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A BRIEF REVIEW OF THEORY OF INVENTIVE PROBLEM SOLVING (TRIZ) METHODOLOGY

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1. INTRODUCTION

This paper provides a fundamental review on the advanced innovative thinking tool known as TRIZ or the Theory of Inventive Problem Solving. It begins by providing with the background of the development of this methodology. From then on, it expands into describing the principles that governs the techniques such as the 40 Inventive Principles, the Contradiction principal and its' matrix, and the 39 engineering parameters. Some suggestions are provided for applying TRIZ in manufacturing and how TRIZ could be integrated with other selected problem solving tools. The paper culminates with the practical value of this powerful technique and the need for further application both by academics and industrialists.

2. THEORY OF INVENTIVE PROBLEM SOLVING (TRIZ)

TRIZ pronounced as 'treez' is a Russian acronym for "Theoriya Resheniya Izobreatatelskish Zadatch" (Yeoh et al, 2009). In English it is *Theory of Inventive Problem Solving*. It originated in the late 1940s, in the former Soviet Union, as an attempt to develop a method, which would support a process of generating new ideas and finding solutions in a systematic way (Souchkov, 2007). According to Savransky (2002), TRIZ is a human-oriented, knowledge-based systematic methodology that is used for inventive problem solving. TRIZ can be used as a powerful tool for igniting the creative imagination with the aim of solving simple and difficult technical and technological problems more quickly and with better results (Kim *et al*., 2009).

Genrich Altshuller and his colleagues, the originators of TRIZ, started the development of this methodology. It is a problem-solving methodology that is based on a systematic logic approach , which was developed by reviewing thousands of patents and the analysis of technology evolution. TRIZ can be used as a powerful tool for igniting the creative imagination with the aim of solving simple and difficult technical and technological problems more quickly and with better results (Kim *et al*., 2009).

2.1. Origin of the TRIZ Theory and Development Background

In 1946, Altshuller (1996) and his colleagues started developing TRIZ in the former Soviet Union. TRIZ has been developed based on an in-depth study of the best inventions and history of the development of numerous products and technologies in different fields and industries. Altshuller reviewed 200,000 patents, which were narrowed down to 40,000 innovative patents. Between 1964 and 1974, the patents under review were evaluated twice to determine relative frequencies for the different levels of innovation. They concluded that the inventive principles and solving techniques involved in these patents were due to a systematic innovation approach (Terninko *et al*., 2000).

Altshuller categorized the patents' different degrees of inventiveness into five levels, ranging from level 1(lowest) up to level 5 (highest). When he recognized that not every invention carries the same inventive value, then almost all the invention problems have at least one contradiction, that is, the level of invention depends on how well the contradiction is resolved (Savransky, 2002). TRIZ categorizes the innovations into five levels, as summarized in Table 1.

Table 1 : Levels of innovation (Terninko *et al.*, 2000)

Level	Description	Percent contribution
1	Apparent or conventional solution: Solution by well-known methods within a specialty	32%
2	Small inventions inside a paradigm : Improvements in an existing system, usually, with some compromise	45%
3	Substantial inventions inside technology: Essential improvements in an existing system	18%
4	Inventions outside technology: New generation of design using science and not technology	4%
5	Discovery: New system usually based on major discoveries	1%

Altshuller (1996) concluded from his research that a rare scientific discovery or a pioneering invention is uncovered and about 95% of the problems that engineers face have been solved within their industry. Only 1% of cases, experts have failed to find a solution to the problems. It should also be noted that the number of trials needed to produce solutions using traditional creativity methods will be radically increased as the level of inventiveness increases. The first official article on TRIZ, "About Technical Creativity," was published in 1956 by Altshuller and R. Shapiro where it introduced concepts such as technical contradiction, ideality, inventive system thinking, the law of Technical System Completeness, and Inventive Principles. In 1975, a new approach for solving inventive problems was introduced: Substance-Field Modeling (also known as *Su-field Modeling*) and the first 5 Inventive Standards (which were later extended to 76 Inventive Standards that were published by Altshuller).

By 1985, Altshuller had written more than 14 books. In these books, his key findings explained the different schools of TRIZ, and individual TRIZ experts continue to improve his methodology. In 1989, several of Altshuller's practitioners moved to the West to continue research and set up consultancy practices. TRIZ was exposed to Western academics and researchers, and several books were translated into Western language. A new TRIZ-based software package Innovation Workbench™ was released in 1990 in the United States by Ideation International, which included the first TRIZ technique used for the causal modeling of inventive situations. Problem formulator and a restructured database of inventive operators were based on Inventive Principles, Inventive Standards, and Physical Effects (currently, Ideation International offers a range of various TRIZ-related software packages). The late 1990s saw a rapid spread of the awareness of TRIZ in technical communities as seen in publications and meetings, and the inclusion of TRIZ in the agendas of the Project Management Institute, the International Congress on the Management of Engineering Technology, the Quality Function Deployment Symposium, the Total Product Development Symposium, the Society of Automotive Engineering, the Institute for Mechanical Engineering (UK), and World Quality Day (Finland), among others. In Japan, TRIZ was first introduced in 1996 by the *Nikkei Mechanical Journal* and has since attracted attention from industries, especially in manufacturing, and has been tried for application.

