IOSR Journal of Computer Engineering (IOSR-JCE)
e-ISSN: 2278-0661, p- ISSN: 2278-8727 Volume 13, Issue 2 (Jul. - Aug. 2013), PP 83-92
www.iosrjournals.org

An Overview of TRIZ Problem-Solving Methodology and its Applications

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Abstract: *TRIZ, which is a Russian word that stands for "Theory of Inventive Problem Solving", is a problem-solving methodology that was invented based on the belief that there are universal principles of invention that are the foundation for creative innovations that help in advancing technology. One of the most widely used approaches to problem-solving in most technology-related fields is the structured problem-solving methodology. Actually, TRIZ enhances the structured problem-solving methodology by applying its principles to the first few phases of the conventional structured methodology with more creative and advanced steps that make the problem-solving process more efficient and effective. A brief description of the structured problem-solving methodology is presented since it has a big influence on the original TRIZ methodology. TRIZ's ways of solving problems are explained in detail, and several main applications of TRIZ in the technology-related and other new fields (non-technology) are discussed. Several suggestions are put forward in order to overcome some of the main issues faced by TRIZ in order to improve its effectiveness in solving problems, especially in non-technical and non-scientific domains.*
Keywords: *Inventive Problem Solving, Problem-Solving Methodology, Structured Problem-Solving, TRIZ*

I. INTRODUCTION

In general, a problem is any difficulty, obstacle or issue that needs to be analyzed and overcome using factual knowledge when solving the problem. On the other hand, problem solving is a cognitive process in which one is required to identify the exact problem and find the solution to the identified problem [1]. Normally, a series of steps should be followed systematically even though sometimes certain steps are skipped or repeated several times depending on the types of problems at hand. It is also important to note that problem solving only occurs whenever an individual or a group of people wants to move from a given undesirable or problematic current state to a desired state or goal [1].

The following is a list of steps that is normally used in problem-solving [2]:

- Identify the problem
- Define the problem
- Determine the best strategy that suits the problem
- Organize and gather facts and knowledge regarding the current problem
- Resource allocation (time, money, people, etc.)
- Monitor progress
- Evaluate the results

There are many techniques and methodologies to problem solving, and one of them is TRIZ methodology. TRIZ is a Russian word that stands for "Theory of Inventive Problem Solving" or TIPS, which is the equivalent phrase for TRIZ in Russian [3]. TRIZ was developed in 1946 by Genrich Altshuller and his colleagues in the former USSR, and it is now being used widely throughout the world in solving complex inventive problems [4][5][6].

TRIZ was created based on the theory or belief that "there are universal principles of invention that are the basis for creative innovations that advance technology, and that if these principles could be identified and codified, they could be taught to people to make the process of invention more predictable [4]". Altshuller discovered that invention is nothing more than the removal of technical contradiction with the assistance of a set of known principles. He emphasized that one does not have to be born an inventor in order to be a good inventor, and he criticized the trial and error method that are normally used to make discoveries [7].

The main rule is that the progress and evolution of technological systems is governed by a set of objective laws, which Altshuller called *Laws of Technological System Evolution* [5][8]. To devise these laws, Altshuller originally started by analyzing around 200,000 patterns and invention descriptions from various fields of engineering from available world-wide patent databases. Altshuller also made a conclusion that there were around 1,500 technical contradictions that could be solved easily by simply applying the discovered principles [7].

From his thorough study and analysis, Altshuller selected and examined the most effective solutions - "the breakthroughs [5][8]." As a result, the following three main findings are concluded [4][6][8]:

- Repetitive problems and solutions occurred across industries and sciences
- Patterns of technical evolution and advancement were repeated across industries and sciences
- Innovations used scientific effects outside the field where they were developed

The above main findings are applied in TRIZ for creating new products or inventions and also to improve current products, systems, and services.

In addition, based on the analysis done on the selected 40,000 innovative patterns, 40 *Inventive Principles* were formulated. In fact, it was also discovered that inventiveness could be taught and trained to others. To date, almost 3 millions existing patents were examined and studied, classified by their level of inventiveness and analyzed thoroughly with the intention of finding new useful principles of innovation [8].

