TRIZ/USIT Paper:

Problem Solving Methodology for Innovation: TRIZ/USIT. Its Philosophy, Methods, Knowledge Bases, and Software Tools

TRIZホームページ

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First Symposium on Knowledge Creation Support Systems,

held on Feb. 27-28, 2004,
at JAIST (Advanced Institute of Science and Technology, Hokuriku) near Kanazawa

English translation by Toru Nakagawa , on Aug. 14, 2004
[Posted here on Aug. 26, 2004]

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Editor's Note (Toru Nakagawa, Aug. 25, 2004)

This paper was presented as an invited talk at the First Symposium on Knowledge Creation Support Sytems held at JAIST near Kanazawa in February 2004. This paper is an intorduction of TRIZ to novices. It reflects my recent understanding of TRIZ, evolving little by little as I learned Darrell Mann's textbook, a number of case studies presented at conferences and Web sites, and practices of applying TRIZ/USIT by myself, etc. Writing an new introductory article is always a good thing not only for readers but for the author himself.

I am grateful to Professor Susumu Kunifuji, JAIST, for his invitation to the Symposium.

Contents:

Abstract

TRIZ ("Theory of Inventive Problem Solving") has been developed by G.S. Altshuller and his associates in a private section in the former Soviet Union for these 50 years. It is a philosophy in technology, a methodology for systematizing science and technology from the standpoint of technology, a way of thinking for creative technology development, a system of huge collection of knowledge of technology, and software tools implementing such knowledgebase, at the same time. It has been introduced to the Western countries after the end of the Cold War, and has been starting to be adopted as a powerful methodology for technology innovation in the industries in USA, Europe, Japan, Korea, etc, This paper describes the whole aspect of TRIZ according to the hierarchy of philosophy, method, knowledgebase, and software tools. In particular, this paper advocates to learn the essence of TRIZ philosophy, to use USIT as a simple and unified process for problem solving in TRIZ, and to fully utilize TRIZ knowledgebase tools; this is called "Steady Strategy" for introducing TRIZ.

Key Words: Technology innovation, Contradiction solving, Technology evolution, System analysis, TRIZ

1. Introduction

TRIZ ('Theory of Inventive Problem Solving') [1] has been developed by Genrich S. Altshuller and his followers in a private section of the former Soviet Union for over 50 years. It is a philosophy in technology, a methodology for reorganizing science and technology from the technology side, a technique for innovation, and a huge system of knowledge base of technology reorganized in such a perspective, altogether at the same time. Its knowledge base and its technique are now provided as software tools, much advanced and comfortably operable on personal computers. In short, TRIZ provides excellent principles (or models) and concrete tools for 'creative thinking' in the whole range of technology.

All these have been introduced into industries in USA, Europe, Japan, Korea, etc. and are now being applied in practices. Since TRIZ adds a 'philosophy of technology' to the quality improvement movements which have served a lot for over half a century even without it, the movement with TRIZ is expected to grow up to a big movement of technology innovation.

However, the introduction of TRIZ has not been so easy. In the prevailing approach taken in USA since 1990s, the contents of TRIZ was kept essentially the same as the classical one mostly developed around 1970s in the former USSR whereas the tools of TRIZ were much modernized with IT technologies. This approach unfortunately failed to build up so wide penetration as originally expected. It is essential rather for the Western countries to re-digest the contents of TRIZ first so as to make TRIZ easier to understand and to apply.

With the efforts for finding such a new generation of TRIZ, Darrell Mann calls it 'Systematic Creativity' [2], and the present author is recommending USIT as a simpler process in TRIZ [3, 4].

As mentioned above, TRIZ is really huge and widely spread in the sense of development history, application fields, and levels of methodology. Thus for understanding it with a good balance, it is highly recommended to read multiple of references, to apply it to multiple of problems, and to think for yourself.

As information sources for TRIZ, Web sites are often used. Refer to the "TRIZ Journal" [5] in USA, and to the "TRIZ Home Page in Japan" [6] edited by the present author and written in English and in Japanese. As a brief and easy-to-understand introduction, I recommend you my 4-page presentation at Japan Creativity Society [1].

In the present article, leaving an introductory description of historical development to the previous one [1], I will introduce you briefly the current TRIZ, i.e. a new-generation of TRIZ. For the purpose, I am going to explain TRIZ downward of its hierarchy, i.e., philosophy, methods, knowledge-bases, and software tools, in this order. It must be noticed, however, that the whole body of TRIZ has not been built in this way, but on the contrary, as well known, has been built up from the bottom, such as by the accumulation of research on patents for extracting essence of inventions.

2. Philosophy of TRIZ (in its Essence)

Original work by the Founder of TRIZ has been translated into Japanese recently in the books [7, 8]. They are unfortunately not suitable, however, for learning the full scope of TRIZ due to being introductory texts in relatively early stages of TRIZ history. The TRIZ textbook by Yuri Salamatov [9] was originally written in Russian, translated into English and then into Japanese, and seems to be reputed as being most systematic, standard, and containing up-to-date research results in the former USSR countries. On the basis of [9], you should better read Darrell Mann's new textbook [2], which can show you the whole scope of TRIZ and its future directions.

Here I am going to show you a slide "Essence of TRIZ in 50 Words" [10], which the present author made for a conference presentation just after translating Salamatov's textbook into Japanese. It is concise and easy to understand.

Recognition that
technical systems evolve
towards the increase of ideality
by overcoming contradictions
mostly with minimal introduction of resources.

Thus, for the creative problem solving,
TRIZ provides a dialectic way of thinking,
i.e.,
to understand the problem as a system,
to make an image of the ideal solution first, and
to solve contradictions

Figure 1. Essence of TRIZ in 50 Words

This claims that the Essence of TRIZ exists at the level of philosophy, and that its first aspect is the new 'recognition' which sees science and technology especially from the technology side while its second aspect is the way of thinking for creative problem solving on the basis of the recognition. Starting from practical analyses of a huge number of patents, and exploring a method for making inventions by overconing difficult problems, TRIZ has built up a recognition of the essence of evolution of technology and has clarified an inventive way of thinking.

The main objects of recognition in technology are technical 'systems'. Systems may be found at various levels such as an automobile, a rubber blade of the wiper, and a network of highways, may have multiple levels of hierarchy, and contain a number of components involved in functional and structural relationships. Such technical systems evolve, i.e. develop in history, in the much larger system of human culture; this is the basic recognition.

The evolution has a general direction, which is the direction of 'increase in ideality', TRIZ understands. The ideality is understood to be 'Benefit / (Cost + Harm)', where Benefit may also be represented as the 'Main Useful Function' which is naturally expected to the technical system. This concept of ideality is almost common with VE (Value Engineering), and shows that TRIZ places the idea of Function at the center of its consideration.

The ideality of technical systems can not be increased without much effort; human beings have been making a huge variety and number of trials and errors to increase it little by little. One small step of increase in ideality is achieved only when a contradiction is overcome, according to the TRIZ understanding. Being faced with some barriers of each problem, ordinary engineering disciplines have been teaching us 'trade-offs' and 'optimizations'. However, only when we solve a contradiction without using such a compromise, the barrier is broken and we achieve a break-through. This breakthrough forms a small step of the evolution of the technical system.

For solving a technical problem, we too often select to add something (e.g., to increase the power source). Most elegant solutions, however, do not waste/consume so much resource and are minimal in adding new elements, as TRIZ observes.