Several of the manufacturing companies in Japan acquired their initial knowledge on TRIZ around 1997 and 1998.

In the United States, TRIZ specialists who had emigrated from the former Union of Soviet Socialist Republics started their activities around 1992. The main body for promoting TRIZ in the United States has been consultants. Among the U. S. companies that introduced TRIZ were General Motors, Johnson and Johnson, Ford Motors, Lockheed, Motorola, Procter and Gamble, Rockwell Int., Xerox, and so on. TRIZ also gained favor among German companies, including Daimler Chrysler, Siemens, Mannesmann, Hilti, BMW, Bosch, and many others (Livotov, 2008).

2.2. TRIZ Way of Problem Solving

A traditional approach toward solving problems is by moving directly from a specific problem to finding a specific solution. However, there are many cases where this approach may not work due to contradictions or conflicts, which prevent good solutions from being generated. In most cases, the solution using this normal problem-solving process will be in the form of a compromise. TRIZ problem solving thinking is different from the other methods of problem solving. The basic strategy of TRIZ is that "In most cases the problem we're facing now, has been already faced by many other people at different times, at different places and in different situation, and most likely been solved in different ways." The focus of the TRIZ approach, as shown in Figure 1, is to "find the solution from those solutions," and it allows connecting the problem to a standard problem and suggesting a standard solution, which provide the direction to be followed in order to determine the best solution for the problem overcoming contradictions (Terninko et al 2000)

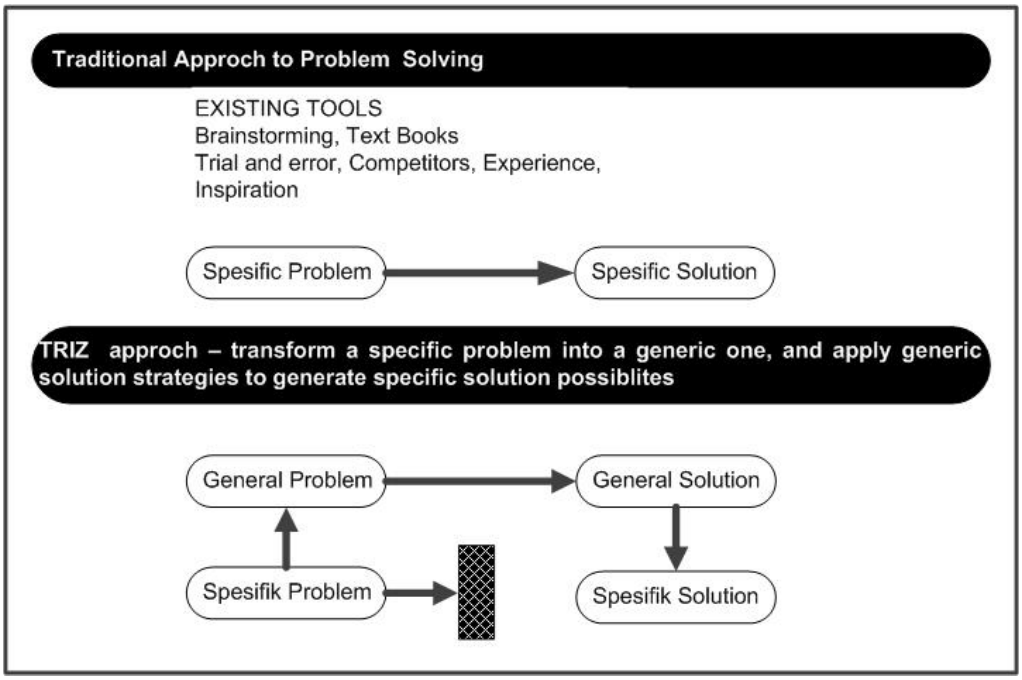

Figure 1 : Comparison between traditional and TRIZ approach to innovation (Frobisher, 2010)

3. THE COMMON TRIZ MODEL AND TOOLS

Various methods and tools are employed in TRIZ innovation technology, which over the years have proved to be successful, including Problem Formulation, Contradiction Matrix, 40 Inventive Principles, Functional Analysis, Separation Principles, Substance Field, Ideal Final Result, Cause and Effect Chain Analysis, and so on. Users can select appropriate tools to solve their problems depending on the type of problems (Tien-Lun and Shao-Ting, 2011). The most important components in TRIZ are depicted in Table 2.

