TRIZ: The Methodology of Inventive Problem-Solving

FEATURE

by Semyon D. Savransky and Craig Stephan

A growing industrial contingent believes that more of a science can be made from the art of inventing. Much of that science may come from TRIZ—the Russian acronym for the Theory of Inventive Problem-Solving, also known as TIPS. In the 1950s, Genrich S. Altshuller and his colleagues in the former Soviet Union developed this methodology. Today, scientists and engineers throughout the former Soviet Union continue to develop and use TRIZ, and it is beginning to be taught and commercialized in the United States [see "TRIZ-Based Tools Promote Innovation," *The Industrial Physicist*, September 1996, and "Structured Inventive Thinking", *The Industrial Physicist*, March 1996].

The TRIZ methodology can be applied to nearly any problem for which an inventive solution is desired.

Altshuller identified about 40 fundamental principles of invention and categorized problem-solving techniques in five levels of inventiveness

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Why invent systematically?

Different inventors take their own approaches to the art and science of inventing, but the process often relies on chance. To overcome the obstacle raised by happenstance, Altshuller examined a large number of patents, looking for the hallmarks of truly creative inventions in order to formulate a methodological approach to inventing. To his surprise, he found that patented inventions from a variety of technical fields usually came about by using one or more of about 40 fundamental principles and that solutions known to one field may be reinvented in another. He categorized the patents' problem-solving techniques in five levels of inventiveness:

Level 1. Using well-known methods within a specialty or company to solve routine design problems accounted for about 32% of the solutions. In the 1960s, for instance, someone finally realized that the length of weighted (lead) shoes for divers could be varied to fit different sizes of feet—after some 70 years of all divers wearing the same-size, and often uncomfortable, shoes.

Level 2. About 45% of the solutions were minor corrections to an existing system made by methods known within the industry. For example, potatoes can rot because of bacteria that are naturally present on their surfaces. Although boiling water can kill the bacteria, too much heat cooks a potato, making it unsuitable for storage; but passing potatoes quickly through a 700 °C flame kills the bacteria without cooking the potato.

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Level 3. Fundamental improvements that rely on methods from another industry to resolve a contradiction (mutually exclusive demands) in an existing system were characteristic of 18% of the solutions. Electrical engineers, for instance, found that replacing an electromechanical relay with a cheap semiconductor relay increases the number of switching cycles before the relay must be replaced, and decreases the switching time and weight of the device.

Level 4. Only 4% of the solutions were classified as new generations of inventions using a new scientific (rather than technological) principle to perform a system's primary function. Examples include well-known inventions such as the microscope, steam engine, photocopying machine, and atomic-force microscope.

Level 5. Rare scientific discoveries or pioneering inventions of an essentially new system made up the final less than 1%. Discoveries such as X-rays, penicillin, and high-temperature superconductors belong to this level of inventiveness.

Each succeeding level represents an increase in the knowledge required of the inventor, the height of psychological barriers that the inventor must overcome, and the potential profit from the invention. Rather than attempting to reproduce the thinking process of the original inventors, Altshuller looked for a methodology that would overcome the psychological barriers, thereby stimulating higher-level solutions. Modern TRIZ uses a systematic approach to guide a would-be inventor to the solutions, and this methodology gives its practitioners an opportunity to resolve problems up to Level 4. (By contrast, common methods of engineering design provide tools for the solutions of technical questions up to Level 2.) Ongoing work in Russia may extend the ideas of TRIZ into discoveries.