Since TRIZ recognizes this kind of large-scale objective nature in the evolution of technical systems, TRIZ realizes that creative problem solving is to enhance the evolution further along the line. The way of thinking for this purpose is firstly to enhance the technological thinking, while secondly to coordinate psychology of individuals, e.g. preparation for enlightenment.

The first feature of TRIZ thinking is to understand the problem as a system. TRIZ tries to explore the background of the problem, to understand the problem in a hierarchy of situation, and to focus at the core point of the problem. It also tries to understand the object of the problem as a technical system, to examine its super- and sub-systems, to analyze the functional relationships among the components in the system, and makes efforts for increasing the ideality of the system.

The second feature of TRIZ thinking is to think about the ideal solution first and then about the ways for approaching to it, in contrast to stay at the analysis and improvement of the current system. Since we know that the direction of evolution of technical systems is towards the increase in ideality, it is quite natural for us to consider the direction itself first and to make our efforts in the direction. The Ideal Final Result is supposed to be a solution which achieves the benefit with no cost and no harm (e.g., the function takes place by itself without anything).

The third feature of TRIZ thinking is the way of thinking for solving contradictions. TRIZ aggressively attacks the problem to reveal the contradiction in it. Revealing a contradiction is the preparation for solving the problem quickly and surely. TRIZ recognizes two forms of contradictions as its basic concepts. First is the situation where 'if one tries to improve one aspect of the system, another aspect gets worse'; trade-offs are usually required in this situation. TRIZ calls this situation 'Technical Contradiction'. Second is the situation where 'two opposite requirements exist at the same time in one aspect of the system'; in this situation we usually can go neither forward nor backward. TRIZ calls this situation 'Physical Contradiction'. TRIZ way of thinking is to examine the problem up to revealing this kind of contradiction and then to solve it. The concrete way of thinking is described later.

The TRIZ way of thinking has the three features described above, and can be summarized in the philosophical terms as 'a dialectic way of thinking'. In the history, dialectic ways of thinking were once widely advocated but were not so concrete and not easy to understand. TRIZ has shown in the field of science and technology the dialectic way of thinking in a concrete manner as described later. It is a very powerful way of thinking to lead creativity and innovations.

As is described so far, TRIZ' recognition of science and technology and its way of creative thinking have a very large scope. They do not depend on any specific area of technology. Mann [2] expects that TRIZ will become the core part of the future way of creative thinking, will develop further by combining and integrating with many other methods, and will form the 'systematic creativity' (involving both the levels of philosophy and methods).

3. TRIZ Methods (or Techniques) for Solving Problems

By making the 'philosophy' mentioned above more concrete, TRIZ provides a variety of methods and techniques for defining the problem as a system, for analyzing the problem situations, for clarifying the direction of evolution, for overcoming contradictions, and for generating concrete solutions, etc. For each of these methods, TRIZ often has a detailed and huge system of knowledge base.

Because of this fact, it was a tradition to take a long time of training for mastering TRIZ. In the former Soviet Union, graduate students and engineers who came voluntarily for learning TRIZ were trained directly by Altshuller and his associates for full two years at the graduate level. This provided highly qualified TRIZ specialists to the fields of research, education, and industrial development. In the current Western countries, however, it is usually unaffordable to give such a long-period training to engineers in industries who would obtain much benefits from TRIZ. Even a training seminar for a week may be regarded too lengthy.

Thus it is often necessary to select some suitable methods of TRIZ depending on the problem situations and to train engineers to become able to apply the selected methods to their problems. Or else in more advanced cases, it is desirable to construct a concise and effective process of problem solving and to train the engineers on the process in a way easy to understand. In the Western countries at present, there are a variety of opinions and positions in selecting the methods and in constructing the processes. In the following subsections I am going to describe the methods and processes which the present author believe most appropriate.

3.1 Method of technology prediction for developing new products

In the industrial situations of technology development, it is very important to think over the questions, 'how the technologies/market situations relevant to the product are going to develop in the future?' and 'in which direction should we develop our new product?'. In contrast to individual complaints and technical problems just in front of us, we should better think over these questions in a much wider scope of vision. We have to consider a wide range of items, and have to manage the ambiguity always accompanied with the forecasting. Nonetheless, forecasting will give much influence on the future direction and success/failure of the organization.

For such a general task, TRIZ provides a clear and useful method. The method is based on the concepts of the system and its evolution (described in Section 2), and is called as 9-Windows Method [2].

9-Windows method uses a tabular form having 3 x 3 boxes (or windows). The central box represents the system (of the problem) in the present. The vertical axis represent the hierarchy of the system (i.e., super-system, system, and sub-system) while the horizontal axis the time (i.e., past, present, and future).