Table 2 : The most important components of TRIZ (Livotov, 2008)

No	TRIZ- Tools, Methods	Field of application
1	40 Inventive Principles for eliminating technical contradictions; system of their application in the form of The Contradictions Table.	Simple to moderately difficult tasks, recommended for newcomers to TRIZ.
2	System of 76 Standards for solving technical problems: 5 classes / 76 standards.	Simple to difficult tasks
3	Step-by-step techniques or algorithms for inventive problem solving (abbr.: ARIZ). Universal tool for solving all kinds of problems.	Extremely difficult problems, comprehensive search for Solutions.
4	Substance-field analysis of technical systems.	Tools for method nos. 2 and 3.
5	Separation principles for eliminating physical contradictions.	ARIZ tool (no.3).
6	Methods for analyzing system resources.	Tool for nos. 2 and 3.
7	Database of physical, chemical, geometrical, and other effects and their technical applications.	TRIZ knowledge base; tools for component nos. 1 to 5.
8	Methods to increase creative thinking, to reduce psychological inertia, and to “leave beaten tracks”: operator DTC (dimensions-time-cost), simulation with “Little People,” and so on.	Psychological aids for all TRIZ components.
9	Method of Anticipatory Failure Identification (AFI) technical systems.	Analysis and prediction of possible sources of failures.
10	Patterns of evolution of technical systems (TS).	Prediction for the development of technical systems, creation of patent fences.

The problem definition tools in TRIZ help in the standardization of a specific problem, and reformulate it into a TRIZ general problem. These tools start off with the model of the problem (e.g. Engineering Contradiction, Physical contradiction, Function Model, and Substance-Field Model), based on this general problem (or model of problem). TRIZ provides the tool for resolving this (e.g. Contradiction Matrix, System of Standard Inventive Solutions). The user still has to take the final step of determining the type of specific solution needed based on the suggested TRIZ general solution (e.g. 40 Inventive Principles, 76 Standard Inventive Solutions). This would be the Model of Solution, where a specific Inventive Principle or specific Standard Inventive Solution is selected, and a solution is generated for solving the specific problem. Other methods/tools also integrate the Model of the Problem, Tool, and Model of Solution, such as ARIZ (Algorithm of Inventive Problem Solving) (Yeoh *et al.,* 2009). The TRIZ process flow for solving a particular problem is depicted in Figure 2.

4. CONTRADICTION

The concept of contradiction is essential to the TRIZ technique, because if there is a contradiction, then it means that there is a problem which needs to be solved. In order to solve the problem, designers have to identify the contradiction and then solve it. A contradiction occurs when two different parameters conflict with each other; so, it is important to identify where the conflict takes place (Tsai, 2009). Terninko *et al.* (2000) pointed out that in comparison with other methods of solving technical problems, contradiction analysis is a powerful method of looking at the problem with a new eye. Once the designer has gained this fresh perspective, the contradiction table becomes the tool for generating numerous solution concepts. If the problem fits into the parameters outlined, the designers may be well on the way to finding a variety of solutions that are both creative and effective. In addition, in order to solve the contradiction, designers have to understand the use of three basic tools, which are developed by Altshuller, and those are the 39 parameter features, the contradiction matrix, and 40 inventive principles. To understand contradictions, designers should understand what kind of contradiction their design problems belong to.