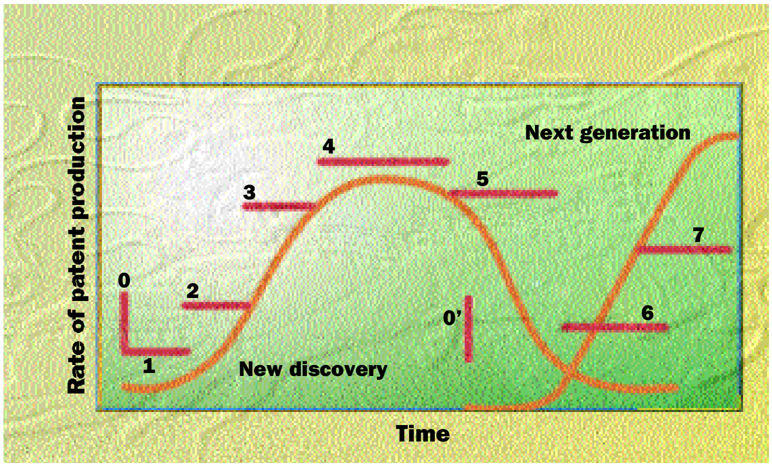

Figure 1. Evolution of a technical system. Numbers refer to the stages described in text.

TRIZ trio

Altshuller's method depends on three major principles: resolution of contradictions, the evolution of systems, and the ideal result.

The basic concept of TRIZ is the *resolution of a contradiction*. A technical contradiction arises from mutually exclusive demands that may be placed on the same system, where improvement of one parameter leads to deterioration of another (Figure 2). Often, resolving a contradiction depends on finding the physical problems that are the hidden root of the technical trouble. For example, a large-area wing makes it easy for a plane to take off, but such a wing creates high drag at supersonic speeds. A compromise solution might employ a wing area that accommodates both demands, albeit imperfectly. TRIZ rejects such compromises and says: The wings should be large during takeoff and small during high-speed flight. Retractable wings would be one way to solve that contradiction.

By studying many technical systems, Altshuller recognized that their *evolution* usually follows a bell-shaped curve when the rate of patent production is plotted as a function of time (Figure. 1). This curve represents a life cycle that can be divided into eight stages, which are listed below along with example stages from the evolution of the internal-combustion-engine-powered automobile:

	Undesired Result (Conflict) / Feature to Improve	1 Weight of moving object	2 Weight of non-moving object	3 Length of moving object	4 Length of non-moving object	5 Area of moving object	6 Area of non-moving object	7 Volume of moving object	8 Volume of non-moving object	9 Speed	10 Force	11 Tension, pressure	12 Shape	13 Stability of object
1	Weight of moving object			15,8, 29,34		29,17, 38,34		29,2, 40,28		2,8, 15,38	8,10, 18,37	10,36, 37,40	10,14, 35,40	1,35, 19,39
2	Weight of non-moving object				10,1, 29,35		35,30, 13,2		5,35, 14,2		8,10, 19,35	13,29, 10,18	13,10, 29,14	26,39, 1,40
3	Length of moving object	8,15, 29,34				15,17, 4		7,17, 4,35		13,4, 8	17,10, 4	1,8, 35	1,8, 10,29	1,8, 15,34
4	Length of non-moving object		35,28, 40,29				17,7, 10,40		35,8, 2,14		28,10	1,14, 35	13,14, 15,7	39,37, 35
5	Area of moving object	2,17, 29,4		14,15, 18,4				7,14, 17,4		29,30, 4,34	19,30, 35,2	10,15, 36,28	5,34, 29,4	11,2, 13,39
6	Area of non-moving object		30,2, 14,18		26,7, 9,39						1,18, 35,36	10,15, 36,37		2,38
7	Volume of moving object	2,26, 29,40		1,7, 4,35		1,7, 4,17				29,4, 38,34	15,35, 36,37	6,35, 36,37	1,15, 29,4	28,10, 1,39
8	Volume of non-moving object		35,10, 19,14	19,14	35,8, 2,14						2,18, 37	24,35	7,2, 35	34,28, 35,40
9	Speed	2,28, 13,38		13,14, 8		29,30, 34		7,29, 34			13,28, 15,19	6,18, 38,40	35,15, 18,34	28,33, 1,18
10	Force	8,1, 37,18	18,13, 1,28	17,19, 9,36	28,10	19,10, 15	1,18, 36,37	15,9, 12,37	2,36, 18, 37	13,28, 15,12		18,21, 11	10,35, 40,34	35,10, 21
11	Tension, pressure	10,36, 37,40	13,29, 10,18	35,10, 36	35,1, 14,16	10,15, 36,25	10,15, 35,37	6,35, 10	35,24	6,35, 36	36,35, 21		35,4, 15,10	35,33, 2,40
12	Shape	8,10, 29,40	15,10, 26,3	29,34, 5,4	13,14, 10,7	5,34, 4,10		14,4, 15,22	7,2, 35	35,15, 34,18	35,10, 37,40	34,15, 10,14		33,1, 18,4
13	Stability of object	21,35, 2,39	26,39, 1,40	13,15, 1,28	37	2,11, 13	39	28,10, 19,39	34,28, 35,40	33,15, 28,18	10,35, 21,16	2,35, 40	22,1, 18,4	
14	Strength	1,8, 40,15	40,26, 27,1	1,15, 8,35	15,14, 28,26	3,34, 40,29	9,40, 28	10,15, 14,7	9,14, 17,15	8,13, 26,14	10,18, 3,14	10,3, 18,40	10,30, 35,40	13,17, 35
15	Durability of moving object	19,5, 34,31		2, 19, 9		3,17, 19		10,2, 19,30		3, 35, 5	19,2, 16	19,3, 27	14,26, 28,25	13,3, 35
16	Durability of non-moving object		6,27, 19,16		1,10, 35				35,34, 38					39,3, 35,23
17	Temperature	36,22, 6,38	22,35, 32	15,19, 9	15,19, 9	3,35, 39,18	35,38	34,39, 40,18	35,6, 4	2,28, 36,30	35,10, 3,21	35,39, 19,2	14,22, 19,32	1,35, 32
18	Brightness	19,1 32	2,35, 32	19,32, 16		19,32, 26		2,13, 10		10,13, 19	26,19, 6		32,30	32,3, 27
19	Energy spent by moving object	12,18, 28,31		12,28		15,19, 25		35,13, 18		8,15, 35	16,26, 21,2	23,14, 25	12,2, 29	19,13, 17,24
20	Energy spent by non-moving object		19,9, 6,27								36,37			27,4, 29,18