In the application of TRIZ all of the above findings are employed to create and to improve products, services, and systems. In addition, new creations of products are also possible by observing past inventions patterns in different technology fields. It is very important to note that, in this information technology (IT) era, most products' life spans are shortened since at almost any time around the world someone is introducing something new and because of that newer products must be produced the soonest possible in order to have the products in the market faster than the competitors. This leads to very short development time and rapid development of products is required. And to ensure that the products can be marketed faster, efficient and effective methodologies are required, and this is where TRIZ is very useful.

II. MOTIVATION

The main goal of this research is to perform a study on TRIZ problem-solving methodology by reviewing its fundamental concepts and the various TRIZ applications in solving engineering-related, technology-related or scientific-related, and also non-technology-related problems. Several objectives of this paper are as the following:

- To review past research and works on TRIZ problem-solving methodology.
- To highlight in detail several engineering applications and non-engineering or non-technical applications that have used TRIZ.
- To propose several suggestions that can help improve TRIZ problem-solving effectiveness.

III. TRIZ BACKGROUND

TRIZ is a Russian acronym for "Teoriya Reshiniya Izobreatatelskikh Zadatch", which means 'Theory of Inventive Problem Solving" in English [8]. TRIZ can be regarded as a philosophy, a process, and a series of tools based mainly on the notion of resolving contradictions [8]. As widely known, problem solving is the "heart of improving designs and the processes to make them [5]." Innovation involves *continuous improvements* to existing designs and processes. TRIZ is a systematic approach for finding advanced and creative solutions to difficult problems in a more efficient and effective manner to ensure that the solutions are up-to-date and still relevant during its launching.

In TRIZ, it is assumed that the degree of complexity of a problem mainly depends on the way the problem is formulated [5], and the clearer the formulation, the most likely and easily that the solution is going to be found. In order to have a good formulated problem, a series of successive reformulations of the initial problem is conducted until an initially ill-defined problem is transformed into a much clear formulated problem with obvious solution or it becomes clearer that the problem cannot be resolved because lacking in the required technology or scientific knowledge [5].

It was discovered that Engineering Systems progress towards "*Ideality*" by overcoming existing contradictions within the systems and these Engineering System evolutions are driven by objective laws [8]. Problems tend to repeat across industries and sciences and it was found that the solutions used to resolve these problems are also repeated correspondingly.

Basically, a general TRIZ problem-solving methodology is shown in Fig. 1 [5]:

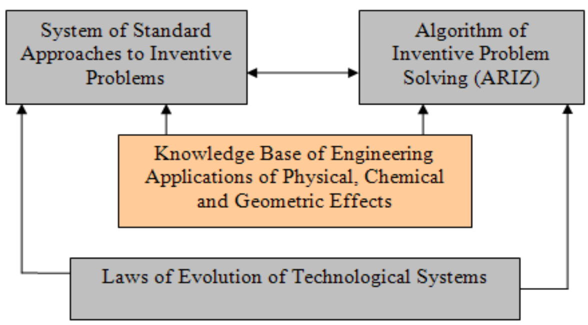

Figure 1. TRIZ problem-solving methodology

The four main components of the TRIZ methodology along with brief descriptions of each component are as follows [5]:

- *Laws of Evolution of Technological Systems*: In TRIZ it is believed that the evolution of technological systems is governed by a set of objective laws that can be used as the basis for problem solving These formulated laws can be reused instead of searching blindly to deliberately develop technological systems (or to solve new problems) [5].
- *System of Standard Approached to Inventive Problems*: "A set of rules for problem solving based on the laws established by Altshuller stating that many problems from different areas of technology can be solved by the same conceptual approaches [5]."
- *Algorithm of Inventive Problem Solving (ARIZ)*: A set of sequential and logical procedures aimed at solving and minimizing the system conflict at the core of the problem.
- *Knowledge Base of Engineering Applications of Physical, Chemical and Geometric Effects*: Contains knowledge of past solutions to similar problems; can facilitate problem solving by suggesting analogies from previous creative solutions.

IV. STRUCTURED AND TRIZ PROBLEM-SOLVING METHODOLOGIES

Various techniques and approaches are used in solving complex problems, but the most common approach used in solving software development or engineering problem is the structured methodology. Ideally, the structured methodology consists of several phases or steps that must be followed in order to solve problems systematically. Fig. 2 illustrates the various phases within the conventional structured problem-solving methodology [6] that is normally used in many problem-solving domains.

