic hybrid circuits to improve density.*

Principle 18. Mechanical vibration

A. Cause an object to oscillate or vibrate.
   - *Electric carving knife with vibrating blades*

B. Increase its frequency (even up to the ultrasonic).
   - *Distribute powder with vibration.*

C. Use an object's resonant frequency.
   - *Destroy gall stones or kidney stones using ultrasonic resonance.*

D. Use piezoelectric vibrators instead of mechanical ones.
   - *Quartz crystal oscillations drive high accuracy clocks.*

E. Use combined ultrasonic and electromagnetic field oscillations.
   - *Mixing alloys in an induction furnace*

Principle 19. Periodic action

A. Instead of continuous action, use periodic or pulsating actions.
   - *Hitting something repeatedly with a hammer*
   - *Replace a continuous siren with a pulsed sound.*

B. If an action is already periodic, change the periodic magnitude or frequency.
   - *Use Frequency Modulation to convey information, instead of Morse code.*
   - *Replace a continuous siren with sound that changes amplitude and frequency.*

C. Use pauses between impulses to perform a different action.
   - *In cardio-pulmonary respiration (CPR) breathe after every 5 chest compressions.*

Principle 20. Continuity of useful action

A. Carry on work continuously; make all prts of an object work at full load, all the time.
   - *Flywheel (or hydraulic system) stores energy when a vehicle stops, so the motor can keep running at optimum power.*
   - *Run the bottleneck operations in a factory continuously, to reach the optimum pace. (From theory of constraints, or takt time operations)*

B. Eliminate all idle or intermittent actions or work.
   - *Print during the return of a printer carriage--dot matrix printer, daisy wheel printers, inkjet printers.*

Principle 21. Skipping

A. Conduct a process , or certain stages (e.g. destructible, harmful or hazardous operations) at high speed.
    - *Use a high speed dentist's drill to avoid heating tissue.*
    - *Cut plastic faster than heat can propagate in the material, to avoid deforming the shape.*

Principle 22. "Blessing in disguise" or "Turn Lemons into Lemonade"

A. Use harmful factors (particularly, harmful effects of the environment or surroundings) to achieve a positive effect.
    - *Use waste heat to generate electric power.*
    - *Recycle waste (scrap) material from one process as raw materials for another.*

B. Eliminate the primary harmful action by adding it to another harmful action to resolve the problem.
    - *Add a buffering material to a corrosive solution.*
    - *Use a helium-oxygen mix for diving, to eliminate both nitrogen narcosis and oxygen poisoning from air and other nitrox mixes.*

Amplify a harmful factor to such a degree that it is no longer harmful.

- *Use a backfire to eliminate the fuel from a forest fire.*

Principle 23. Feedback

A. Introduce feedback (referring back, cross-checking) to improve a process or action.
    - *Automatic volume control in audio circuits*
    - *Signal from gyrocompass is used to control simple aircraft autopilots.*
    - *Statistical Process Control (SPC) -- Measurements are used to decide when to modify a process. (Not all feedback systems are automated!)*
    - *Budgets --Measurements are used to decide when to modify a process.*

B. If feedback is already used, change its magnitude or influence.
    - *Change sensitivity of an autopilot when within 5 miles of an airport.*
    - *Change sensitivity of a thermostat when cooling vs. heating, since it uses energy less efficiently when cooling.*
    - *Change a management measure from budget variance to customer satisfaction.*

Principle 24. 'Intermediary'

A. Use an intermediary carrier article or intermediary process.
    - *Carpenter's nailset, used between the hammer and the nail*

B. Merge one object temporarily with another (which can be easily removed).
    - *Pot holder to carry hot dishes to the table*

Principle 25. Self-service

A. Make an object serve itself by performing auxiliary helpful functions
    - *A soda fountain pump that runs on the pressure of the carbon dioxide that is used to "fizz" the drinks. This assures that drinks will not be flat, and eliminates the need for sensors.*
    - *Halogen lamps regenerate the filament during use--evaporated material is redeposited.*
    - *To weld steel to aluminum, create an interface from alternating thin strips of the 2 materials. Cold weld the surface into a single unit with steel on one face and copper on the other, then use normal welding techniques to attach the steel object to the interface, and the interface to the aluminum. (This concept also has elements of Principle 24, Intermediary, and Principle 4, Asymmetry.)*