Figure 2. Part of a matrix of improvements versus undesired results includes number references to suggested principles for resolving conflict.

Stage 0. Scientists make a (Level 4-5) discovery, such as the scientific understanding of thermodynamics, and may not recognize its potential applications.

Stage 1. Important components, such as the first internal-combustion engines, are developed before a system (e.g., automobile) exists.

Stage 2. A new system—such as the first complete automobile—appears, but its development is slow.

Stage 3. Society recognizes the value of the new system, and its development becomes rapid, with many patents issued. For automobiles, this stage included mass production and the resulting lowered cost that brought the product within the reach of an average person, thereby spurring a wave of development as manufacturers competed for a large and growing market.

Stage 4. The system becomes mature, and its development saturates at some level.

Stage 5. Resources for improving the original system concept are exhausted, and the patent-production rate drops back toward zero. Evidence for Stages 4–5 for automobiles came about in the 1950s, when the vehicles included at least primitive forms of most nonelectronic devices available today—automatic transmissions, power steering and brakes, fuel injection, and so on—but the absence of electronic controls limited the vehicles' effectiveness in many cases.

Stage 6. The next generation of the system emerges to replace the original system. For automobiles, electronic controls coupled to a mechanically mature powertrain began in the 1980s, permitting sweeping changes in driveability and emissions control.

Stage 7. Some limited operation of the original system may coexist with the new system. For the automobile, this stage lies ahead, with the electric car as a potential future competitor.

The characteristics of a given technological system change in a predictable manner as it evolves and matures over time. Altshuller and his colleague Boris Zlotin categorized this evolution in seven rules:

1. At first, a system's subsystems develop spasmodically, resulting in contradictions. The ones with the slowest-moving life cycles hold back the evolution of the total system.

2. As the system matures, it becomes more dynamic and controllable, and the flow of energy and information in the system is optimized.

3. The system at first increases in complexity, but then becomes simpler because of integration.

4. Assemblies change from uncoordinated parts to integrated designs and, finally, to parts with characteristics that can be changed dynamically.