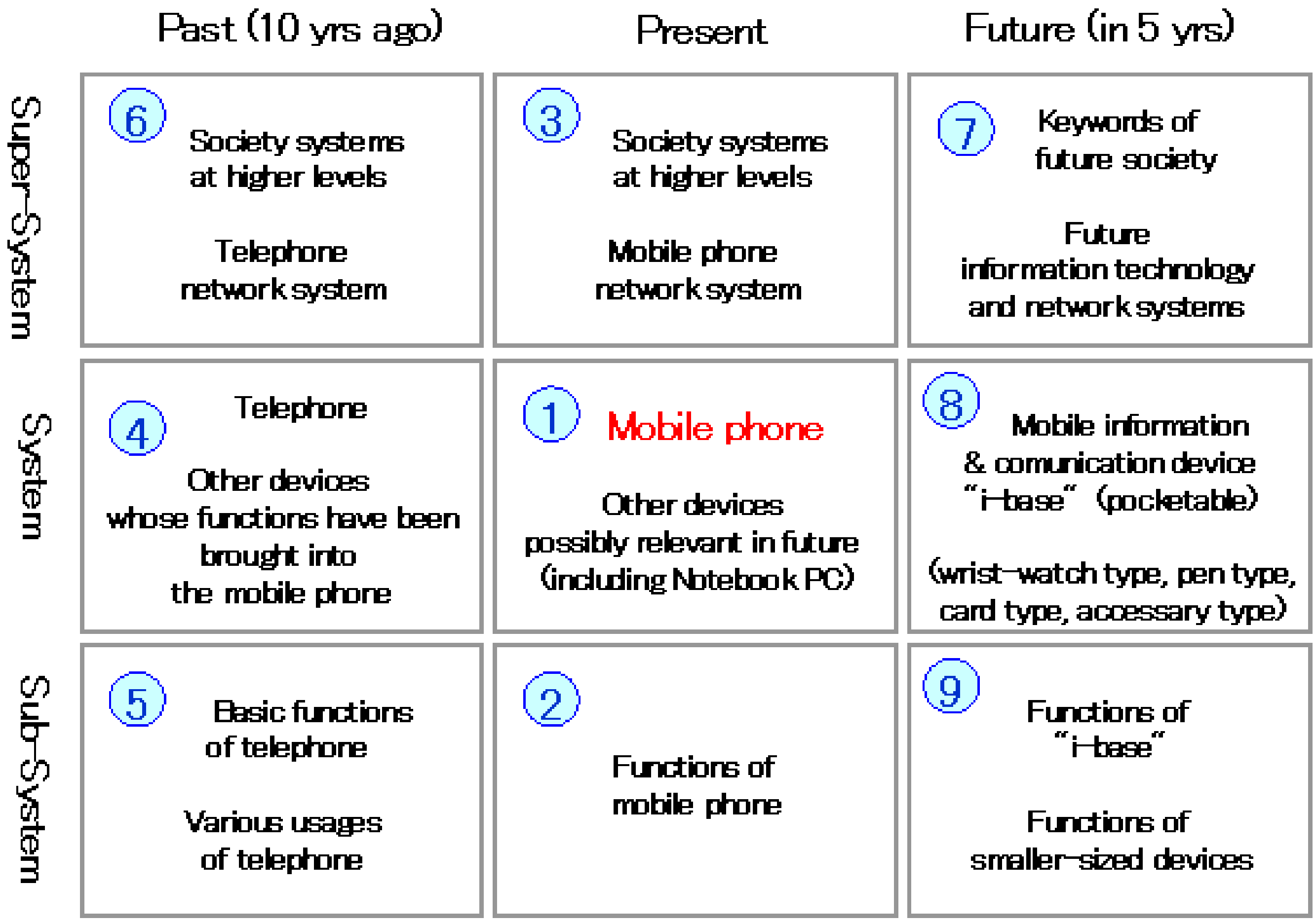

Figure 2. An example of description in the 9-window method: Forecasting the future of mobile phone

Let me explain the method with an example of 'forecasting the mobile phone'. Figure 2 shows an outline of the 9-windows I obtained (rather informally) during the discussion with my undergraduate students [11]. The numbers in circles in the figure represent the basic order of consideration of the windows. In fact, we go back and forth in this method while viewing the whole scheme.

First we put in the center (1) the present state of the mobile phone. Then in the present-subsystem window (2) we listed up the functions (in place of components) of the current mobile phone. In the present-super-system window (3) we briefly wrote about the mobile-phone network system, and then further wrote some relevant society systems. Then in the past window (4) we placed the fixed telephone, and wrote its functions and usage at the bottom-left (5), and listed up the telephone network system at the top-left (6). At this stage, by viewing the present from the past, we realize (or reconfirm) that the current mobile phone has been formed by merging many functions of separate equipments in the past and that its size has been much reduced. Thus, we decided to add in the central window a number of equipments other than the current mobile phone (e.g., notebook PCs, pocket electric dictionaries, etc.)

In the next stage we are going to consider the future, say 5 years from now. For this purpose, we first fill the upper-right window (7) with the keywords representing the future society and future technology in general and with some future of the IT technology. Then, we think of future systems (8) having the main useful function of the current mobile phone. Mini and ubiquitous equipments are imagined, but at the same time, since miniature size is not always convenient, equipments with the size similar to or even slightly larger than the current one are imagined having much wider functions. Thus various such functions are listed up in the bottom-right (9). During this discussion, the future systems are imagined to be composed at different sizes (one is suitable for carrying in bags or in pockets and the other is much smaller and suitable for carrying more directly attached to the body) and communicating among them.

The 9-window method outlined above can be applied very easily and is highly suitable for group work to clarify various images of the future. If you learn general trends of evolution of technical systems (see TRIZ knowledge-base described later) and if you are familiar with the background of the technology field, you (or your group) will be able to build up future visions in a more persuasive way.

As an example of application of this method, the future vision of the toilet space in Shinkansen trains is a nice case study reported by JR-East [12].

3.2 Methods for Defining Problems (or Tasks)

It is often said that having found what is the problem to be solved has solved 90 per cent of the problem. It is not so clear, however, how to find and define the problems. TRIZ has provided various processes for this purpose. Basically, one should pick up a problem situation from his/her sense, reveal the situations around it systematically, and then focus onto a task at some appropriate level.

Mann [2] recommends the benefit analysis at the initial stage. Concerning to the problem initially brought-in, we should consider 'why (i.e. for what purpose) do we want to solve this?' upward of the problem hierarchy, and also 'what is stopping us solving the problem?' downward, and then (on some basis of our value criteria) set our task at some appropriate level.

Sickafus [3] requests in the problem definition stage of the USIT process to clarify the following items: (1) unwanted effect (or phenomenon), (2) a problem statement written in a line or two, (3) a concise sketch of the problem situation, (4) plausible root cause(s) (maybe multiple), and (5) a minimal set of objects relevant to the problem. Conciseness is requested in all these items so as to eliminate ambiguity and to make a sharp focus of the problem.

Among these, the identification of root causes is particularly important but can only be done after some observations and experiments. During the group work of problem solving sessions, however, we do not have time to do experiments. Hence, if the root cause(s) are not clear yet through the experiments, Sickafus advises us to list up as many attributes (or properties) of each object (or component) as possible as the plausible root causes.

Mann [2], on the other hand, suggests to identify 'root contradictions' in place of 'root causes', as a process much simpler and more effective. Whereas the 'root causes' can not always be identified clearly even after a huge efforts of experiments and surveys, the 'root contradictions' can be revealed much more easily and can lead us directly to the core part of the problem.

3.3 Methods to Analyze the System of the Problem

The problem analysis in TRIZ places much emphasis on the analysis of function relationships. Components (or objects) of the system are represented with nodes while the functional relationships among them with arrows in the functional diagrams.

In Classical TRIZ, it is advised to focus the problem very sharply to the zone of conflict and to describe only two objects and the functional relationship between them. When the functional relationship is not useful but either harmful, insufficient, excessive, or lacking, the problem appears here. Corresponding to the pattern of the problem in this 'Substance-Field Model', TRIZ is going to provide recommendations of solution patterns, for which 76 patterns of 'Standard Solutions' have been developed in TRIZ [9].

Many of TRIZ researchers in the Western countries, as well as most TRIZ software tools, prefer to draw a multiple of objects (instead of only two) relevant to the problem and to analyze functional relationships among them. By distinguishing the functions into useful, harmful, insufficient, excessive, and lacking ones, they are going to analyze complex problems in the system.

Such diagrams of functional relationships are often become complex. Thus, USIT [3, 4] recommends to draw it in a simpler manner by focusing onto the functions really relevant to the problem. For example, let us think about a problem of improving the ordinary picture hanging kit of a nail and a string so as not apt to being tilt. Many people who are trained with ordinary functional analysis would describe that the string supports the weight of the frame and the nail supports the weight of the string, and so on. Although such functions are the main functions of the picture hanging kit in the ordinary sense, they are not directly relevant to keeping the frame at the right position (without tilting). In USIT we should describe that the string (according to its lengths of the right and left parts) decides the arrangement of the frame, and that the nail adjusts and holds the right and left lengths of the string. Even though it may take some time to master the USIT way of functional analysis, the representations are much useful.

Another useful way of analyzing the system is to reveal the attributes (i.e., kinds or categories of properties) relevant to the problem. For this purpose, USIT [3, 4] provides most compact yet powerful process. USIT requests the problem solver to list up as many attributes of each object that are relevant to the unwanted effect, and then to classify them into the ones having increasing (correlating) and decreasing (anti-relating) relationships. The attributes listed up as plausible root causes earlier in the problem definition stage are now examined more closely in their increasing/decreasing relationships with the unwanted effect.

The problem situation is also analyzed in terms of space and time.

3.4 Methods for solving contradictions

Through the problem definition and analysis stages so far, the core task of the problem may eventually be revealed as contradictions. Methods for solving the contradictions have been clearly demonstrated by TRIZ; this is one of the biggest contributions of TRIZ to the world of technological philosophy.

