An Introduction to TRIZ

The Russian Theory of Inventive Problem Solving

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ISBN: 1-928747-0-00

Editor's Preface

Stan Kaplan's *Introduction to TRIZ* was one of the first books on the Theory of Inventive Problem Solving to appear in the U.S. It quickly became known as the best TRIZ primer available in English—a distinction that it maintains today, nine years after it was first published.

Dr. Kaplan's straightforward explanation of the basic elements of TRIZ theory, and his description of the tools that emerged from the first three decades of TRIZ development, are relevant for experienced engineers and novices alike. His analogy between the search for an inventive solution and the process of solving a quadratic equation is both simple and profound, and makes the TRIZ problem-solving approach comprehensible to anyone with a knowledge of basic algebra.

Although TRIZ continues to evolve, its foundation remains intact—and is essential study for those pursuing a thorough understanding of this powerful methodology.

Victoria Roza
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Abstract

The work on the Russian theory TRIZ, begun by Genrich Altshuller in 1946 and continued since then by his students and followers, has grown into a very impressive and useful body of work. This work includes, in addition to the inventive methodology itself, databases of physical phenomena, and numerous examples of inventive problems and their solutions over a wide range of applications. When put to use, TRIZ not only helps one solve specific current problems but, over time, it serves to enlarge the user's repertoire of thought patterns in much the same way that studying calculus does. It makes the mind more flexible and, yes, more creative.

Until recently this theory has been largely unknown in the Western world, mainly because the literature of the theory has been almost entirely in Russian. Within the last decade, two of Altshuller's books have been translated, and a number of papers, articles and training materials in English have begun to appear. At the same time, the theory has continued to evolve, expanding vastly in application, improving in methodology, and becoming easier to understand and use.

This book is intended to be a contribution to this movement. Because TRIZ is potentially of great importance to the technology of the West, and of great personal value to those who study it, this book attempts to provide a point of entry to the theory for English-speaking audiences. For this purpose, it sketches the historical evolution of the theory, and casts over this a conceptual framework, or point of view, from which many (though not all) of the principles and techniques developed during this evolution can be seen as parts of a coherent whole.

The key idea in this framework is what we shall call the Principle of Abstraction. This familiar principle is used extensively in engineering, mathematics, medicine, and other problem-solving fields. It consists essentially of establishing a system of classification for problems in the field, and a system of operators that map the problem categories into corresponding solution categories. Altshuller's inspiration was to see that this same principle could be applied to the domain of inventive problems. This book explains how this application was made.

1. Introduction

We begin with the question: ***What is TRIZ?***

The letters T, R, I, Z are the English acronym for the Cyrillic words which, pronounced phonetically, are *Teoriya Resheniya Izobretatelskikh Zadatch*, and which, translated, mean Theory of the Solution of Inventive Problems.

This title by itself brings up a second question: ***Can such a theory exist?*** After all, isn't invention a creative process? And isn't it therefore mysterious, capricious, random, and highly dependent on the individual in whom it occurs? The answer given by Genrich Altshuller constitutes the fundamental premise of TRIZ *(figure 1)*.

Inventive problems can be codified, classified, and solved methodically, just like other engineering problems.

Figure 1

We next give a brief review of the history behind this rather surprising answer.

2. History of TRIZ

The creator of TRIZ, Genrich Altshuller, was born in Russia in 1926, made his first invention at age 14, and was later educated as a mechanical engineer. At the time he started working on TRIZ, in 1946, he was employed in the patent department of the Soviet navy, assisting inventors in filing their patents. While there he became intrigued by the question of how an invention happens. Is it a matter of luck? The result of a mental “light bulb” turning on, as in the comics? Or can inventions be seen as the result of systematic patterns of inventive thinking?

Altshuller adopted an empirical approach to answering this question. He studied thousands of patents, looking for commonalities, repetitive patterns, and principles of inventive thought. As he found them he codified and documented them. His results, when eventually published, attracted many enthusiasts who continued and expanded the work over the years, reviewing what is now estimated to be more than two million patents worldwide. As a result of this work, hundreds of technical papers and many books on TRIZ have been published, including 14 books by Altshuller himself. A professional TRIZ society has been formed, courses have been developed, and an estimated 50,000 Soviet engineers have been trained in or exposed to the subject.