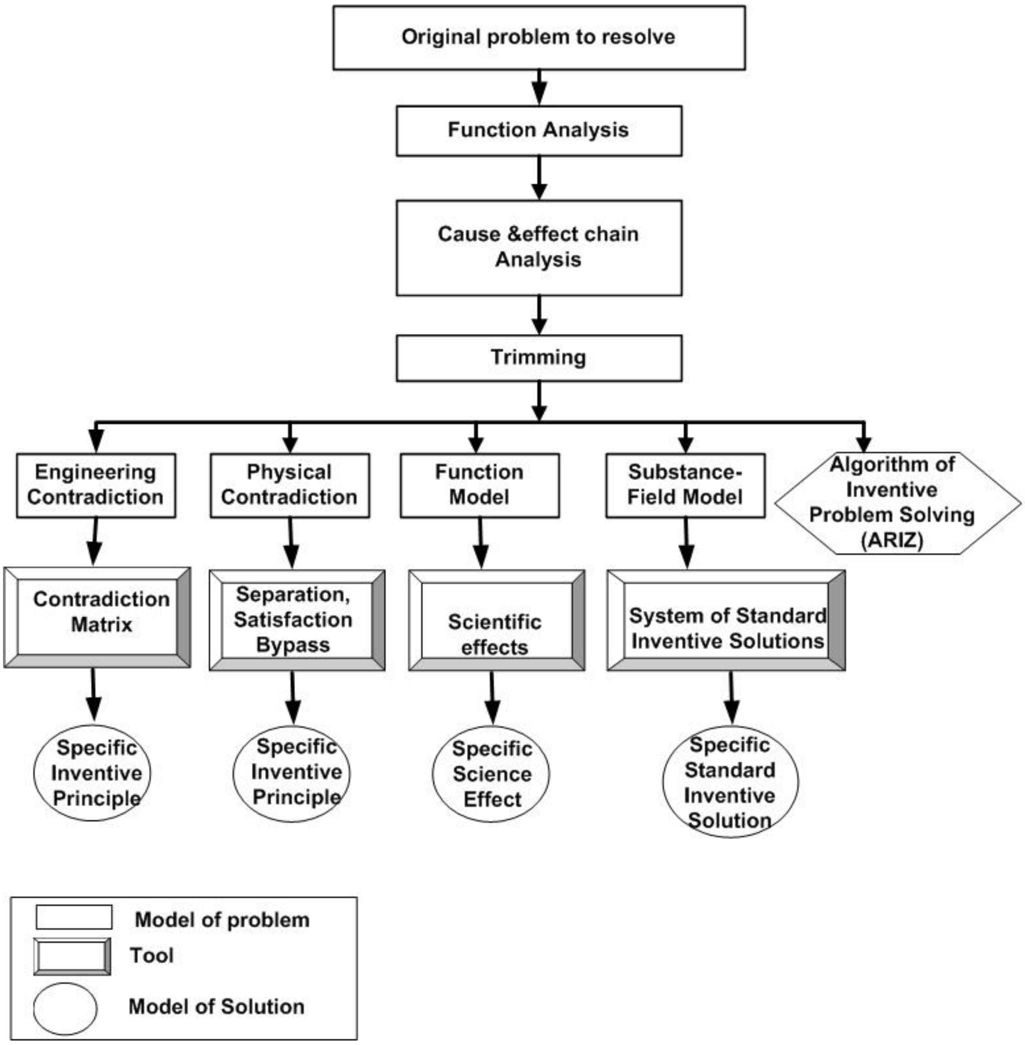

Figure 2 : TRIZ problem solving map (Yeoh *et al.*, 2009)

4.1. Technical Contradictions

TRIZ has established a form of representing the essence of problems, that is, technical contradictions, with a table showing useful hints to solutions. An engineering contradiction is a situation in which an attempt to improve one engineering characteristic results in the worsening of another different characteristic. In order to represent the situations of various technical contradictions, TRIZ uses 39 parameters of systems and has provided a problem matrix of size 39 by 39. Then, by surveying a huge number of patents, each patent was analyzed to find which type (among 39 x 39) of technical contradiction is treated and which principle of invention (among 40) is used in its solution.

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The accumulation of this analysis has revealed which principles are most used in each of the 39 x 39 types of problems. The top 4 principles in each type of problem were recorded in a tabular form of 39 x 39 elements; the resultant table is called the Contradiction Matrix. In Figure 3, Mann (2002) illustrated how a technical contradiction takes place, where different parameters conflict with each other, and how the use of TRIZ can solve this problem with both good conditions, and also showed the difference between using a traditional design strategy and TRIZ.

