中國機械工程學刊第三十九卷第一期第 21~32 頁(民國一百零七年)
Journal of the Chinese Society of Mechanical Engineers, Vol.39, No.1, pp 21~32 (2018)

Simplifying Algorithm for Inventive Problem Solving: S-ARIZ

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Keywords: TRIZ, ARIZ, innovative design, innovation

ABSTRACT

This work presents a novel and efficient design tool called S-ARIZ. A comparative analysis is performed of algorithms for inventive problem solving (Russian acronym of ARIZ). The eight ARIZ versions initially introduced allow designers to become familiar with another TRIZ approach in addition to the contradiction matrix, inventive principles, and substance-field (Su-Field) analysis. The comparison results provide a valuable reference for designers using the innovative design method. Based on the comparison results, each version of ARIZ consists of three stages: analysis for examining contradictions, contradiction removal for resolving conflicts and solution extension for extending the usage of a solution. The three individual stages that show what suitable TRIZ tools (or concepts) and auxiliary features are available to obtain system information are compared in detailed. System contradictions are also resolved, along with the solutions verified as well. Finally, a simplified ARIZ (S-ARIZ) is developed for easy use by designers in different fields. An example demonstrates the effectiveness of the proposed method.

INTRODUCTION

Altshuller developed TRIZ in 1946 after summarizing the results obtained in an analysis of numerous patents (Ideation 1999). Altshuller proposed many innovation design tools, including the contradiction matrix, invention principles, substance-field (Su-Field) analysis, idealization analysis, and the algorithm for inventive problem solving (ARIZ). These methodologies enable product designers to find innovative concepts and creative ideas efficiently.

Paper Received March, 2015. Revised July, 2015. Accepted July, 2015.Author for Correspondence: Jahau Lewis Chen

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ARIZ method is still evolving (Zlotin and Zusman 1999). For example, Altshuller proposed ARIZ-56, ARIZ-59, ARIZ-61, ARIZ-64, ARIZ-68, ARIZ-71, ARIZ-77, ARIZ-82 (A, B, C, D), and ARIZ-85 (A, B, C, AS, V). ARIZ-56 was the first revision of ARIZ, which used a set of steps for solving problem by finding and resolving technical contradictions. The three stages of ARIZ-56 are the analytical, operation, and synthesis stages. The natural prototypes of the operation stage in ARIZ-56 were moved to the end of the operation stage, and a new step (identification of the Ultimate Final Result) was introduced in ARIZ-59. ARIZ-61 extended the operation stage of ARIZ-59, and ARIZ-64 introduced rules for meeting the requirements of each step and a new section that clarified and verified the problem statement.

ARIZ-68 divided the analytical stage into problem selection and problem statement clarification (specification of the problem condition). A patent review was then performed to find helpful information. ARIZ-71 introduced time and cost concepts to the operation stage, which helped modify the dimensions of a problem. ARIZ-71 also added recommendations, notes, and examples to simplify use of the approach. ARIZ-75 and ARIZ-77 improved some logical steps and usage recommendations, and ARIZ-77 introduced a micro-level concept and analyzed the solution processes.

ARIZ-85C included nine problem-solving stages. Many ARIZ researchers and designers such as Fey (Fey and Rivin 2006) have developed their own versions of Altshuller's ARIZ-85C. Currently, most users agree that Altshuller's ARIZ-85C is the most powerful ARIZ version.

Ziotin and Zusman (1992) retained the main ideas and procedures of ARIZ-85C in their proposed platform for a machine version called ARIZ-SMV91(E) (S: scenario; M: machine; V: version; E: experimental). The Ideation Research Group presented ARIZ-92 (Nakamura 2003), which incorporated all major tools of the classical TRIZ and was based on conventional ARIZ. Nakamura (2003) combined ARIZ-92 and NM (Nakayama, Masakazu) method to create ARIZ-02, which generates solutions by improving existing systems or by developing new systems.

Case studies of ARIZ include Fey *et al.* (1994), who used ARIZ to solve real-life engineering problems by evaluating innovative solutions.

Krasnoslobodtsev and Langevin (2005a) used ARIZ to develop a robot for cleaning, finishing and diagnosing a surface in any orientation in space. Krasnoslobodtsev *et al.* (2005b) used ARIZ to help Samsung Electronic Company solve a problem involving air conditioner compressor components (*i.e.*, shaft, pin, double cam, roller, and cylinder) and a problem involving a driving pin and cam-bush. Processes developed by Krasnoslobodtsev and Langevin (2006) used ARIZ to help Samsung solve technology problems such as those related to printer ink cartridges and vacuum cleaners. Chen and Chen (2013) combined eco-innovation concepts and ARIZ to help designers solve problems without increasing the environmental impact. Chen and Chen (2014) presented a new design tool by integrating design-around concepts and ARIZ, which can help designers easily to prevent patent infringements and succeed in innovating by designing around.