3. An Early Result — Levels of Inventive Solutions

One of the first things Altshuller noticed as he sifted through the many patents was that they represented technical solutions which were vastly different in their degree of inventiveness. To provide language with which to describe this, he set forth a semi-quantitative, somewhat loosely defined but, nevertheless, useful scale of inventiveness as shown in *figure 2.*

SOLUTION LEVELS

LEVEL 1: Standard

- **Solutions by methods well known within the specialty**

LEVEL 2: Improvement

- **Improvement of an existing system, usually with some compromise**
- **Methods from the same industry**

LEVEL 3: Invention inside paradigm

- **Essential improvement of an existing system**
- **Methods from other fields**

LEVEL 4: Invention outside paradigm

- **Creating a new generation of a system**
- **Solution "not in technology but in science"**

LEVEL 5: Discovery

- **Pioneer invention of an essentially new system**
- **Usually based on major discovery, new science**

Figure 2

Altshuller defined Level 1 on this scale to represent solutions to routine-type design problems, obtained using methods well known within the particular specialty. In solutions at this level the existing system is not changed, although particular features may be enhanced or strengthened. An example of such a solution is an increase in the thickness of insulation around a pipe carrying liquid oxygen into a furnace.

Level 2 solutions were defined as those which, while basically leaving the existing system unchanged, yield new features and lead to definite improvements. An example of a Level 2 solution is the inclusion of a mirror in a welder's mask to focus the light of the arc on areas where improved visibility is needed. Inventions at this level are achieved by methods well known within the same industry.

Altshuller defined Level 3 solutions as those that constitute an essential improvement of an existing system. An example of this is the automatic transmission. Level 3 inventions usually involve technology known in other industries but not widely known within the industry in which the inventive problem arose. Solutions to Level 3 problems thus create paradigm shifts within their industries; they are found outside the range of accepted ideas and principles of that industry.

Level 4 inventions are characterized by solutions found, in Altshuller's words, "not in technology but in science," i.e., through the utilization of previously little-known physical effects and phenomena. Examples are the use of materials with thermal memory (shape memory metals), and the use of the magneto-hydraulic effect in a nautical jet engine.

Level 5 inventive problems are usually beyond the limits of contemporary scientific knowledge. A solution at this level requires the discovery of some new phenomenon which is then applied to the inventive problem. Level 5 inventions usually lead to the creation of wholly new systems and industries. Lasers, aircraft, and computers are good examples here.

4. Regularities in the Evolution of Technological Systems

In his examination of many thousands of patents, Altshuller also noticed consistent patterns or "regularities" in the way technological systems evolved over time. He articulated these patterns ([1], pp. 223-231) in the form of eight *Laws of Evolution of Technological Systems (figure 3)*, as follows:

Laws of Evolution of Technological Systems

1. Law of Completeness of Parts of a System

2. Law of Energy Conductivity in a System

3. Law of Harmonization of Rhythms

4. Law of Increasing Ideality

5. Law of Uneven Development of Parts

6. Law of Transition to a Super-System

7. Law of Transition from Macro- to Micro-Level

8. Law of Increasing Substance-Field Involvement

Figure 3

1. Law of Completeness of Parts of a System

A technical system arises as the result of a synthesis of previously separate parts into a single whole. In order to "live" and be viable the system must include four basic parts: an *engine*, i.e., a source of energy; a *working organ* that performs the function of the system; a *transmission* that conveys the energy from the engine to the working organ; and a *control organ* through which the system is controlled or steered. If any one of these parts is missing or insufficient, the system is incapable of surviving and prevailing against its competition.

2. Law of Energy Conductivity in a System

A technical system evolves in the direction of increasing efficiency in the transfer of energy from the engine to the working organ. This transfer can take place through a *substance*, e.g., a shaft, gears, etc.; through a *field* such as a magnetic field; or through a *substance-field* combination, e.g., a stream of charged particles. The selection of the form of this transfer is at the heart of many inventive problems. As an example, Altshuller cites the problem of heating a substance inside a moving centrifuge and maintaining it at a specific temperature. The solution was to deliver heat through an electromagnetic field, which does not hinder the motion of the centrifuge. Inside the centrifuge the electromagnetic energy is converted to heat by a ferromagnetic disc with a Curie point at the desired temperature.