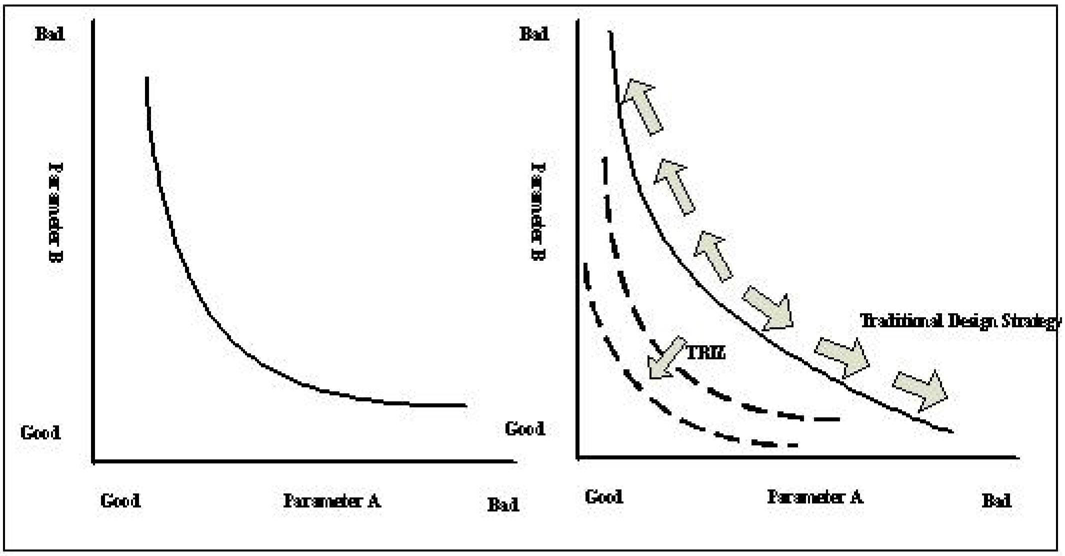

Figure 3 : How a technical contradiction happens and how TRIZ can be used to solve it (Mann, 2002)

When using this matrix, one has to think of which matrix element his/her problem should be assigned to and then, one should consider the four principles of inventions suggested by the matrix as the hints, so as to realize them into a solution for solving his/her own problem. The capability of flexible thinking is needed for using these hints. Figure 4 shows a flow chart of the use of the contradiction matrix for solving a technical contradiction.

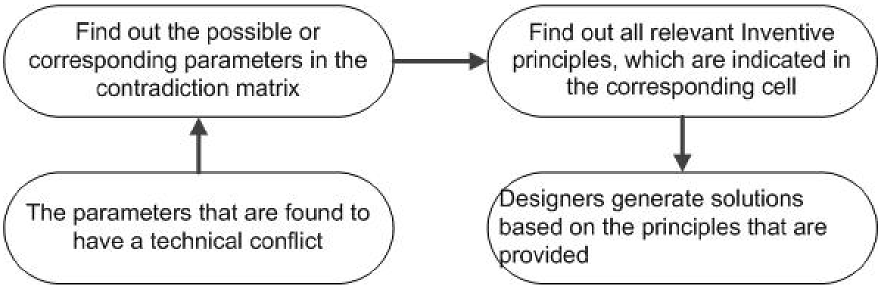

Figure 4 : Procedure for solving a technical contradiction

4.2. Contradiction Matrix

Contradiction Matrix, one of the most popular TRIZ tools, is often considered the heart of TRIZ, mainly because other tools are thought to be less complex and more powerful (Mann and Dewulf, 2003). Once the improving and worsening system parameters are identified, then the contradiction matrix, which is structured from 39 engineering parameters

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and 40 inventive principles, is a matrix table format, when people face design contradictions, they can search for the appropriate parameters, and then generate 1 to 4 suitable design principles for resolving the particular problem (Yen and Chen, 2005).

The contradiction matrix has been directly built based on the study of 200,000 successful patents. This is a tool that presents all contradiction parameters in the form of a tabular matrix for selecting the inventive principle to be used for resolving a particular contradiction. After reviewing these successful patents, Altshuller and his colleagues identified and summarized 39 engineering parameters that frequently appeared in these patents. Table 3 shows these parameters, the contradiction matrix cross-references, the solutions to the contradictions between these parameters, and the inventive principles that are used to solve them.

Table 3 : The 39 engineering parameters

1. Weight of moving object	11. Stress or pressure	21. Power	31. Object-generated harmful factors
2. Weight of stationary object	12. Shape	22. Loss of Energy	32. Ease of manufacture
3. Length of moving object	13. Stability of the object's composition	23. Loss of Substance	33. Ease of operation
4. Length of stationary object	14. Strength	24. Loss of Information	34. Ease of repair
5. Area of moving object	15. Duration of action by a moving object	25. Loss of Time	35. Adaptability or versatility
6. Area of stationary object	16. Duration of action by a stationary object	26. Quantity of Substance	36. Device complexity
7. Volume of moving object	17. Temperature	27. Reliability	37. Difficulty of detecting and measuring
8. Volume of stationary object	18. Illumination intensity	28. Measurement accuracy	38. Extent of automation
9. Speed	19. Use of energy by moving object	29. Manufacturing precision	39. Productivity
10. Force	20. Use of energy by stationary object	30. Object-Affected harmful factors	

However, in order to use the 39 parameters effectively, the designers should observe these parameters more carefully. The suggested inventive principles from the contradiction matrix are, thus, based on the most principles that solve the contradiction. If there are no suggested inventive principles to be used (which has cells that are blank in the matrix) in this case, then all 40 inventive principles will need to be reviewed in order to choose which inventive principles will help solve the problem. Similarly, if the suggested inventive principles do not help by providing ideas for solving the problem, then the designer will need to review all remaining 40 inventive principles. The suggested inventive principles from the Cntradiction Matrix are thus based on the most probable inventive principles that solve the contradiction. If there are no suggested Inventive Principles to be used (which has cells are blank in the matrix), then all 40 inventive principles will need to be reviewed to choose which inventive principles will help solve the problem. Similarly, if the suggested inventive principles do not help by providing ideas for solving the problem, then the designer will need to review all remaining 40 inventive principles (Yeoh *et al,* 2009).