INTRODUCTION OF TRIZ RELATED CONCEPTS AND ARIZ SPIRIT

ARIZ is formed by a series of complex and logical steps. Before going to comparing the following ARIZ versions, there are some basic TRIZ concepts introducing in the section about ARIZ. The comparison results are shown in Section 3.

TRIZ related concepts

(a) Main Function (MF): It is the major value of the problem.

(b) Actions**:** Actions are performed by tools on objects and can be classified as useful (desirable) or harmful (undesirable). Distinguishing actions is subjective since different designers may have different classifications for a given actions. Su-Field analysis (see Section 2.1 (d)) includes four possible actions (Fig. 1).

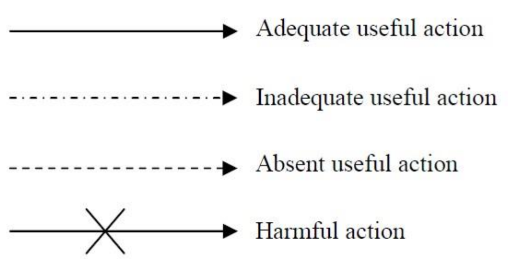

Fig. 1. Four representations of an action.

(1) Adequate useful action (may require enhancement).

(2) Inadequate useful action (requires enhancement).

(3) Absent useful function (requires introduction).

(4) Harmful action (requires elimination).

Table 1. The 39 engineering parameters [1].

No.	parameter	No.	parameter
1	Weight of moving object	21	Power
2	Weight of stationary object	22	Waste of energy
3	Length of moving object	23	Waste of substance
4	Length of stationary object	24	Loss of information
5	Area of moving object	25	Waste of time
6	Area of stationary object	26	Quantity of substance
7	Volume of moving object	27	Reliability
8	Volume of stationary object	28	Accuracy of measurement
9	Speed	29	Accuracy of manufacturing
10	Force	30	Harmful factors acting on object
11	Tension or pressure	31	Harmful side effects
12	Shape	32	Ease of manufacture
13	Stability of the object	33	Ease of operation
14	Strength	34	Ease of repair
15	Duration of action of moving object	35	Adaptability
16	Duration of action of stationary object	36	Device complexity
17	Temperature	37	Control complexity
18	Brightness	38	Level of automation
19	Energy spent by moving object	39	Productivity
20	Energy spent by stationary object		

(c) Contradiction matrix and inventive principles

Contradictions are common in engineering problems. A technical contradiction arises when the system improves one parameter but negatively affects another. For example, reducing the length of a car to enable easy parking decreases passenger comfort. Altshuller classified 39 parameters (Table 1) and 40 inventive principles (Table 2) by analyzing numerous patents and presenting a contradiction matrix table (Table 3). Step 1 locates the "feature to improve" the parameter in the columns and the "undesired result" parameter in the rows with respect to the original problem. Step 2 resolves this contradiction by using the recommend inventive principles which are listed in the intersecting cell. Based on the recommended principles, the feasible conceptual solutions to the problem are identified. A physical contradiction refers to a situation in which a system parameter requires opposite states (*e.g.,* cold and hot). Such a contradiction can be resolved by separated principles (Section 2.1 (g)) or TRIZ inventive principles without generating contradictory information (Chen and Liu 2001).

(d) Substance Field analysis and Standards

A Substance Field (Su-Field) analysis uses substances and fields to construct simple models of systems. The basic Su-Field model contains two substances (S1 and S2) and one field (F) (Fig. 2). The term “substance” can include materials, tools, components, people, or surroundings. A “field” is defined as an energy that interacts between substances. Fields may be mechanical, thermal, electrical, magnetic, or chemical. A system model can be simplified by appropriately combining substances and fields.

Table 2. The 40 inventive principles (Ideation 1999).

No.	parameter	No.	parameter
1	Segmentation	21	Rushing through
2	Extraction	22	Convert harm into benefit
3	Local quality	23	Feedback
4	Asymmetry	24	Mediator
5	Combining	25	Self-service
6	Universality	26	Copying
7	Nesting	27	Disposable object
8	Anti-weight	28	Replacement of a mechanical system
9	Prior counteraction	29	Pneumatic or hydraulic construction
10	Prior action	30	Flexible film or thin membranes
11	Cushion in advance	31	Porous material
12	Equipotentiality	32	Change the color
13	Inversion	33	Homogeneity
14	Spheroidality	34	Rejecting and regenerating parts
15	Dynamicity	35	Transform the physical/chemical state
16	Partial or excessive action	36	Phase transition
17	Shift to a new dimension	37	Thermal expansion
18	Mechanical vibration	38	Strengthen oxidation
19	Periodic action	39	Inert environment
20	Continuity of useful action	40	Composite materials

Table 3. Part of the contradiction matrix and using process (Ideation 1999).