A variation of the structured methodology to problem solving is presented in Fig. 3 [8] where an iteration is added to check the effectiveness of the solution. If the implemented solution does not solve the problem, then a new solution is generated. This repetitive step in carried out until a satisfactory solution that solves the problem is generated.

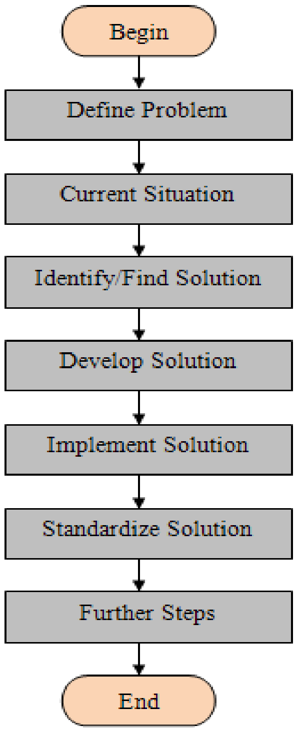

Figure 2. Conventional structured problem-solving methodology's phases [6]

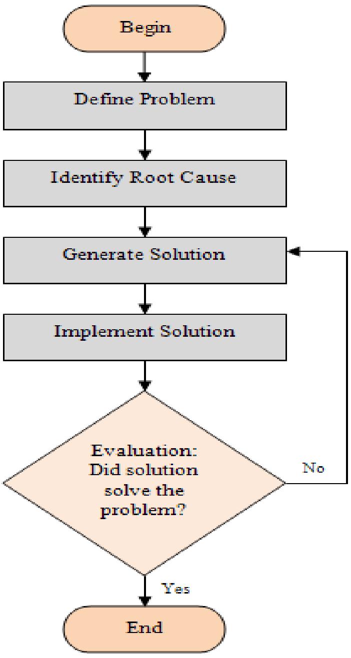

Figure 3. Structured problem-solving methodology's phases with an iteration [8]

When TRIZ was first introduced, it was used to complement the conventional structured problem-solving methodology because the two methodologies have a lot in common. Several earlier phases of TRIZ are almost the same as the structured methodology. It has been proven that using both the TRIZ and structure problem-solving methodologies in finding solutions to problems has resulted in better innovative results. Fig. 4 presents the steps taken in TRIZ problem-solving methodology [8][9].

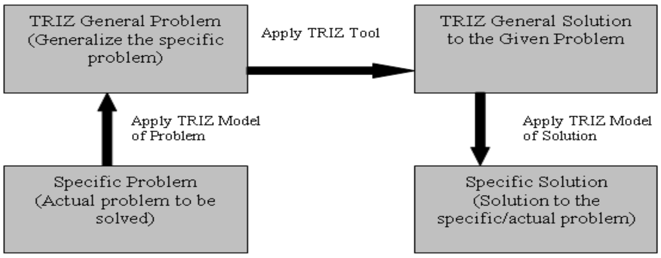

Figure 4. TRIZ's way of solving a problem

Based on Fig. 4, it is obvious that TRIZ methodology of problem solving is not the same as the normal problem-solving process. In a normal problem-solving scenario, the problem solver directly tries to find a specific solution to a specific problem, and in most cases, this is difficult to accomplish because of the complexity of the problem. In addition, finding a specific solution from scratch is very time-consuming. Most of the time, there exist contradictions among the various parameters that prevent the generation of good solutions [8] to the problems faced, and TRIZ simplifies this process.

Fig. 5 presents a modification of the diagram in Fig. 4 that shows what tool and what principles are used in solving the general problem. It also shows where the 39 *System Parameters* are used [10][11] within TRIZ's steps.