Figure 5 shows an extract of the contradiction matrix and how it is used. The "Y" axis of the matrix shows "improving" parameters, whereas the "X" axis of the matrix shows all "worsening" parameters. Each cell of the matrix suggests which of the 40 inventive principles can be used to solve a particular contradiction. In addition, inside each cell, these principles are listed in the order of frequency according to which they were found in the patents.

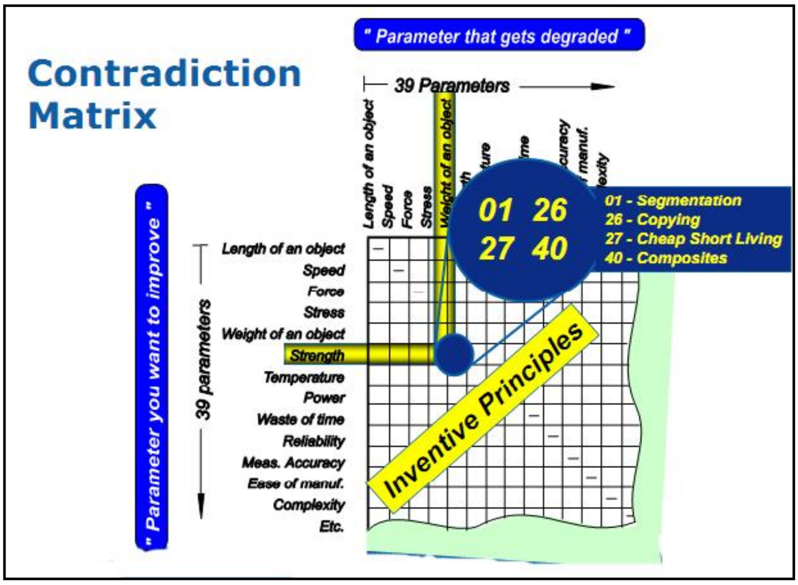

Figure 5 : The use of the contradiction matrix (Yeoh, 2008)

4.4. 40 Inventive Principles

Genrich Altshuller, discovered forty patterns of inventive solutions, known as *40 Inventive Principles*, by extracting them from technical patents. The 40 Inventive Principles are solutions that have been known to solve a specific contradiction that appears in the contradiction matrix. Using these known solutions in new problems can result in innovative solutions. These principles are very important in the contradictions while solving any problem, and are considered one of the most accessible and useful of TRIZ creativity tools in a variety of problem-solving situations (Zhang *et al*., 2003). Designers generate their own solutions based on these principles that are indicated through the use of the contradiction matrix, which provides a systematic access to the most relevant subset of Inventive Principles depending on the type of a contradiction along with their own experience, available resources, own knowledge, and, possibly, use of patent databases as well (Souchkov, 2007). In addition, these principles can be used without a contradiction matrix only if designers understand and clearly know what the contradiction is and its causes.

5. THE APPLICATION OF TRIZ IN MANUFACTURING

Since its introduction in 1946, the Theory of Inventive Problem Solving (TRIZ) has been widely applied as a problem-solving tool in the industry. Today, TRIZ is widely recognized as a leading method for innovation worldwide. Its applications extend to all applicative fields, including manufacturing, service, aeronautics, and architecture (Shirwaiker, 2008). According to Su and Lin (2008), TRIZ has gained increasing interest that is applied in the process manufacturing industry. The TRIZ methodology offers a well-structured and high-power inventive problem-solving process. The application of TRIZ thinking tools in various industries has successfully replaced the unsystematic trial and error method in the search for solutions in the daily life of engineers and developers. Problems related to manufacturing can occur at different levels depending on the nature of the problems. They can be classified into three levels as shown in Figure 6. They are :