		Undesired Result (Conflict)			
Feature to Improve	Engineering Parameter		33 Ease of operation	34 Ease of repair	
	:	-	-	-	-
	10 Force	-	1, 28, 3, 25	15, 1, 11	-
	11 Tension or pressure	-	11	2	-
	:	-	-	-	-

Recommend Inventive principles 2: Extraction

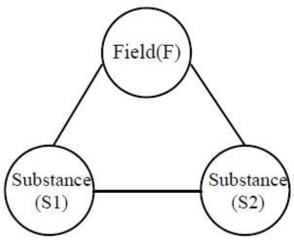

Fig. 2. Model of Su-Field.

By transforming the systems into Su-Field models, the analytical results can usually be classified into several typical patterns. The corresponding improvements suggested for solving these models are called “Standards” (Ideation 1999; Fey and Rivin 2006). Standards can help designers model possible solutions. Building the correct expressions of systems in the models and choosing the appropriate corresponding Standards is essential for constructing improved problem solving models and for developing new inventions.

(e) Ideal Final Result: An ideal final result (IFR) refers to the performances of the function of something are performed without physical entities.

(f) Mini-problem: The system remains unchanged or is simplified even if its disadvantages disappear or if a desired improvement is achieved, or as maximum problems (maxi-problems), in which all changes are allowed.

(g) Separated principles: Separated principles are generic approaches to resolving contradictions by separating opposite properties in space, in time, or between the overall system and its components.

(h) Smart little people method: The smart little people (SLP) method can represent changeable elements of the problem model. Step 1 graphically represents the contradiction of the problem. Step 2 modifies the graphical model so that the SLP method can be performed without the contradiction (Ideation 1999).

ARIZ spirit

ARIZ has many versions, with each one having the same three basic objectives (Fey and Rivin 2006).

(1) Problem formulation: Problems must be formulated before they can be solved, and their contradictions must also be solved.

(2) Breaking psychological inertia: ARIZ method is designed so that problems are solved by humans rather than by computers. Therefore, the method can help users to suppress psychological inertia and to develop virtually any power imaginable.

(3) Integrating the powers of various TRIZ tools or concepts: Owing to that ARIZ contains many basic TRIZ notions and tools, arranging them logically makes ARIZ one of the most powerful innovation tools for analyzing problem conditions carefully and for deriving solutions by applying TRIZ concepts.

COMPARISON OF DIFFERENT ARIZ VERSIONS

This section compares and analyzes the ARIZ versions (56, 61, 68, 77, 85C, 85AS (Altshuller-Savransky) (Savransky 2000), 85C (Fey) (Fey and Rivin 2006) and 85V (Salamatov 1999). The comparison results can be used by designers to develop new versions of ARIZ.

Comparison and analysis of ARIZ structure

Tables 4 (a)-(c) show the similarities and differences between different versions of ARIZ.

All versions are structured in three main stages. Stage 1 is the analysis stage in which information and components about contradictions are obtained from problem selection and model structure. In Stage 2, TRIZ tools or other methods are used to solve contradictions in the system. Stage 3 is the solution extension (integration) stage, which extends the applications of the obtained solution. The symbol X indicates the absence of related parts (ARIZ-85V).

The problem solving procedure used in ARIZ-85C has nine steps. ARIZ-85AS is similar to ARIZ-85C except for an additional information stage. ARIZ-85V performs nineteen steps to obtain solutions after contradictions have been removed. However, it does not further confirm or extend the solutions used. ARIZ-85C (Fey) has four processing stages. ARIZ-77, ARIZ-85C, ARIZ-85AS, ARIZ-85C (Fey), and ARIZ-85V feature resource analysis functions for finding space, time, and environmental resources and information during the problem solving process.

Comparison of analysis stages

Table 5 compares the analysis stages. In the problem analysis stage, tools and other feature analysis methods are used to find related system information: main functions and contradictions are the most important information. ARIZ-85C, ARIZ-85C (Fey), and ARIZ-85V replace parameters with physical entities because their purpose is solving practical problems. When selecting analytic tools, contradiction matrix is only used for analysis in ARIZ-85AS. ARIZ-68, ARIZ-77, and ARIZ-85AS introduce an operator to break down the psychological inertia of users for problem analysis. ARIZ-77, ARIZ-85C, and ARIZ-85AS analyze problems by introducing the concept of hierarchy (including sub-system, other system, super-system) that converts the system in the analysis phase. By expressing problems and contradictions with simple descriptions and drawings, they solve contradictions more easily compared to the contradiction removal stage in ARIZ-85C, ARIZ-85AS, ARIZ-85C (Fey), and ARIZ-85V.

In ARIZ-77, ARIZ-85C, ARIZ-85AS, 85C (Fey), and 85V, the independent resource analysis is performed in the analysis stage. In particular, ARIZ-77, ARIZ-85C and ARIZ-85AS can derive innovative solution from the analysis stage, explaining why these versions may neglect some resolving steps.

Table 4. Overview of ARIZ structure.

(a) Part 1 Aanalysis stage.