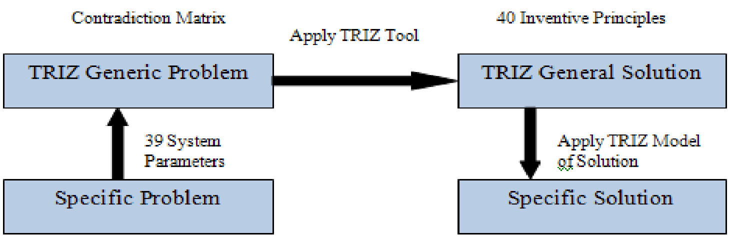

Figure 5. Schema of solution of problems using TRIZ [10][11]

The first step in TRIZ methodology is to convert the specific problem into a TRIZ general problem that basically models the problem [12]. The general problem is considered as the *Model of Problem*, and TRIZ has the required *Tool* for resolving this *Model of Problem*. An example of a *Tool* is the *Contradiction Matrix* [8]. A *Contradiction Matrix* is a TRIZ Tool that is used for generating potential *Inventive Principles* that can assist in finding the right solution. A contradiction in engineering problems is a situation where an attempt to improve a specific characteristic or parameter of the system causes another characteristic to worsen [8]. In TRIZ, an engineering system's parameters must be mapped to the pre-determined 39 *System Parameters* or *Contradiction Parameters* [8][10][13][14]. Once all the improving and worsening *System Parameters* are identified, then only the *Contradiction Matrix* is used in generating potential solution to the problem. A specific solution must be derived by the user based on the suggested general TRIZ solution by referring to the *40 Inventive Principles* [8][10][13][14] and the *76 Inventive Solutions*. This would result in the *Model of Solution* to the specific problem.

TABLE I. TRIZ 39 SYSTEM PARAMETERS [13][14]

1. Weight of moving object	11. Tension, pressure	21. Power	31. Harmful side effects
2. Weight of nonmoving object	12. Shape	22. Waste of energy	32. Manufacturability
3. Length of moving object	13. Stability of object	23. Waste of substance	33. Convenience of use
4. Length of non-moving object	14. Strength	24. Loss of information	34. Repairability
5. Area of moving object	15. Durability of moving object	25. Waste of time	35. Adaptability
6. Area of nonmoving object	16. Durability of nonmoving object	26. Amount of substance	36. Complexity of device
7. Volume of moving object	17. Temperature	27. Reliability	37. Complexity of control
8. Volume of nonmoving object	18. Brightness	28. Accuracy of measurement	38. Level of automation
9. Speed	19. Energy spent by moving object	29. Accuracy of manufacturing	39. Productivity
10. Force	20. Energy spent by nonmoving object	30. Harmful factors acting on object	-

Table I [8][10][13][14] presents a full list of the *39 System Parameters*, while Table II [8][10][14][15] contains the *40 Inventive Principles*. A unique integer value is assigned to each *Inventive Principle*, which is used in the *Contradiction Matrix* to indicate what *Inventive Principle(s)* is (are) to be applied in solving the generic problem at hand. Since the *Contradiction Matrix*'s table is quite complex, only a portion of the table is presented in Table III to illustrate how it is used.

TABLE II. TRIZ 40 INVENTIVE PRINCIPLES [14][15]

1. Segmentation	11. Cushion in Advance	21. Rushing through	31. Use of porous materials
2. Extraction	12. Equipotentiality	22. Convert harm into benefit	32. Changing the color
3. Local Quality	13. Inversion	23. Feedback	33. Homogeneity
4. Asymmetry	14. Spheroidality	24. Mediator	34. Rejecting and regenerating parts
5. Combination	15. Dynamicity	25. Self-service	35. Transforming physical or chemical states
6. Universality	16. Partial, overdone or excessive action	26. Copying	36. Phase transition
7. Nesting	17. Moving to a new dimension	27. Inexpensive short life	37. Thermal expansion
8. Counterweight	18. Mechanical vibration	28. Replacement of a mechanical system	38. Use strong oxidisers
9. Prior Counteraction	19. Periodic action	29. Use pneumatic or hydraulic systems	39. Inert environment
10. Prior Action	20. Continuity of useful action	30. Flexible film or thin membranes	40. Composite materials

TABLE III. AN EXTRACTION OF THE CONTRADICTION MATRIX [8][15]

	Worsening Feature/Parameter → Improving Feature/Parameter ↓	Weight of Moving Object	Weight of Stationary Object	Length of Moving Object	Length of Stationary Object
		1	2	3	4
1	Weight of Moving Object	+	-	**15, 8, 29, 34**	
2	Weight of Stationary Object	-	+	-	**10, 1, 29, 35**
3	Length of Moving Object	**8, 15, 29, 34**	-	+	-
4	Length of Stationary Object		**35, 28, 40, 29**	-	+

The *Contradiction Matrix* was developed based on thorough studies on roughly 40,000 innovative patents. Based on Table III, if the Improving Feature/Parameter is *Length of Moving Object* (Row 3) and the Worsening Feature/Parameter is *Weight of Moving* Object (Column 1), then the set of *Inventive Principles* to be used is 8, 15, 29, and 34 (refer to Table II for the details). The proposed set of *Inventive Principles* to be used is based on the most probable set of *Inventive Principles* to solve the contradiction.