For the 'Technical Contradictions' where trying to improve one aspect of the system is hindered by another aspect getting worse, the Classical TRIZ has classified the patterns of the contradictions in a matrix form and then accumulated the knowledge from patent analyses to show which type of ideas (i.e. 'Inventive Principles') the inventors so far have used most often for each pattern of contradiction. As the result of accumulating a huge amount of work, TRIZ has built up the tool named 'Altshuller's Contradiction Matrix' [7, 9], see a later section.

Further for 'Physical Contradictions' where there exist two opposing requests simultaneously on one aspect of the system, TRIZ has derived a method with which this type of contradictions can surely be solved. This amazing method is called 'Separation Principle' [2, 9].

Once you find a Physical Contradiction in your problem, you should examine the apparent simultaneous requests opposing with one another by asking the questions of 'can we separate the requests with respect to space?', 'can we separate them with time?', and 'can we separate them with some other condition?'. If you find a separation of the requests, you should build two separate solutions which fully satisfy each request. Then finally find a way to use the two solutions together (i.e., in combination). In this process directed by the Separation Principle, the final combination step is the only stage when we need to figure out some inventive way.

As an instructive example where a Physical Contradiction was solved, let us see the case study of 'water-saving toilet system' reported by Kyeoung-Won Lee et al. [13]. Ordinary toilet systems consume about 13 liters of water every time for flushing away stools, and this is a part of the global scale problem for saving water. The reason for needing so much water at a time is the S-shaped drainpipe under the toilet bowl. The S-shaped pipe serves to keep water in the bowl and prevent bad smells from coming out from the sewer or cesspool. When flushing the stool, water is rapidly added to raise the water level and all the water in the bowl will flow away as the result of the siphon effect. This situation can be summarized in Table 1 in the form of a Physical Contradiction:

Table 1. Physical Contradiction of the water toilet system

Ordinary time	S-shaped pipe serves to keep water in the bowl, and to stops the bad smell.	S-shape pipe is necessary	Keep it exist.
When flushing	S-shaped pipe causes to consume so much water for flushing the stool.	S-shape pipe is an obstacle.	Eliminate it.

It is clear that the contradicting requests can be separated in time. Thus, TRIZ Separation Principle tells us 'Let the S-shaped pipe exist at ordinary time and eliminate (or disappear) while flushing'. How can we combine the 'exist' and 'eliminate' solutions? What should we do in front of this 'Zen questions'? It is the key that this does not mean the existence and disappearance of something real, but means the existence and disappearance of something in an effective sense. In short, the S shape of the pipe should effectively disappear only while flushing.

When I explained this problem at my class of sophomer students up to this point, the students could speculate the solutions by themselves. They said: 'The shape of the pipe should change, So we should better make it not of steel but of something flexible, like soft plastics. The pipe should be pulled upward during ordinary periods, and should be lowered while flushing. etc. etc.' The solution obtained by Lee et al. [13] is essentially the same as this students' idea, but is slightly more elegant in the way of lowering (or falling aside) the pipe, and in the way of lifting and lowering the pipe with a mechanism of a string, a pulley, and a counterweight without using any power. Lee et al. developed 'a super-water saving toilet system' which uses only 3 liters of water at a time, made proof experiments, and obtained a US patent recently. The problem which most people in the whole world knew for about 100 years (?) has been solved very well for the first time. Lee et al. says they have formulated and solved this problem using TRIZ. The solution, as a hindsight, is so simple that undergraduate students or even school children could have imagined of.

3.5 Methods for making an image of ideal solutions

One of the methods developed by Altshuller is the 'Modeling with Smart Little People (SLP)' [7,9]. In this method, we imagine that a part of the system is composed of a group of smart little people, who can adapt the situation and perform anything like in a magic. This is a kind of animation method, but is improved in the points that there are a large number of little people involved.

By an example, let me show our recent case of improving the design of a stapler so that it can join more number of papers without the staple being crashed [14]. After a number of simple experiments, we have observed that just before being crashed the staple becomes M-shaped, even though the top-middle part is never pushed. The staple which cannot go further into the papers because of the resistance cannot stand the pressure from above and is forced to go in to the inside space (i.e. between the horizontal part of the staple and the paper) where the staple is not supported. We have considered what to do in this case by use of the images of Smart Little People.

The little people are now located below the staple as well and are supporting the staple from the inner side so that the staple does not bend in to the inner space. When the staple comes down, the little person who cannot find his/her space any more escapes one by one. They escape towards the front of the staple. The little people support the staple as long as they can and escape just before being caught; thus the staple can be driven down fully without being bent. After joining a pile of papers and when we are ready to join another pile with the next staple, the little people are already at their positions below the staple. The following figure demonstrates this image. We have derived a rough design of a stapler with this improvement implemented.