Stage	ARIZ							
	56	61	68	77	85C	85AS	85C(Fey)	85V
Analysis	(I) Analyze	(I) Analyze	(I) Choose problem	(I) Choose problem	(I) System analysis	(O) Information	(I) Formulate the system model	(1) Evaluate the problem.
			(II) Describe problem conditions	(II) Formulate model		(I) Analyze the problem		
			(III) Analyze	(III) Analyze model	(III) Define IFR and physical contradiction	(II) Simplify problem		(2) Define mini-problem.
								(3) Formulate the conflicting pair of components
								(4) Draw TC-1 and TC-2
								(5) Define the main process
								(6) Intensify the conflict
						(III) Clarify problem		(7) Formulate the problem model
								(8) Specify the chosen conflict
					(II) Resource analysis		(III)Analyze the available resources	(9)-(11) Analyze resources
						(IV) Apply resources.		

(b) Part 2 Contradiction removal stage.

Stage	ARIZ							
	56	61	68	77	85C	85AS	85C(Fey)	85V
Contradiction removal	(II) Operate	(II) Operate	(IV) Operate	(IV) Remove PC	(IV) Utilize Su-Field resources	(V) Apply TRIZ knowledge bases	(II) Analyze the system conflicts and formulate a mini-problem	(12) Define IFR-1
								(13) Intensify the IFR
								(14) Formulate the PC
								(15) Define IFR-2
					(V) Use database			(16) Model miniature dwarf
						(VI) Replace problem		(17) SFR mobilization
								(18) Use the principles for eliminating PC
					(VI) Repeat if no solution is found			(19) Use the pointers to effects

(c) Part 3 Solution extension stage.

Stage	ARIZ							
	56	61	68	77	85C	85AS	85C(Fey)	85V
Solution extension	(III) Synthesis	(III) Synthesis	(V) Synthesis	(V) Evaluate the solution	(VII) Verify solution	(VII) Analyze the solution(s)	(IV) Develop the conceptual solution	X
				(VI) Develop solution	(VIII) Apply solution	(VIII) Apply selected solution		
				(VII) Analyze the resolving process	(IX) Analyze the problem solving process	(IX) Analyze solving process		

Table 5. Comparison of analysis stages.

Analysis stage / Item	ARIZ-	56	61	68	77	85C	85AS	85C (Fey)	85V
System information	Main function (MF)	●		●	●		●	●	●
	Parameters			●	●		●		
	Contradictions (Conflicts)	●	●	●	●	●	●	●	●
	Intensified contradictions					●	●	●	●
	Actions				●		●	●	●
	(Major) components				●	●	●	●	●
Tool	Contradiction Matrix						●		
	Su-Field					●	●		
	Standards				●	●	●		
	IFR		●	●	●	●	●		
	Mini-problem					●	●		●
	Separated principles								
	Patents			●	●				
Resource analysis					●	●	●	●	●
Other (auxiliary) features	Formulations				●	●	●	●	
	Operator			● time-dimension-cost	● size-time-cost		● size-time-cost		
	Change system levels (to transform the problem)				●	●	●		●

	Simplify problem description				●			●	
	Draw					●	●	●	●
	Ignore unnecessary steps (if the solutions have been generated)				●	●	●		
	Quantitative indices (indicators)			●	●		●		

Table 6. Comparison of contradiction removal stages.

Contradiction removal stage	ARIZ-	56	61	68	77	85C	85AS	85C(Fey)	85V
Item									
System information	Parameters		●						
	Intensified contradictions							●	
	Actions		●						
Tool	Contradiction Matrix			●	●				
	Su-Field				●	●		●	●
	Standards							●	
	IFR								●
	Intensified IFR								●
	Evolution rule (one step back)					●	●		
	Mini-problem							●	
	Maxi-problem						●		
	Separated principles			●	●				
	Database	●	●	●	●	●	●		●
	Smart Little People (SLP) method					●			●(MD)*
	Principles for eliminating physical contradiction								●
Other (auxiliary) features	Formulations							●	●
	Trace back (if the solutions have not been generated)		●			●	●		
	Change system levels	●	●			●			
	Different resolution branches							●	
	Ignore unnecessary steps (if the solutions have been generated)				●		●		

*The definition of Miniature dwarfs (MD) is the same as Smart Little People (SLP) method.

Comparison of contradiction removal stages

In this stage, contradictions are solved using a portfolio of tools and features and innovative solutions are obtained. Some versions of this stage attempt to identify the required system information and then generate solutions using proper tools. Table 6 compares the contradiction removal stages of the eight ARIZ versions.

In the contradiction removal stage, which is divided into three parts, contradictions are removed using tools and features. The analysis stage already obtains most of the required system information.

(1) Although the most common TRIZ tool, the contradiction matrix is limited as an analytical tool in ARIZ, only ARIZ-68 and ARIZ-77 adopt the tool in the contradiction stage.

(2) In ARIZ-77, ARIZ-85C, ARIZ-85C (Fey), and ARIZ-85V, Su-Field is a conventional means of removing contradictions. A problem is examined during the analysis stage, based on use of ARIZ-85AS of the Su-Field tool.

(3) ARIZ-85V uses IFR in conjunction with other non-traditional TRIZ tools (*i.e.* principles for eliminating PC and MD) to remove contradictions.