Another concept in TRIZ that must be emphasized is the *Ideality* of the system [16], which basically means that "the ideal system" that needs to be developed where all of its components perform at the greatest possible capacity. *Ideality* measures how close a system is to the "ideal machine" and it is normally expressed as follows:

$$Ideality = \frac{\sum Benefits}{(\sum Costs + \sum Harms\ )}$$

All useful functions that result from the system are considered as the system's *benefits*. *Harms* are any unwanted or undesirable outputs of the system including any waste products or side effects produced by the system. One of TRIZ's main objectives is to increase *Ideality* by moving closer towards the ideal final result (IFR), which is considered to be the most optimal situation. And based on the above mathematical expression, IFR can be achieved by increasing the *benefits* of the system, reducing its *harmful* outputs, and also by reducing costs of producing the system towards achieving its *benefits*. Consequently, the end product is automatically the result of an innovative problem-solving approach, which is considered as an invention.

V. TRIZ APPLICATIONS

TRIZ is normally used to solve engineering-related, technology-related, and scientific problems. In the past many applications in science and technology employed TRIZ in getting results effectively and efficiently with the assistance of the various proven steps used within TRIZ. TRIZ problem-solving methodology is famous for its ability to produce solutions to problems based on past related technologies and at the same time allows users to come up with innovative products really fast. Nowadays, TRIZ has been applied to solve various types of problems ranging from engineering to problems that are not technology-related. Several applications of TRIZ in various problem domains are explained in more detail below just to give some ideas on how TRIZ can be applied in solving inventive or creative problems.

One of the applications of TRIZ is in Computer Aided-Design (CAD). In a paper [17], the authors applied TRIZ and evolutionary algorithms (EA) to solve inventive problems based on dialectical negation. TRIZ and EA are integrated for creating a new conceptual framework that will enhance computer-aided problem solving. The two basic ideas being presented in this paper are "the *inversion* of the traditional EA selection ("survival of the fittest"), and the incorporation of new dialectical negation operators in evolutionary algorithms based on TRIZ principles [17]."

The three laws of dialectics used are given below [18]:

- *The law of the transformation of quantity into quality and vice versa*
- *The law of the interpenetration of opposites*
- *The law of the negation of the negation*

The results showed that TRIZ and evolutionary algorithms (EA) support the idea that inventiveness can be learned, implemented, and developed systematically using some known principles and this approach will save a lot of the inventors' precious time.

Fig. 6 illustrates a *concept map* [17][19] of the inventive problem (IP) solving process performed under the dialectic negation perspective.

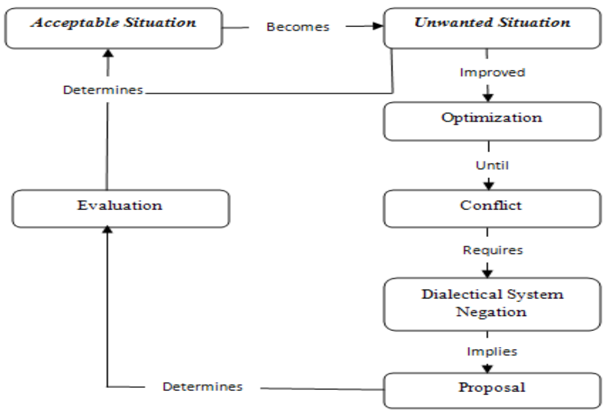

Figure 6. Inventive problem (IP) solving generic stages [17]

The cycle will start again when a new unwanted or undesirable situation reoccurs, and more contradictions will be tackled to make the system become more ideal.