B. Use waste resources, energy, or substances.
    - *Use heat from a process to generate electricity: "Co-generation".*
    - *Use animal waste as fertilizer.*
    - *Use food and lawn waste to create compost.*

Principle 26. Copying

A. Instead of an unavailable, expensive, fragile object, use simpler and inexpensive copies.
    - *Virtual reality via computer instead of an expensive vacation*
    - *Listen to an audio tape instead of attending a seminar.*

B. Replace an object, or process with optical copies.
    - *Do surveying from space photographs instead of on the ground.*
    - *Measure an object by measuring the photograph.*
    - *Make sonograms to evaluate the health of a fetus, instead of risking damage by direct testing.*

C. If visible optical copies are already used, move to infrared or ultraviolet copies.
    - *Make images in infrared to detect heat sources, such as diseases in crops, or intruders in a security system.*

Principle 27. Cheap short-living objects

A. Replace an inexpensive object with a multiple of inexpensive objects, comprising certain qualities (such as service life, for instance).
    - *Use disposable paper objects to avoid the cost of cleaning and storing durable objects. Plastic cups in motels, disposable diapers, many kinds of medical supplies.*

Principle 28 Mechanics substitution

A. Replace a mechanical means with a sensory (optical, acoustic, taste or smell) means.
   - *Replace a physical fence to confine a dog or cat with an acoustic "fence" (signal audible to the animal).*
   - *Use a bad smelling compound in natural gas to alert users to leakage, instead of a mechanical or electrical sensor.*

B. Use electric, magnetic and electromagnetic fields to interact with the object.
   - *To mix 2 powders, electrostatically charge one positive and the other negative. Either use fields to direct them, or mix them mechanically and let their acquired fields cause the grains of powder to pair up.*

C. Change from static to movable fields, from unstructured fields to those having structure.
   - *Early communications used omnidirectional broadcasting. We now use antennas with very detailed structure of the pattern of radiation.*

D. Use fields in conjunction with field-activated (e.g. ferromagnetic) particles.
   - *Heat a substance containing ferromagnetic material by using varying magnetic field. When the temperature exceeds the Curie point, the material becomes paramagnetic, and no longer absorbs heat.*

Principle 29. Pneumatics and hydraulics

A. Use gas and liquid parts of an object instead of solid parts (e.g. inflatable, filled with liquids, air cushion, hydrostatic, hydro-reactive).
   - *Comfortable shoe sole inserts filled with gel*
   - *Store energy from decelerating a vehicle in a hydraulic system, then use the stored energy to accelerate later.*

Principle 30. Flexible shells and thin films

A. Use flexible shells and thin films instead of three dimensional structures
   - *Use inflatable (thin film) structures as winter covers on tennis courts.*

B. Isolate the object from the external environment using flexible shells and thin films.
   - *Float a film of bipolar material (one end hydrophilic, one end hydrophobic) on a reservoir to limit evaporation.*

Principle 31. Porous materials

A. Make an object porous or add porous elements (inserts, coatings, etc.).
   - *Drill holes in a structure to reduce the weight.*

B. If an object is already porous, use the pores to introduce a useful substance or function.
   - *Use a porous metal mesh to wick excess solder away from a joint.*
   - *Store hydrogen in the pores of a palladium sponge. (Fuel "tank" for the hydrogen car--much safer than storing hydrogen gas)*

Principle 32. Color changes

A. Change the color of an object or its external environment.
   - *Use safe lights in a photographic darkroom.*

B. Change the transparency of an object or its external environment.
   - *Use photolithography to change transparent material to a solid mask for semiconductor processing. Similarly, change mask material from transparent to opaque for silk screen processing.*

Principle 33. Homogeneity

A. Make objects interacting with a given object of the same material (or material with identical properties).
   - *Make the container out of the same material as the contents, to reduce chemical reactions.*
   - *Make a diamond cutting tool out of diamonds.*