(4) ARIZ-56, ARIZ-61, ARIZ-68, ARIZ-77, ARIZ-85C, and ARIZ-85AS use a database to help remove contradictions and solve contradictions by obtaining analogous solutions in the existing technology, nature, patent literature or TRIZ knowledge base (*e.g.*, effects, typical transformations).

(5) ARIZ-85C (Fey) and ARIZ-85V develop formulas for sending information to help designers to determine when to remove contradictions.

(6) ARIZ-61, ARIZ-85C, and ARIZ-85AS adopt the concept of backtracking (*i.e.* repeating analysis) if it fails to obtain feasible solutions in this stage. ARIZ-77 and ARIZ-85C (Fey) perform backtracking in solution extension stage.

Comparison of solution extension stages

ARIZ searches for the innovation that obtains the most comprehensive solution with the least change; therefore, most versions extend the solutions after removing contradictions. Table 7 shows a comparison of solution extensions.

When a feasible solution is identified, all versions except for ARIZ-56 and 85C (Fey) attempt to develop applicable technologies. ARIZ-56, ARIZ-61, ARIZ-68, ARIZ-85C, and ARIZ-85AS apply solutions to other contradictions of the problem. ARIZ-77, ARIZ-85C, and ARIZ-85AS analyze patents to confirm whether the solution is innovative and compare actual solutions, theoretical solutions, and other solutions obtained from other TRIZ approaches. ARIZ-85C (Fey) uses IFR to verify solutions. If no solution is obtained, the problem is analyzed at the system level (*i.e.* different solutions are found for each system level); otherwise, earlier steps are repeated to search for additional solutions.

Table 7. Comparison of solution extension stages.

Solution extension stage	ARIZ-	56	61	68	77	85C	85AS	85C(Fey)	85V
Item									
Solution development	Review the obtained solution	●	●		●	●	●		X
	Solve other contradictions	●	●	●		●	●		
	Develop the new technique		●	●	●	●	●		
Tool	IFR							●	
	Patents				●	●	●		
	Separated principles							●	
Other (auxiliary) features	Trace back (if the solutions have not been generated)				●			●	
	Change system levels							●	
	Ignore unnecessary steps (if the solutions have been generated)							●	
	Compare physical and theoretical solutions				●	●	●		
	Compare with TRIZ heuristics				●	●	●		

DISCUSSION OF ARIZ STRUCTURE

Now that each stage of ARIZ has been introduced, this section describes each stage in further detail.

Analysis stage

The main function (MF), contradictions and parameters must be identified at the beginning of the analytic problem stage. ARIZ replaces parameters by true conditions for resolving physical problems, and ARIZ can find information about components, the functions of components, and the interactions between components and contradictions.

Ideal Final Result (IFR) is the major analytic tool in ARIZ because IFR can define the final result of the problem. The Su-Field, Standards and mini-problem are suitable for removing contradictions.

Formulations can help designers comply with regulations (*e.g.*, IFR and mini-problem). When searching for contradictions in problems, questions are easier to understand when presented graphically rather than in words alone.

The mini-problem of ARIZ maximizes innovation with minimum resources. Notably, the boundary conditions of the problem must be defined before removing the related contradiction.

In resource analysis, resources and conditions (*e.g.*, space, time and environmental resource) associated with the original problems are evaluated for use in solving conditions for innovations.

Contradiction removal stages

This stage presents the tools used in the physical contradiction removal stage (Table 6).

(1) Su-Field: Contradictions by fields (F) and substances (S) are depicted graphically.

(2) Standards: After graphically presenting the problem as a Su-Field model, Standards are used to find potential resolution.

(3) Database: ARIZ is based on variable TRIZ concepts. The database is an important information source because designers can use it to find removal information related to their professional field, even if their understanding of TRIZ is limited.

Solution extension stages

The stage finds conceptual solutions that can be used to promote innovation after removing contradictions. If the solutions do not satisfactorily solve the problems, the user can repeat the analysis or attempt separate analyses for different principles (*e.g.*, separate analyses for space and time).

Most TRIZ tools focus on achieving conceptual solutions. ARIZ solves physical questions so that solutions can be used directly. The solutions can be extended by applying patents or newly developed technologies.

SIMPLIFIED ARIZ (S-ARIZ)

Based on the above discussions, the section presents a simplified problem-solving ARIZ with only three stages: analysis stage, contradiction removal stage and solution extension stage. Figure 3 shows a flow chart of the S-ARIZ.

Analysis stage of S-ARIZ

Section 4.1 specifies that the analysis stage S-ARIZ should contain the following information:

(1) Main Function (MF): The major function of the problem.

(2) Contradictions: Choosing which contradictions to resolve is a major part of the problem solving procedure. Information must be obtained by analyzing the contradiction.

For the component related to the contradiction, it can find the physical information (*i.e.*, not parameters) about its useful action (UA) and harmful action (HA).

(3) Table 5 shows the problem solving tools used in each ARIZ version. The S-ARIZ uses IFR for problem analysis because it defines the final goal that must be resolved before using S-ARIZ.