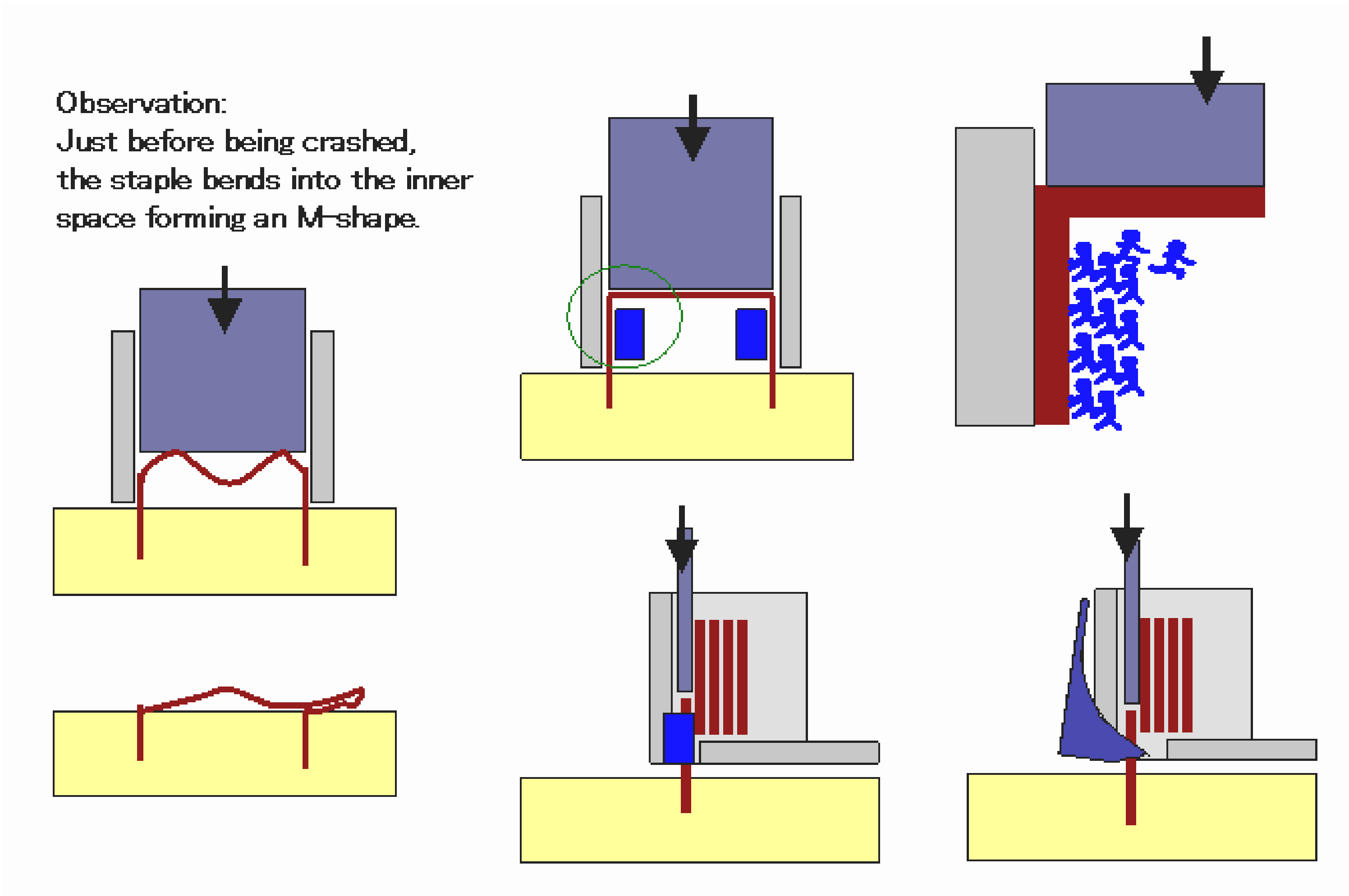

Figure 2A. Exmple of Smart Little People's Modeling: the Stapler

In USIT this method has been improved further and is called 'Particles Method'. Guideline of its thinking process is described and a number of case studies are reported [3, 4].

3.6 Methods for Generating Solutions

TRIZ researchers have analyzed a huge number of patents, extracted the essence of their ideas, and derived a collection of "Principles for Invention". They are usually called '40 Inventive Principles', but they actually contain about 100 sub-principles. It is the basic TRIZ method to show the Principles one by one as a hint for encouraging an analogical thinking in relation to the user's own problem. TRIZ can also provide with '76 Inventive Standard Solutions' corresponding to each problem situation formalized in the 'Substance-Field Model' [7, 9, 2].

The present author et al. [15, 16] have shuffled all the variety of TRIZ solution generation methods and reorganized into a new system based on the USIT solution generation methods. Consequently, USIT has the following 5 Solution Generation Methods (with 32 sub-methods in total).

(1) To pluralize the objects.
(2) To change the attribute dimensionally.
(3) To re-distribute the functions.
(4) To combine the solution pairs.
(5) To generalize the solutions.

All these solution generation methods are formalized as operators to be applied onto the specified type of operand, are supported with brief but effective guidelines, and can have references to a large number of cases originally accumulated for TRIZ.

For instance, as a solution to the 'Picture Hanging-Kit Problem' Sickafus devised a unique nail as shown in Figure 3 [3]. The string for hanging the picture frame is adjusted at the smooth part of the nail, and then after adjustment the string is pushed forward and is held at the rough part of the nail. This idea can be derived by four solution generation methods in USIT as follows [4]:

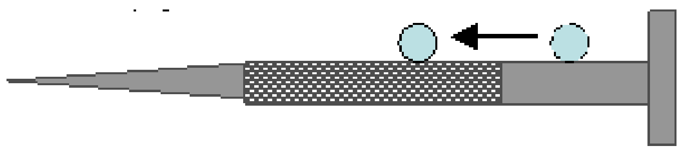

Figure 3. Sickfus' nail for hanging a picture with a string

(1) Divide the nail object into halves, make the surface of one half rough and the other half smooth, and then integrate them to use together.

(2) Change the value of the smoothness attribute of the nail surface differently depending on the part of the nail.

(3) Separate the nail's functions of adjusting the lengths of the two sides of the string and of holding the string at its position, and assign the two functions to different parts of the nail prepared appropriately.

(4) Combine two solutions, one to make the string adjustment easy with a smooth surface of the nail and the other to make the string holding tight with a rough surface of the nail, by using different parts of the nail.

Examining this solution further, we have found that even though the combination in space is apparent in the above description (4) the combination of solution pairs in time is more essential for this solution. Once we have understood the problem in this manner, we have found ourselves having passed through the barrier already and we can generate a variety of solutions to this problem.

3.7 Processes for Creative Problem Solving

In Classical TRIZ, the whole process of solving problems in TRIZ was called ARIZ (Algorithm of Inventive Problem Solving). With the aim of making ARIZ as powerful as possible even for very difficult problems, Altshller made much efforts for improving ARIZ more and more, and developed a number of versions of it in his life [9]. It presumes the usage of a number of knowledge bases and involves a delicate logic; and hence it requires a long time of training.

Mann, in his textbook [2], explains all the analysis and solution-generation methods in TRIZ in a manner easy to understand and with a lot of insightful examples. He sets up a special stage for 'selecting tools' and explains how to select most appropriate (analysis and) solution-generation tools depending on the problem situations and the problem solver's skills. This selection method, however, implies that only some sections of TRIZ are to be learned and used by the users.

On the other hand, Sickafus [2] has constructed a full process, namely USIT, for solving problems as a simplified scheme of TRIZ. The present author has adopted it and refined it further. Thus the current USIT process is shown in the flow chart, Figure 4.