In another paper [20], in an attempt to overcome conflicts between the advancement in technology and the environment, TRIZ was introduced in balancing between technical innovation and its environmental impact. Chang and Chen [20] presented a conflict-problem-solving CAD software that integrated TRIZ into the eco-innovation idea. Design engineers normally use eco-design methods in reducing the product's environmental impact that will occur throughout its life cycle. The harmful impact of the product must be minimized. Using the proposed 'Eco-Design Tool' software, the software engineers can acquire the most feasible or optimal solution efficiently. The five major functions of 'Eco-Design Tool' are as follows [20]:

- *Eco-design targets search by the analytic hierarchy process technique*
- *Product evaluation*
- *TRIZ engineering parameter recommendation reflecting eco-efficiency elements*
- *TRIZ inventive principle exploration by the statistic technology*
- *TRIZ inventive principle interpretation*

Based on the authors' eco-innovative product examples, it was shown that the proposed 'Eco-Design Tool' software was able to assist design engineers, in particular those novices, in producing products that are more environmental-friendly.

TRIZ has also been used in education systems to increase students' problem-solving ability. In a paper [21], at RMIT, a group of forty-two engineering students were enrolled in a course on TRIZ for a duration of 13 weeks, and it was discovered that most of the students were not aware of any other problem-solving methodology or tools before learning TRIZ problem-solving methodology.

As a result of this experiment, the students' perceptions of their capabilities in solving problems have changed significantly, and their thinking abilities have also changed (improved) in such a way that they were able to come up with better ideas that they would never thought of while doing their final project [21]. It was also discovered that the course on TRIZ tools has greater impact on students' problem-solving ability much more than the disciplines based courses [21]. Some of the most significant findings from this research of teaching TRIZ are as follows [21]:

- *Improved ability to attempt open-ended problems*
- *Improved structured/systematic thinking*
- *Able to look beyond the current knowledge*
- *Changed in thinking style*
- *Acquired good problem-solving skills (after completing the course)*

Obviously, from the above results of teaching TRIZ to engineering students, it can be concluded that TRIZ was able to improve the students overall problem-solving ability and also able to increase the students' level of self-confidence in tackling new problems.

In another paper [22], a framework that integrated both the structured and TRIZ methodologies to problem solving was proposed. In this study, the structured methodology was enhanced in such a way that the phases within the structured methodology were slightly modified to consider the integration of the TRIZ approach to problem solving.

This framework considered the various software development methodologies, such as the following [23]: *Waterfall*, *Prototyping*, *Spiral*, *Incremental*, *Rapid Application Development*, *Object-Oriented*, *Extreme Programming*, *Agile*, and many more. Basically, each methodology has the standard software development phases such as *Requirements Specifications*, *Analysis & Design*, *Implementation*, *Testing*, *Verification & Validation*, *Documentation* and *Maintenance*.

Fig. 7 illustrates the TRIZ problem-solving methodology's framework as proposed in [22] for software development and programming problems. The framework was adapted from the structured problem-solving methodology's framework and TRIZ methodology's framework given in [6][8].