(4) Resource analysis: Analyzes the related space and time information related to a problem:

(a) Specify the conflict domain (CD):

The conflict domain is the space information about the problem.

(b) Specify the operation time (OT):

Define the period during which the system conflict must be resolved

(c) Define the possible resources (substance or field):

- Resources of the CD
- Resources of environment
- Resources of overall system

(5) Use a simple figure to show the problem without the component representing the contradiction. Remove the component which the contradiction happened and continue the following section removing the contradiction.

(6) Mini-problem: determine whether formulation (a) or (b) obtains a better solution (X-resource replaces the component with the contradiction):

(a) If the original component that caused the contradiction is not present, the X-resource can increase the original useful action (UA) without hindering the performance of primary function (PF).

(b) If the original component that caused the contradiction is not present, the X-resource can preserve the original useful action (UA) and eliminate the harmful action (HA).

Contradiction removal stage of S-ARIZ

The contradiction should be resolved after the problem analysis. Section 4.2 introduced some of the tools used to resolve contradictions. The suggested tools for S-ARIZ are the following:

(1) The Su-Field tool can be used to represent the problem caused by a contradiction.

(2) Designers can use a Standard to resolve the above situation: Standards offer many different models for resolving contradictions.

(3) Database: Designers unable to identify a feasible Standard to resolve the above contradiction model can use different databases from different fields to resolve contradictions.

Solution extension stage of S-ARIZ

This stage obtains a conceptual solution by performing the following steps.

(1) Choosing resources (fields or substances) in step (4) of Section 5.1 to obtain a resolution.

(2) If the ideal result is achieved and fulfils the IFR (from (3) of Section 5.1); a solution can be formulated; otherwise, go to (1) of Section 5.3, repeat the analysis with a different resource.

If the outcome is still unsatisfactory, S-ARIZ suggests the following steps:

(a) Go to (6) of Section 5.1 and check whether the mini-problem is related to the problem (*e.g.*, UA or HA is unrelated to the PF or belongs to another component).

(b) Go to (2) of Section 5.1, and find another contradiction to resolve.

(C) Use separated principles to modify the result and find new solutions.

If the above procedure, which uses the main structure of S-ARIZ, obtains ideas that are applicable to file patents, S-ARIZ suggests analyzing patents – regardless of whether related information has been presented. If presented, the innovation can utilize design-around concepts to modify the new ideas (Liu et al. 1998; Nydegger and Richards 2000).

CASE STUDY OF S-ARIZ

Screws are widely used to connect components in manufacturing. Products are usually destroyed or recycled at the end-of-life (EOL) stage because human disassembly is expensive and efficiency is too low. Direct destruction also raises environmental concerns. The TRIZ methods have been used to invent smart fasteners composed of shape-memory alloy and plastics (SMA and SMP) with unique temperature and material properties (Chen and Chen 2007; Justel et al. 2005 and 2006). However, use of these products is limited because of high material costs. This study used S-ARIZ to resolve this problem.

Analysis stage

(1) MF: Connecting two different components is the primary function.

(2) Contradictions: Screws are popular connecting tools, but they pollute the environment because their low cost makes recycling infeasible and because they can cause the release of toxic substances when using.