1. Design for manufacturing
2. Manufacturing processes
3. Manufacturing systems

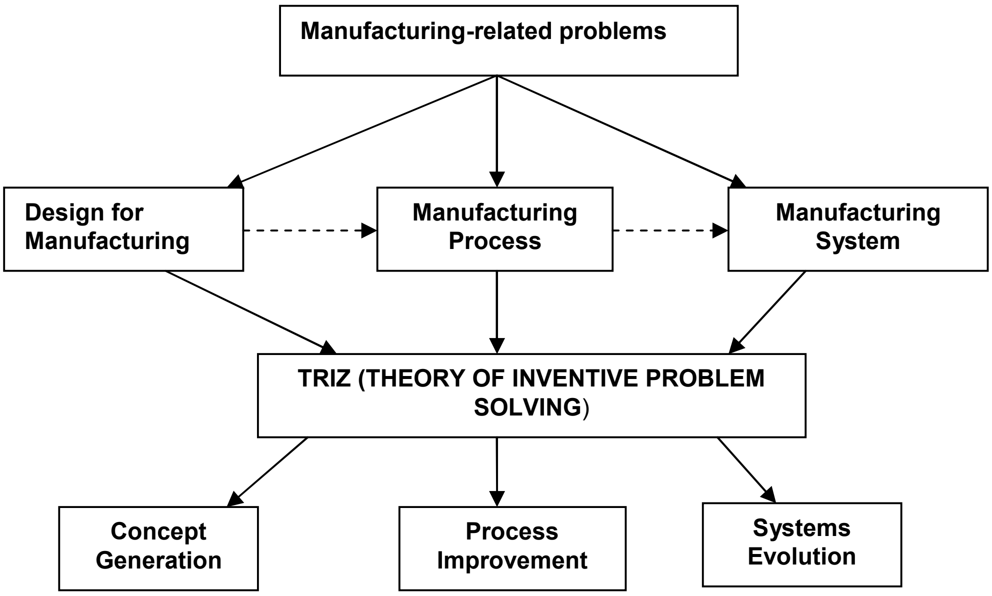

Figure 6 : TRIZ applications at various levels of manufacturing-related problems (Shirwaiker, 2008)

TRIZ help in concept generation for solving design problems related to manufacturing. Innovative tools, such as TRIZ, help in solving design problems, and the logical mode of reasoning within TRIZ enables designers to come up with unpredictable and often quite remarkable inventive solutions in a systematic manner (Ahmed, 2005). The application of the Theory of Inventive Problem solving (TRIZ) in the automobile industry was proposed by Cascini and Rissone (2004) with the aim of approaching the redesigning of structural parts from metals to polymers. Basic problem-solving TRIZ tools (Contradiction Matrix-Principles and the substance-field-substance) methods was used for redesigning a motor scooter wheel, made by an aluminum casting, in order to reduce its cost. The use of tools based on TRIZ is proposed to avoid a trial-and-error approach when looking for a suitable design solution. Li (2010) combines the theory of inventive problem solving (TRIZ) and the analytical hierarchy process (AHP) for designing the automated manufacturing systems. The tools have been applied in the contradiction matrix table, 40 innovative principles, and 39 engineering parameters with the aim of compromising the trade-off between design contradictions and engineering parameters.

On the other hand, Bariani *et al*. (2004) presented a new approach that combines the design for the manufacture and assembly (DFMA) method with the theory of inventive problem solving (TRIZ). Their approach was developed by merging the common characteristics and connecting the complementary aspects of the two methods, which were then applied to the redesigning of a satellite antenna. The results have resulted in a comparatively lower manufacturing cost for the new design and a 43% reduction in the

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assembly time. TRIZ has been successfully applied in order to enhance manufacturing processes. Kransnoslobodtsev and Langevin (2006) proposed an educational program that contained the practical use of implementing the TRIZ application in conditions of real projects for different divisions of the high-tech industry at Samsung Electronics.

Hsieh and Chen (2010) proposed combined TRIZ to conduct welding process design and also to provide necessary concept design suggestions on the friction spot welding (FSW) process. The TRIZ tool used in welding process can acquire different innovative principles and avoid much unnecessary trial-and-error work. Supply-chain management is a systems approach that is used in manufacturing. A new model has been tested by Kazue *et al*. (2007) with the aim of developing a type of supply-chain management system for small companies using the TRIZ to support company-purchasing decisions and also for enhancing a competitive supply chain.

5.1. Integration of TRIZ with Other Problem-Solving Tools

Some researchers have recognized the lack of using a single creative technique and have started combining creative techniques in order to reveal more knowledge about the effects of using them. Mann (2000) pointed out that the TRIZ is integrated with other systematic innovation methodologies, such as Six Sigma, FMEA, QFD, DFMA, and Lean Manufacturing, as depicted in Figure 7. The combined methods are beginning to be successfully applied across a number of widely disparate problem types.