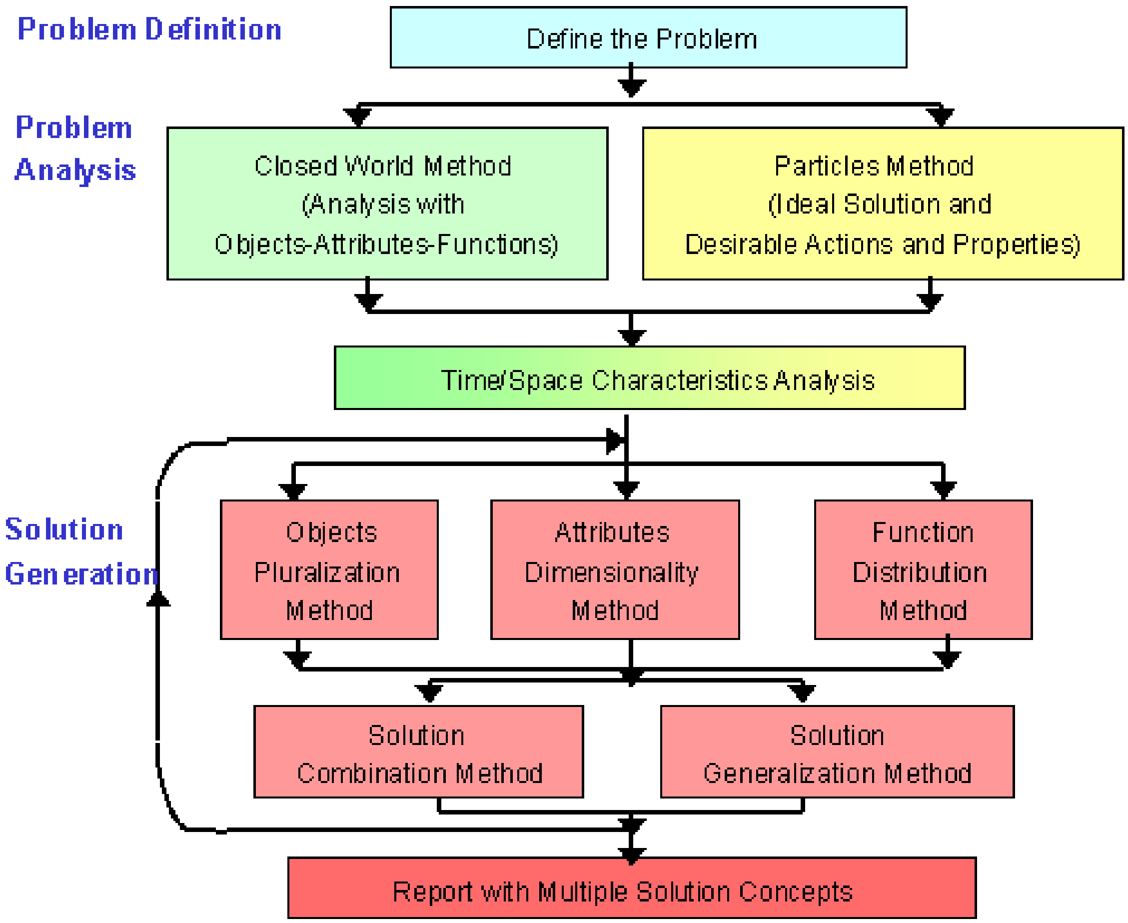

Figure 4. Flowchart of the USIT Process

The whole process is performed in three stages of problem definition, problem analysis, and solution generation. In the analysis stage, we have two principal methods, the one for analyzing the current system and the other for making an image of ideal solution. You may use either one of them, but you are strongly advised to use them both (firstly to analyze the current system and then to make an image of the ideal solution). In the solution generation stage, the solution generation operators explained in the previous subsection are to be applied repeatedly. In this manner, a large number of solution concepts can certainly be obtained for any problem.

4. TRIZ Knowledge Bases and Software Tools

While surveying patents, Altshuller recognized that even novel inventions had some common patterns of ideas in their essence and he obtained the idea of research which later resulted in TRIZ. Then he made efforts over 40 years for extracting the patterns, making models of them, and distilling them into various principles. The man-power devoted to the research and development of TRIZ in the former USSR countries is estimated to be around 1500 person year [2]. Working basically with papers and pencils, they achieved the construction of a huge knowledge base and published them in a number of textbooks.

Many associates and students of Altshuller emigrated to USA after the end of the Cold War, and developed software tools of TRIZ knowledge bases. Because of the nice scheme of the original knowledge bases, the software tools work very comfortably on PCs and provide highly useful information. Such software tools have been introduced into a large number of industries in the world, and have been converted into Japanese as well [17]. However, the users often complain of the oldness of the technical cases (mostly the techniques of 1960s and 1970s) in the software.

Recently, CREAX [18, 19] (in Belgium) built an institute with 25 full-time patent specialists in India, and conducted a large-scale research program to fully analyze the US patent data base granted during the period from 1985 to the present, by applying a modernized version of Altshuller's research scheme. The research results were accumulated and reorganized on

PCs, confirmed the TRIZ findings mostly in the principle level, made the TRIZ knowledge bases fully up-to-date especially in the case studies and data aspects. The results were also reflected in the new textbook [2], and were built in the software tools [20] which are easier to use and less expensive than the preceding ones.

4.1 '40 Inventive Principles'

Altshuller first built a knowledge base called 'Inventive Principles' by extracting information from a huge number of patens. 40 principles are listed starting with division and including taking-out, asymmetry, universality, dynamization, composite materials, etc.. Most of the principles have a few sub-principles and all are illustrated with a number of actual cases for reference. They are expressed in a way independent of specific fields of technology. Reading the 40 Inventive Principles and their examples has been a typical way for beginners to learn TRIZ.

4.2 'Contradiction Matrix'

In order to answer the question 'which Inventive Principles should we use for solving our specific problems?', Altshuller next built a large reference table named the 'Contradiction Matrix'. He used the formulation of 'Technical Contradiction' mentioned previously in order to represent and classify the whole variety of problems. He selected 39 parameters first to describe various aspects of systems. They include length, weight of object, strength, ease of manufacture, reliability, etc. Thus he set up a 39 x 39 table (or a matrix) with these parameters. Then examining the contents of patents one by one, he tried to interpret the focus of the problem in terms of the technical contradiction, 'which parameter was to improve?' and 'which parameter was preventing the improvement because of getting worse?'. He also tried to identify the essence of the invention in terms of his 40 Inventive Principles. Thus one patent was recorded as a datum in the matrix in the form of one principle number in an appropriate box. After accumulating such records for a huge number of patents, there appear the inventive principles which have been used frequently by inventors so far for each box in the matrix. Thus the top four most frequently-used principles were shown in each box of the matrix. Altshuller's Matrix constructed in this manner is printed in almost all TRIZ textbooks.

Mann and his coworkers [19] have analyzed recent US patent database by applying this Altshuller's scheme with refinement and modernization, and fully updated the contents of the Contradiction Matrix. They expanded the parameters up to 48 (adding new parameters like noise, security, etc.) and rearranged them to express some kind of order. The new Contradiction Matrix is now published in the name of 'Matrix 2003' and is implemented in CREAX' software tool [20].

Many TRIZ users like to use the Contradiction Matrix. The pitfalls in the old Matrix are difficulty in finding the parameters suitable to express user's own problems and, sometimes, apparent irrelevance of the suggested Inventive Principles to the specific problem. Japanese users who have tried to use the new Matrix in comparison with the classical one have evaluated it 'much easier to use and more useful'. It is also useful to refer directly to recent US patents from the suggested Inventive Principles.

4.3 Knowledge Base of Physical Effects

Various natural laws, phenomena, and effects observed in science, and also various means, devices, equipments, techniques derived in technology have been accumulated in TRIZ to form a knowledge base. TRIZ calls it 'a collection of physical, chemical, and mathematical effects' or briefly as 'Effects Database'. This database implemented in software tools is really useful to learn knowledge and techniques which are developed and known in different specialties and in different sections of industry/society.

A software tool developed by Invention Machine [21] can read technical documents like patents and papers, analyze the semantics of the texts, and extract/accumulate various technical knowledge in the form of 'Subject - Object - Action'. By processing a large body of such form of knowledge, different new applications are now emerging.

4.4 Knowledge Base for Finding Means from Target Functions

A new TRIZ way of organizing knowledge is the knowledge base for searching technical means from target functions. In practices of technology development, we often have something or some function we want to do and then we are looking for some good ways to achieve it. In the conventional Western approaches, we are going to build a huge knowledge base of science and technology and then to use it in an inverse search with the power of computers. TRIZ, on the other hand, has built a general hierarchical system representing what we want, and reorganized the whole knowledge of science and technology in this system. For this purpose, whatever we want to do is expressed in terms of functions. Thus, TRIZ has built a hierarchical system of functional representations and the whole body of science and technology knowledge is classified and accumulated in this system. This scheme and this knowledge base are found very useful.

4.5 Knowledge Base of Trends of Evolution of Technical Systems

TRIZ has also found that in the course of evolution of technical systems there are some typical steps and directions of development common in different technical systems. Such typical patterns are called 'Trends of Evolution of Technical Systems' and many of them are found. For example, Mann's textbook [2] lists up 31 trends with illustrative examples and examines what kind of improvement (i.e. increase in ideality) is brought in by the one-stage jump in the trend pattern.

For example, the 'trend of segmentation of objects' tells that the object in a system evolves from a monolithic solid, to segmented solids, to powders, to fluid (or liquid), to foam, and to gases, etc. The benefits of jumping one step further are interpreted in various terms, such as becoming easier to handle, increasing in performance, etc. Similarly in the 'trend of dynamization' tells that the internal freedom of motion of components increases, such as bending with joints.