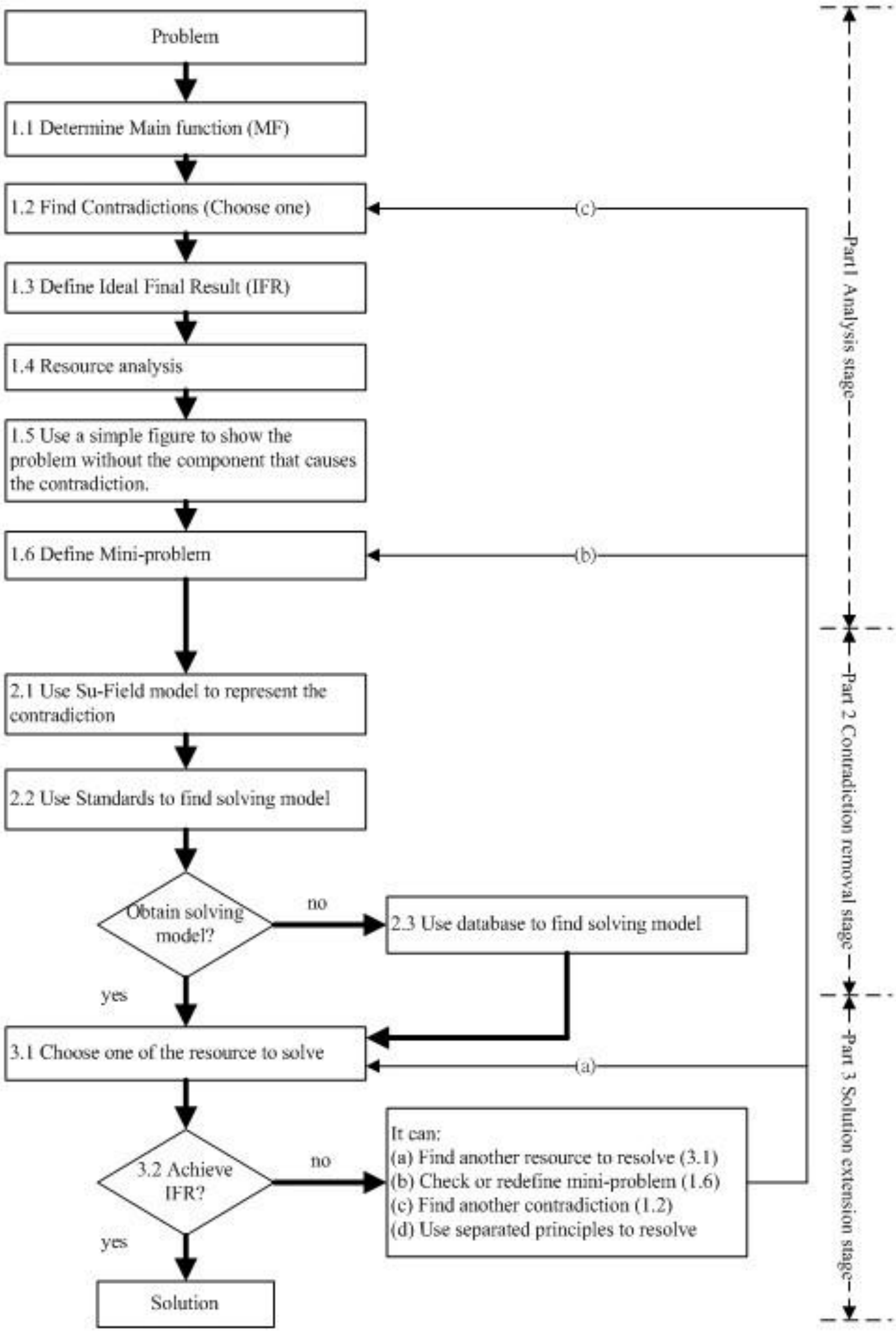

Fig. 3. Flow chart of an S-ARIZ implementation.

(a) HA: The harmful action is environmental pollution.

(b) UA: The useful action is ease of use and low cost.

(c) Component: Screws.

(3) IFR: Find fasteners with low environmental impact.

(4) Resource analysis:

(a) CD: (1) The space that is the main body of screws, or (2) The space that screws are assembled with components.

(b) OT: The time when products are assembled or disassembled.

(c) Define the possible resources (substance or field):

- Resources of the CD: Screws
- Resources of environment:

<a> the components that are connected by screws;

<b> the mechanical field.

- Resources of overall system: the different disassembly tool or method.

(5) Graphically depict the problem using a simplified figure without the component representing the contradiction (Fig. 4). As Fig. 4 shows, components A and B cannot be connected together without the screws. The symbol X represents an undesired action that the system must prevent. The undesired action in this case is lack of connection capability.

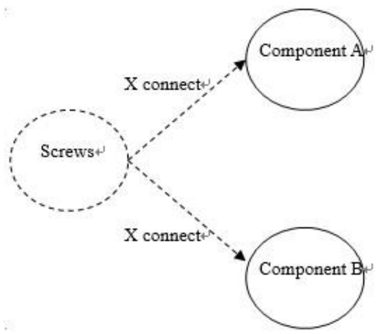

Fig. 4. System Conflict associated with lack of screws

(6) Mini-problem: Avoiding the use of screws enables easy maintenance of the X-resource at an inexpensive cost (UA) with limited environmental pollution (HA), but without decreasing connecting capability (PF).

Contradiction removal stage

(1) Draw the Su-Field model for the contradiction.

Use Su-Field method to model the problem without the use of screws (Fig. 5).

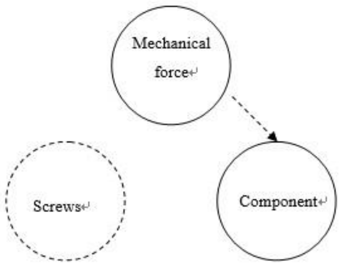

Fig. 5. Incompatibility of component without screws.

(2) Using standards to find a resolution model.

Referring to Standards may reveal corresponding solutions. In this case, Standard 1.1.1 is a possible model (Fig. 6) for enhancing the effectiveness and controllability of an incomplete Su-Field model, which must be completed by introducing missing elements. Introducing an X-resource adds mechanical fields to the component and the X-resource.

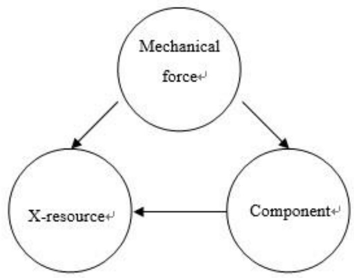

Fig. 6. Component connected using X-resource.

(3) Designers from different fields can use different databases to resolve contradictions.