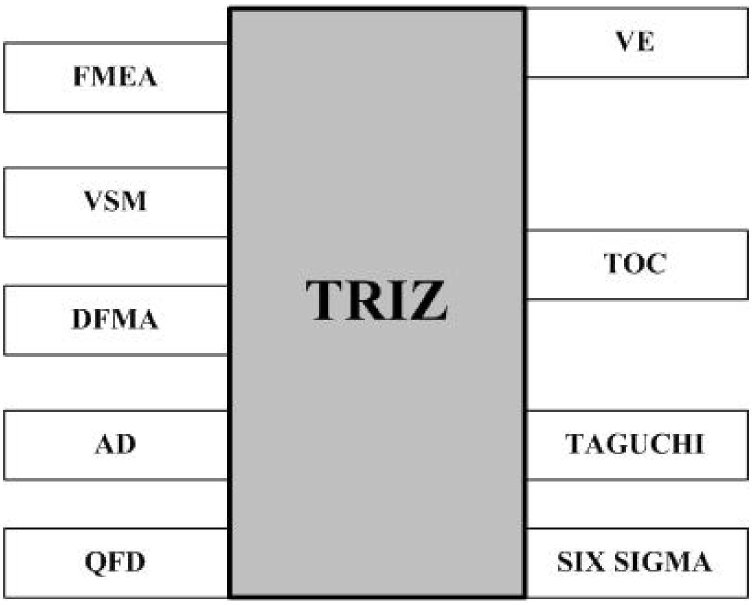

Figure 7 : Integration of TRIZ with other systematic innovation tools (Mann, 2000)

According to Hipple (2005), it is easy to combine tools such as Six Sigma, Design for Six Sigma, QFD, and FMEA with TRIZ problem solving and technological forecasting with these processes and tools, because most of these enterprise tools are problem-identifying processes that couple easily with the strong problem-solving capabilities of TRIZ. According to Rantanen and Domb (2002), technological competitive advantages and innovations can benefit by using TRIZ, which enhances Six Sigma, Constraints Management, Supply-Chain Management, QFD, FMEA and Taguchi methods. Among all the techniques, TRIZ plays a vital role in enhancing the analytical and solution skills that are used to solve product design and manufacturing problems. Wang and Chang (2010) reported that the integrated

(QFD)/AHP (Analytic Hierarchy Process) and TRIZ/FMEA were used for constructing the pattern of product design. This method can be practically used for a design strategic process that is executed in an enterprise. Such an integration provides engineers with an approach that converts the customer's requirements to engineering parameters, avoids narrow thinking for products, and creates new ideas.

Campbell (2003) proposed the use of a combination of brainstorming and TRIZ; brainstorming could be used to enhance the effectiveness of TRIZ by helping bridge the gap between the general and the specific solutions. Organizations are using TRIZ coupled with many other techniques, such as QFD, FMEA, simulations, and so on. Among all the techniques, TRIZ plays a vital role in enhancing the analytical and solution skills used to solve product design and manufacturing problems. Yen and Chen (2005) proposed a tool instead of traditional FMEA that emphasized environmental, safety, and healthy operations during the product's life cycle in order to evaluate the priority of removing the failures or reducing their risks, by integrating the TRIZ invention problem-solving method.

5.2. Practical Value of TRIZ

TRIZ is one of the most powerful and effective practical methodology used for creating new ideas. Currently, TRIZ tools are used in more than 5000 companies and government organizations across the world. However, TRIZ does not replace human creativity. Instead, it amplifies it and helps it move in the right direction. As proven during long-term studies, virtually everyone can invent and solve non-trivial problems with TRIZ (Souchkov, 2007). In general, the use of TRIZ provides the following benefits:

1. TRIZ helps companies to generate more solutions that are of low cost and higher quality in the shortest amount of time and provides additional tools for engineers to create innovative solutions effectively that will raise the degree of personal creativity.
2. TRIZ enables an organization to increasing the ratio of "Useful ideas/useless ideas" during problem solving by providing immediate access to hundreds of unique, innovative principles and thousands of scientific and technological principles stored in the TRIZ knowledge bases.
3. Using TRIZ allows a systematic approach to innovation rather than relying on trial and error.
4. TRIZ, in concert with other Strategic Thinking tools, generates a set of data that changes the way organizations think and plan the future, and the way they connect strategy with execution.
5. TRIZ offer a broad range of generic patterns of inventive solutions to reducing the risk of missing an important solution to a specific problem.

6. CONCLUSIONS AND RECOMMENDATIONS

This paper has provided a basic understanding of TRIZ methodology through the introduction of the contradiction principles, the Inventive principles, the engineering parameters, and the application in manufacturing. In addition, companies can benefit from using TRIZ as well. TRIZ helps define and solve problems much faster and with relatively small efforts; thus, avoiding large investments that generate new working ideas and concepts. The utility of any methodology, tool technique, lies in the application of it. The real benefits comes from using it to solve the problems that require inventive solutions. TRIZ is not for the obvious and simple problems but for the difficult and complex ones. The opportunity lies in various problems, including engineering, management, administrative and social issues. Future researchers should explore this opportunity which hopefully can generate tangible as well as intangible benefits that eventually will solve many of the complex problems that all of us face today. Future researchers must obtain relevant knowledge through certified training and self learning if they intend to venture into doing research using TRIZ.

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