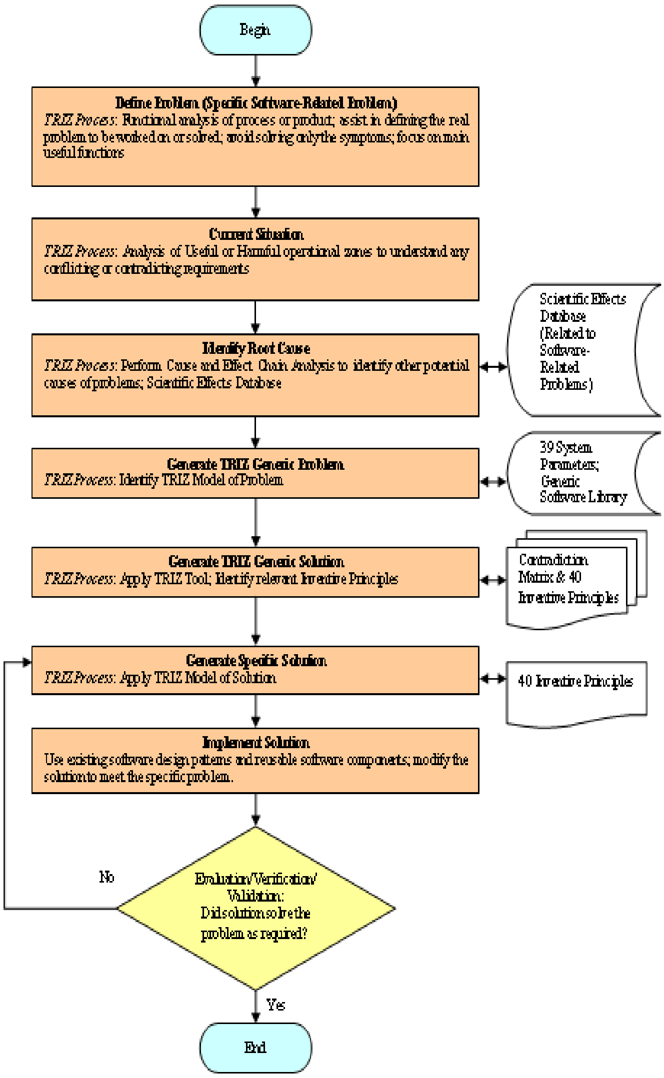

Figure 7. TRIZ problem-solving methodology's framework for software development and programming problems [22]

There are several other applications that used TRIZ in solving inventive problems such as in mobile network industry, control strategies, semiconductor manufacturing, product R & D design, quality assurance, and also in business modeling.

VI. SUGGESTIONS FOR IMPROVING TRIZ

When TRIZ was first introduced, it was meant to be used to solve engineering-related problems, and in the past many applications had employed TRIZ in getting results effectively and efficiently. TRIZ problem-solving methodology is famous for its ability to produce solutions to problems based on past related technologies and at the same time allows users to come up with innovative products really fast.

But, as described earlier, quite a number of research works also used TRIZ in problem domains or areas that are non-engineering or non-technology-related (non-technical). Based on this new development, the following are suggestions that can further improve the application of TRIZ in wider areas of problem domains, especially those that are not considered as technology-oriented problem areas.

- Add several more innovative steps or processes to the existing general steps of the original TRIZ problem-solving methodology to make the methodology more comprehensive. The steps should be general enough to cater for both technical and non-technical problems.
- Include an intelligent component (with heuristic algorithms) in the overall TRIZ methodology that will try to derive new solutions based on the available knowledge stored in the knowledge base using inferences and reasoning similar to human's ways of reasoning.
- Include a method that allows automatic expansion or growth of the knowledge base used by TRIZ in deriving the solutions.

- Integrate TRIZ with other problem-solving methodologies that have not been considered in past research works.

VII. FUTURE WORK AND CONCLUSION

Problem solving nowadays is getting more and more challenging because all components or parts that need to be assessed or analyzed are changing rapidly, and there are always possibilities that by the time a solution is formulated for the current state of a system, new problems may arise. So, in the future, an intelligent reasoning and learning component (as suggested earlier) could be embedded within TRIZ so that new solutions that are being devised also consider the most recent developments within similar problem domains and be more pro-active in projecting potential future problems. It is better if TRIZ includes a step that uses artificial intelligence techniques such as case-based reasoning, genetic algorithms, and neural networks in generating several alternatives to the problem at hand, and later the most optimal solution is derived from a pool of possible solutions.

Based on the review on TRIZ and its application performed in this paper, it can be concluded that TRIZ has an enormous influence on the problem-solving and decision-making process. TRIZ problem-solving methodology is still gaining further popularity since its application has been extended beyond its initial problem domain, which is engineering and technology-related. TRIZ is now widely used in education in instilling more systematic problem-solving strategy in students so that they are able to effectively and efficiently solve new problems without depending too much on others.

In conclusion, if we want to solve problems by studying certain patterns (models) in the current problem domain and try to find previously solved solutions that are similar to the conceptual design of the problem at hand, and from there a specific solution can be derived, then TRIZ is the most suitable problem-solving methodology. Most problem-solving methodologies attempt to solve problems by trying to directly find specific solutions to the problems, and this approach is very time-consuming, costly, and also will not guarantee that the specific solution is usable or suitable because it has not been tested in the past. TRIZ on the other hand, uses past conceptual or general solutions to derive a specific solution for the current problem. And, this method of problem solving definitely saves significant amount of time and energy in inventing new products.

Acknowledgement

This research project was partially funded by the Ministry of Higher Education (MOHE) Malaysia under the Fundamental Research Grant Scheme (FRGS).

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