Since a possible solution model is found in step (2) in Section 6.2, a database is not needed to find a solution model here. If a model is not found in (2) of Section 6.2, designers can search their own databases for solution models.

Solution extension stage

(1) Select the main body of screws to innovate.

(2) As mentioned earlier, smart fasteners are good solutions but are limited by their high costs. The solution proposed in this study is to use time separated and space separated principles to innovate:

- The time separated principle classifies use time and disassembly time as two different situations.
- According to the space separated principle, a fastener currently in use has a screw shape. When the fastener is disassembled or not used,

the shape changes.

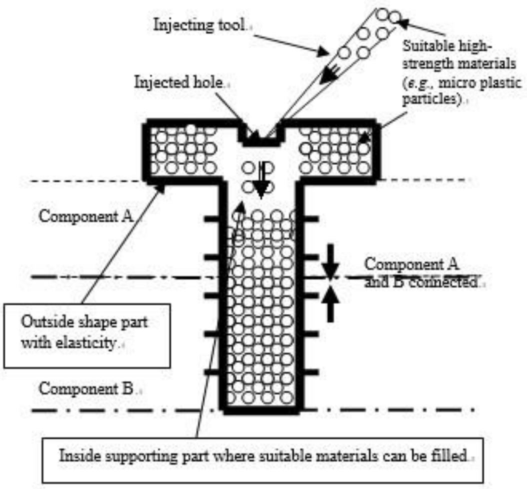

Fig. 7. Overview of proposed screw with outer shape and inner supporting part.

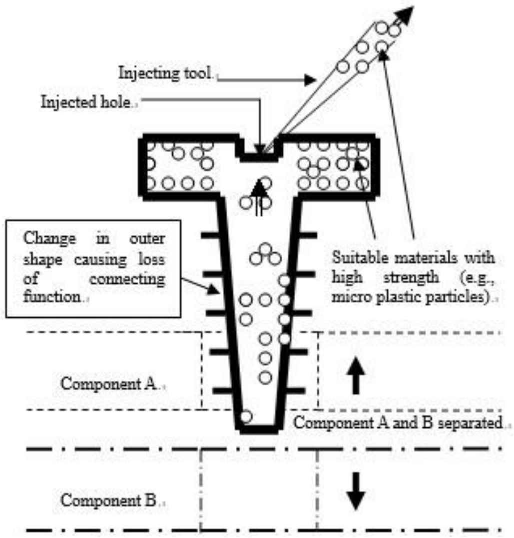

Fig. 8. Changed shape of screws without inner supporting part.

Formulating the concept of a solution

To maximize strength, screws are generally composed of a single material. The proposed solution is to divide the screw into an outer part and inner part.

The outer part consists of highly elastic material. When the suitable tool fills applicable material (*e.g.,* micro plastic particles with high strength) into the case, the new screws can be used to connect any components (Fig. 7.). Suitable tools can be used to separate the inner parts from the screws during disassembly. If the shapes of the screws change due to lack of inner support, the screws can be disassembled between component A and component B (Fig. 8). These outside and inner materials are recyclable, and the new screw sets can be reused several times.

CONCLUSIONS

Despite the use of ARIZ for nearly sixty decades, exactly how its different version have evolved has never been examined. For design purposes, this study describes how the various of ARIZ differ from and resemble each other. The current status of ARIZ and development trends are also clarified for researchers developing new versions of ARIZ.

Of all TRIZ innovation methods, ARIZ is the most effective one, owing to its formation by completely logical steps and many TRIZ concepts rather than a single TRIZ method. Each ARIZ version has its own unique features and procedure. Although the most widely used TRIZ method, the contradiction matrix is seldom used to solve ARIZ-related problems, implying that the contradiction matrix is limited in analyzing problems and removing contradictions.

Based on S-ARIZ, this study innovates new screw sets with enhanced recyclability to reduce their environmental impact. The new screw sets can also be disassembled by suitable tools, which decrease human disassembly-related costs.

ACKNOWLEDGEMENTS

The authors would like to thank the National Science Council of the Republic of China, Taiwan, for partially supporting this research under Contract No. NSC97-2221-E-006-055.

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簡化的解決創新問題演算法:**S-ARIZ**

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摘 要

本文旨在提出新穎有效的設計工具 S-ARIZ。從一開始的介紹 TRIZ 概念與本研究中所收集到的 8 個完整版本 ARIZ。比較此 8 個版本的 ARIZ 之間的異同，將各版本的架構詳細分析後發現 ARIZ 其實主要由三大階段所構成，分別是分析問題階段、移除矛盾階段與解的延伸階段，各版本的解題流程都可以歸納進為這三階段，從整體架構以及各階段細微的步驟來分析，並提出一個簡化版的 ARIZ(S-ARIZ)，透過分析比較異同的方式將 TRIZ 工具中的眾多概念分別放置到三個階段，透過邏輯的步驟讓 S-ARIZ 具有創新解答的功能，同時步驟也較不繁雜，有較容易推廣的效果。以一案例展示所提出方法的有效性。