Principle 34. Discarding and recovering

A. Make portions of an object that have fulfilled their functions go away (discard by dissolving, evaporating, etc.) or modify these directly during operation.
   - *Use a dissolving capsule for medicine.*
   - *Sprinkle water on cornstarch-based packaging and watch it reduce its volume by more than 1000X!*
   - *Ice structures: use water ice or carbon dioxide (dry ice) to make a template for a rammed earth structure, such as a temporary dam. Fill with earth, then, let the ice melt or sublime to leave the final structure.*

B. Conversely, restore consumable parts of an object directly in operation.
   - *Self-sharpening lawn mower blades*
   - *Automobile engines that give themselves a "tune up" while running (the ones that say "100,000 miles between tune ups")*

Principle 35. Parameter changes

A. A. Change an object's physical state (e.g. to a gas, liquid, or solid.
   - *Freeze the liquid centers of filled candies, then dip in melted chocolate, instead of handling the messy, gooey, hot liquid.*
   - *Transport oxygen or nitrogen or petroleum gas as a liquid, instead of a gas, to reduce volume.*

B. Change the concentration or consistency.
   - *Liquid hand soap is concentrated and more viscous than bar soap at the point of use, making it easier to dispense in the correct amount and more sanitary when shared by several people.*

C. Change the degree of flexibility.

- *Use adjustable dampers to reduce the noise of parts falling into a container by restricting the motion of the walls of the container.*
- *Vulcanize rubber to change its flexibility and durability.*

D. Change the temperature.
- *Raise the temperature above the Curie point to change a ferromagnetic substance to a paramagnetic substance.*
- *Raise the temperature of food to cook it. (Changes taste, aroma, texture, chemical properties, etc.)*
- *Lower the temperature of medical specimens to preserve them for later analysis.*

Principle 36. Phase transitions

A. Use phenomena occurring during phase transitions (e.g. volume changes, loss or absorption of heat, etc.).
- *Water expands when frozen, unlike most other liquids. Hannibal is reputed to have used this when marching on Rome a few thousand years ago. Large rocks blocked passages in the Alps. He poured water on them at night. The overnight cold froze the water, and the expansion split the rocks into small pieces which could be pushed aside.*
- *Heat pumps use the heat of vaporization and heat of condensation of a closed thermodynamic cycle to do useful work.*

Principle 37. Thermal expansion

A. Use thermal expansion (or contraction) of materials.
- *Fit a tight joint together by cooling the inner part to contract, heating the outer part to expand, putting the joint together, and returning to equilibrium.*

B. If thermal expansion is being used, use multiple materials with different coefficients of thermal expansion.
- *The basic leaf spring thermostat: (2 metals with different coefficients of expansion are linked so that it bends one way when warmer than nominal and the opposite way when cooler.)*

Principle 38. Strong oxidants

A. Replace common air with oxygen-enriched air.
- *Scuba diving with Nitrox or other non-air mixtures for extended endurance*

B. Replace enriched air with pure oxygen.
- *Cut at a higher temperature using an oxy-acetylene torch.*
- *Treat wounds in a high pressure oxygen environment to kill anaerobic bacteria and aid healing.*

C. Expose air or oxygen to ionizing radiation.

D. Use ionized oxygen.

- *Ionize air to trap pollutants in an air cleaner.*

E. Replace ozonized (or ionized) oxygen with ozone.
- *Speed up chemical reactions by ionizing the gas before use.*

Principle 39. Inert atmosphere

A. Replace a normal environment with an inert one.
- *Prevent degradation of a hot metal filament by using an argon atmosphere.*

B. Add neutral parts, or inert additives to an object.
- *Increase the volume of powdered detergent by adding inert ingredients. This makes it easier to measure with conventional tools.*

Principle 40. Composite materials

A. Change from uniform to composite (multiple) materials.
- *Composite epoxy resin/carbon fiber golf club shafts are lighter, stronger, and more flexible than metal. Same for airplane parts.*
- *Fiberglass surfboards are lighter and more controllable and easier to form into a variety of shapes than wooden ones.*