5. A transition is made from concentrating on macroscopic to microscopic objects in the system, which often produces better performance or control.

6. Human involvement decreases with increasing automation.

7. The system becomes a subsystem of a more general system that is closer to the ideal system.

An inventor can use this information either to avoid the common mistake of trying to correct the wrong subsystem, or to beat competitors to future patents. For example, Altshuller used this knowledge to predict the future of flat-glass manufacturing. At that time, manufacturers passed hot glass through a series of rollers, but the glass tended to sag between them, resulting in a wavy product. Using Rule 5, Altshuller predicted that the rollers' size would decrease down to an atomic scale. Several years later, manufacturers introduced the float-glass process, which floats the glass on a bath of molten tin—i.e., microscopic rollers.

As a system evolves, it should become more nearly perfect—providing increasing satisfaction of human needs at a decreasing cost—and move toward what TRIZ calls the *ideal system*. The ideal system cannot be reached in practice, but actual systems approach the ideal by increasing beneficial functions and eliminating

harmful factors. For example, the modern multimedia computer is rapidly approaching the ideal—performing the functions of a television, telephone, fax machine, music center, and so on, and has a weight and price that is thousands of times smaller than the original mainframe computers.

TRIZ tools

Most problems will have an ideal solution plus many other good solutions. TRIZ offers several tools for finding these good solutions. One tool provides a detailed problem-solving algorithm, which we will illustrate through the following example.

Recently, one of the authors of this article, Savransky, made a one-day visit to a company that produces security paper for banknotes and other legal documents—a field in which he had no prior knowledge. A check of patents in the field revealed that this type of paper guards against counterfeiting by incorporating various security features, including additions such as glassy thread or magnetic or fluorescent substances. With this bit of background learned the day before the visit, it was possible to quickly set about applying TRIZ to the company's operation.

First, select a technical problem: The paper should have many different levels of security features without increasing the cost of the paper. Second, formulate a physical contradiction: The security features should be readily apparent—so that anyone can easily recognize that a bill is made from the genuine paper—but they should also include "invisible" levels of detection, and it should be very difficult to make or copy such paper. Third, formulate an ideal solution: The paper itself should provide the security features without any additions to it.

Having stated the problems and the goal, find resources for the solutions. Presently the security paper consists of cotton with a small amount of chemicals in water solution between the cotton fibers; these materials, plus the existing security features, were the available "resources" upon which to base problem solutions. The TRIZ methodology suggested several possible approaches: Write information into the existing glassy or magnetic threads in the paper; make the security features in the paper dynamic (not static) to disguise their presence, perhaps by use of an additive whose signal becomes apparent some period of time after it is activated; put fluorescent or other indicators in the water solution between the cotton fibers, rather than as separate additives; or add indicators in the cotton when it is grown.

That led to the next step: Determine the strength of the solutions and choose the best one. The proposed solutions were discussed with the company's R&D group, whose members had much experience the security-paper field. ugh they already knew about the possibility of writing in the magnetic threads, they had never considered the possibility of writing information in the glassy fibers. The other TRIZ-based solutions were also novel and they accepted several of them as a basis for future research.

Finally, predict the development of the system considered within the problem. In this case, it was concluded that the system will evolve to include dynamic security and security in the cotton itself. Here, the main system is the banknote, the security paper is one of two main subsystems (the other is the print on the banknote), and the supersystem is the banking system, which includes devices for checking the authenticity of a banknote. The subsystems of the paper itself are the major material (cotton) and additions (threads and other security features). The four TRIZ-based solutions could increase a banknote's security without a change of the "print" subsystem. Some new security features could be recognized by existing devices; others would require the adaptation of new methods.

In addition to principles and algorithms, TRIZ currently offers several other tools—including standard solutions, and lists of physical, chemical, geometrical, and biological effects—that can be used in solving a problem. Although no technique can produce a creative solution by itself, TRIZ gives an inventor a logical starting point and a systematic approach to inventive problem-solving.

Further Reading

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http://w3.advn.com/~semyon/triz 0000.htm

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