One of the trends to be noticed here is the 'trend of developing a mono-system to bi-system and to poly-system'. For example, a system with a speaker develops into a dual-speaker stereo system, and then to a multiple-speaker surrounding system. The trend tells further that once a system reaches at a certain level of complexity, it evolves further by unification and simplification of the system. This reflects the TRIZ recognition of general transformation from 'heavy, thick, long and big' technologies to 'light, thin, short, and small' ones.

4.6 The Role of TRIZ Knowledge Bases

The positions of all these TRIZ knowledge bases can be viewed as shown in Figure 5 [1]. When we want to solve our own specific problems, we would like to obtain support from science and technology; but in their conventional scheme they are not so easy to access. TRIZ has provided information in several new schemes, which are useful in making the knowledge of science and technology easily accessible for us.

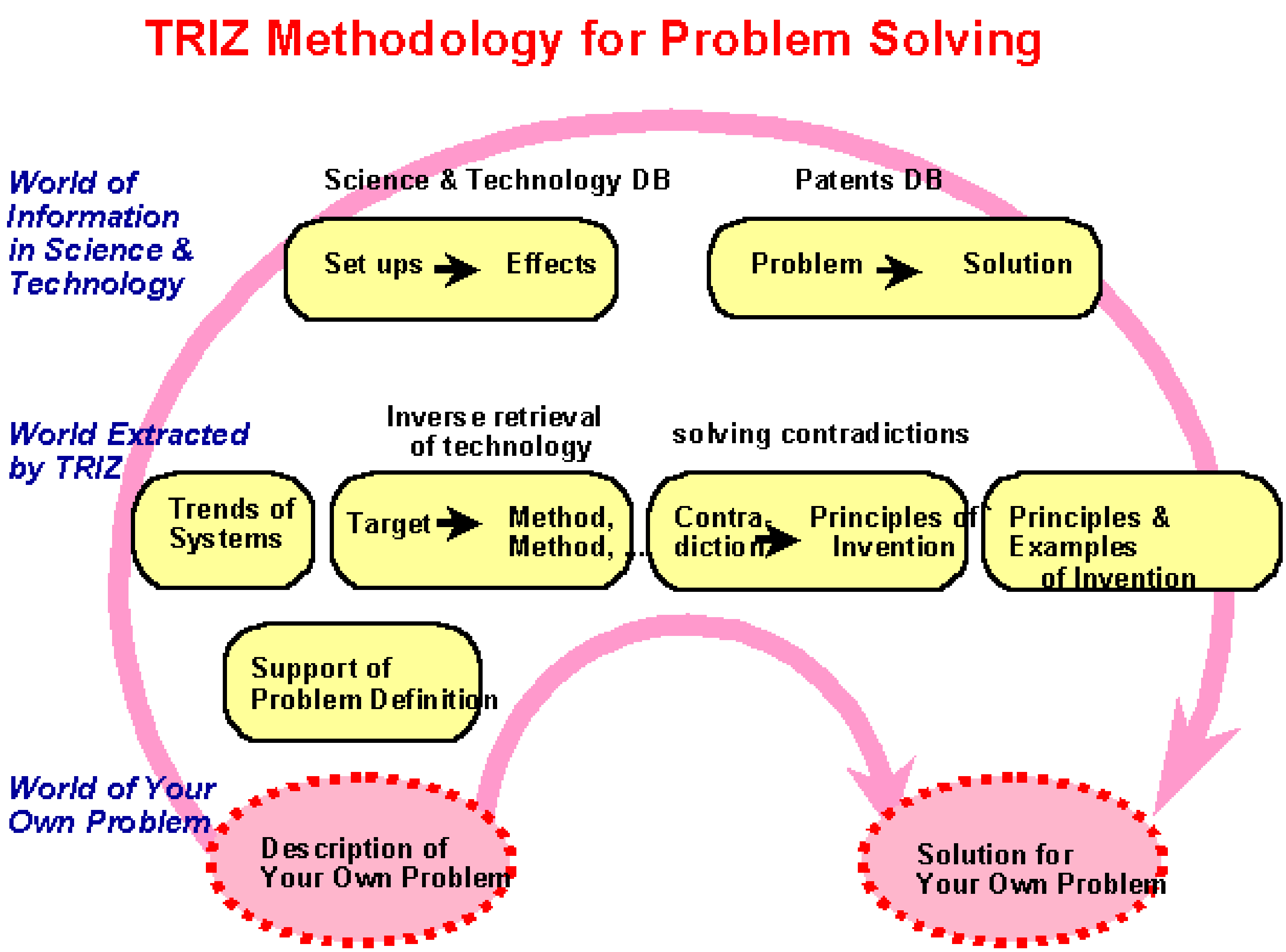

Figure 5. The Role of TRIZ Knowledge Bases

4.7 TRIZ Software Tools

In early 1990s many TRIZ experts emigrated from former USSR countries to USA and implemented TRIZ knowledge bases into software tools on PCs. This is the first generation of TRIZ software tools, for which TechOptimizer [21] of Invention Machine Inc. and Innovation Work Bench [22] of Ideation International Inc. are representative. They cost 10 to 30 thousand dollars and have been introduced into many big industries. The knowledge bases contain valuable information unobtainable elsewhere and are convenient to use.

These software tools also implement some of the TRIZ techniques, such as cause-effect analysis, functional analysis, substance-field analysis, and the contradiction matrix. These components of techniques are not so easy to use for most of the users who are not familiar enough with TRIZ techniques. When the software tools are going to guide the process of problem solving, users are often confused and puzzled in the process. Currently there are some different opinions on this matter: whether to train users to get familiar with the built-in techniques, whether to refine or remodel the software tool in the technique parts, and whether to suppress the idea o f guiding users in the process at moment.

Since around year 2000, several new TRIZ software tools have been built in various countries in Europe. They feature easier access and lower prices (around 1 to 3 thousand dollars). These are the second-generation TRIZ software tools, for which CREAX' Innovation Suites [20] may be the representative. As mentioned above, this software tool implements the up-to-date TRIZ knowledge bases reflecting their recent research projresults, corresponds to the description of Mann's textbook [2], and is refined in their human interfaces.

5. Introducing, Penetration, and Future Evolution of TRIZ

As is explained so far, TRIZ is a philosophy which can support creative problem solving for technology innovation, is a way of creative thinking, and provides a huge knowledge base and software tools. For industries in the midst of severe competition in innovation, TRIZ should certainly be a powerful means if one can use it well.

As for the ways of introducing TRIZ in Western countries, especially in Japan, the present author has written several times [1, 23, 24]. Current situations and future directions of TRIZ in Japan may be referred to [25].

First of all, industries, especially manufacturing industries should introduce TRIZ. Concerning to the strategy of introducing TRIZ, the present author had recommended the 'Slow-but-Steady Strategy' since 1999 in contrast to the 'Hurrying and Forcing Strategy' prevailing in USA, and recently since January 2003 he is recommending the 'Steady Strategy'.

This strategy is to introduce TRIZ in a 'digested form', the contents of which are described all through the present paper. In this strategy, we should learn TRIZ philosophy in its essence, should use USIT as a simple and unified process for problem solving, and should actively use TRIZ knowledge bases [4, 24].

For mastering USIT, you can study it with several papers and case studies, and more effectively by attending at training seminars. In USIT training seminars in industries, beginners of TRIZ/USIT can master USIT in two days with the program shown in Figure 6.

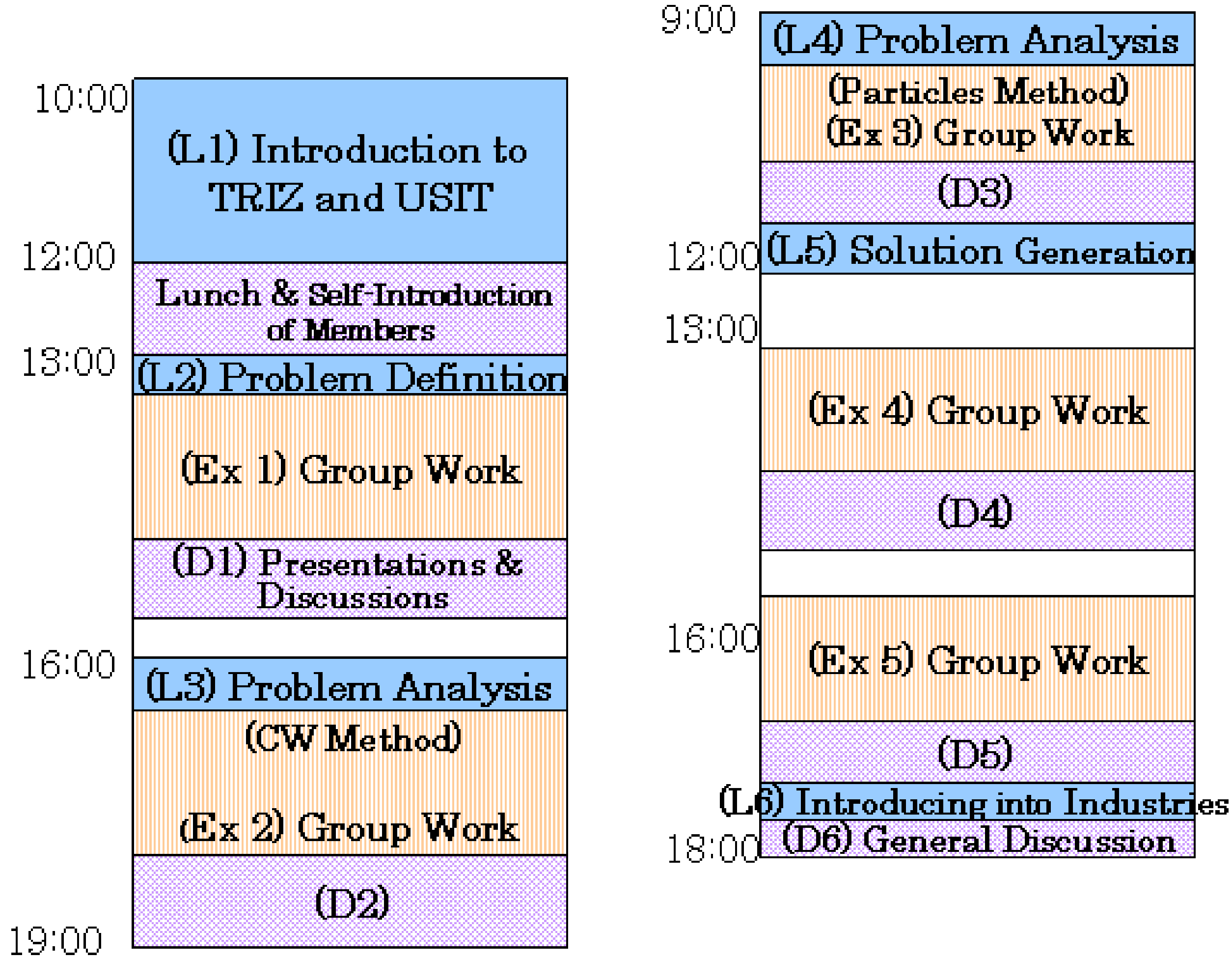

Figure 6. USIT 2-day Training Seminar Program

In this training seminar, a general introduction of TRIZ and USIT is give first for 2 hours. Then we have group practices of solving three real industrial problems in parallel by 15 to 25 participants along the process of USIT. The group practice is conducted in 5 sessions along the USIT process. Each session is composed of three sub-sessions: a short lecture about some details what to do in the session, the group practices in parallel, and the presentation and discussion by all the participants. Each participant practices solving one problem in a group, and can understand the actual process of solving other two problems as well. Each group can usually generate 15 to 40 solution concepts for real industrial problems which are brought in by one of the participants and nobody knew its solution beforehand.

USIT intends to encourage the engineers to make a full use of their technical background knowledge and to generate new ideas through a systematic process in a group work. In the process we do not depend on any handbook or software tool (we may use them afterwards if appropriate). With higher the knowledge and ability of each person, the better results are obtainable in USIT.

In Japan, TRIZ has become known better gradually, and the voluntary groups of TRIZ pioneers in industries have acquired capabilities of applying TRIZ, and are obtaining better support and approval by their organizations. On the basis of such a progress in the general background surrounding TRIZ, the present author has been advocating, in place of the former 'Slow-but-Steady Strategy', the 'Steady Strategy' of introducing TRIZ [25].

Introduction of TRIZ into Japanese universities has been proceeding little by little, especially in mechanical engineering departments of the Univ. of Tokyo, Kanto Gakuin Univ., Shibaura Inst. of Tech., Shizuoka Univ., Yamaguchi Univ., etc. [25] The present author teaches TRIZ at Faculty of Informatics of Osaka Gakuin University. He gives a course of lectures on the topic of 'Methodologies for Creative Problem Solving' to sophomer students; the full lecture notes of the 13 lectures in the non-mandatory class are posted in the Web site [26]. In his seminar group, the students are going to build a tutorial system for selflearning TRIZ and USIT. It intends to be a simple collection of Web pages understandable and useful for ordinary high-school and undergraduate students; but currently it is not successful yet for them to write the contents of the courseware suitable for this goal.

Before concluding this paper, I would like to mention about the extension of the field of application of TRIZ. TRIZ has its general scope covering all the fields of technology. It can well work in various fields related to physics, chemistry, medicine, agriculture, etc.

TRIZ will develop further as a creative way of thinking for technological innovation, by unifying and being complemented with various relevant methods. Mann [2] calls such a new generation of the way of thinking 'Systematic Creativity' and foresees that TRIZ will develop further as the core for the integration.

For introducing TRIZ into a new field of application, it is a good way of learning to interpret TRIZ sayings, e.g. its 40 Inventive Principles, in terms of the target field. For example, in the field of information science and software development, various principles of software design have been developed in software engineering, and many of them correspond well to TRIZ findings.

In particular, a large number of people seem to be interested in the introduction of TRIZ into the business and management field. Among many research work, Mann is going to publish another textbook in this field.

The next step of approach is to carry various principles and models in different fields into TRIZ so as to enhance the TRIZ understandings themselves. In this sense, the present author feels that principles and models in the fields of chemistry, biology, and medicine, etc. are not well adopted in TRIZ yet. Under these current situations, it is remarkable that Vincent et al. [27] are working to convert biological knowledge, especially those amazing mechanisms which animals and plants have developed in the nature, into the technological framework of TRIZ

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