3. Law of Harmonization of Rhythms

A system evolves in the direction of increasing harmony of the rhythms and natural frequencies of its parts. As an example of this Altshuller describes a patent for improving the mining of coal by drilling a bore hole into the seam, filling it with water, and transmitting pressure pulses through it to break up the coal. Seven years later, another patent improved the process by applying the impulses at a frequency equal to the natural frequency of the coal mass. Altshuller points out that, had the inventors been aware of the Law of Harmonization of Rhythms, the seven-year delay could have been avoided.

4. Law of Increasing Ideality

A technical system evolves in such a direction as to increase its degree of *ideality*. Ideality is defined as the quotient of the sum of the system's useful effects, U_i, divided by the sum of its harmful effects, H_j.

$$\textbf{Ideality} = \mathbf{I} = \frac{\Sigma\, \mathbf{U_i}}{\Sigma\, \mathbf{H_j}}$$

Useful effects include all the valuable results of the system's functioning. Harmful effects include the system's cost, the space it occupies, the fuel it uses, the noise it makes, effluents, etc. Thus, this law states that as the system evolves, the sum of the U_i trend upward and the sum of the H_j trend downward.

Taking this trend to its limit, Altshuller introduced the notion that the *Ideal Final Result* (IFR) of a line of inventive evolution is obtained when the U_i are large and the H_j are zero. Stated another way, an ideal machine has all the desired useful outputs but no harmful effects, including no cost or usage of space. Thus the IFR can be stated as follows:

The function of the machine exists, but the machine itself does not.

5. Law of Uneven Development of Parts

This law states that although the system as a whole improves monotonically, the individual parts of the system do not improve synchronously but rather individually, in fits and starts. Altshuller cites the example of cargo ships, whose carrying capacity and engine power have increased rapidly, but whose braking system has not kept pace (this is why, for example, a modern oil tanker takes many miles to stop).

6. Law of Transition to a Super-System

When a system has reached the limit of its own development, it can continue evolving by becoming a subsystem of a more general system. In this way the original system is raised to a qualitatively new level.

As an example, Altshuller cites one of his own early inventions – a heat-resistant suit worn by mining rescue teams. The problem was to design a suit that would protect a man for two hours in an outside temperature of 100^{o} C. The suit was required to weigh less than 10 kg, as the man was already carrying a breathing apparatus (12 kg) and instruments (7 kg). Altshuller's approach was not to create a refrigerating suit under 10 kg, which was impossible, but rather to create a higher-level super-system in which liquid oxygen served as a refrigerating substance. Upon absorbing the heat, the liquid oxygen evaporated and was then used for breathing. With this new system, Altshuller calculated that a man could work for an hour in a temperature of 500^{o} C.

7. Law of Transition from the Macro- to Micro-Level

This law states that the development of working organs proceeds first on a macro- and then on a micro-level. An obvious example of this can be seen in the electronics industry, where in less than a lifetime we have seen a transition from rooms full of vacuum tubes, to transistors, to super large-scale integrated circuits.

The glass industry provides another example: in the past, glass plates were manufactured by rolling hot glass onto a conveyor. During this process the glass tended to sag slightly between the rollers of the conveyor, resulting, when the glass cooled, in a slight waviness or non-planarity of the plates. To reduce this waviness, one could use rollers of smaller diameter spaced closer together, but this would lead to increased cost and complication. Thus we have here a contradiction between cost and waviness.

The solution, patented by an English company, was to roll the glass out on a bath of liquid tin. This constituted a transition from macro-rollers to micro-rollers (i.e., atoms of tin).

8. Law of Increasing Substance-Field Involvement

As we will describe below, Altshuller developed a way of modeling systems in which he viewed a technical system as composed of two *substances* interacting through a *field*. He called this model the *Su-Field triangle*. The meaning of this eighth law is that systems that do not represent complete Su-Field triangles evolve toward such completeness. Also, the nature of the field tends to evolve from mechanical or thermal to electrical or magnetic.

Although in [1] Altshuller identified only the above eight as *Laws of Evolution*, there are many other concepts and principles throughout his work which can be viewed as additional laws of this type. For example:

Law of Increasing Dynamism

As a technical system evolves, parts which were originally fixed become moveable or adjustable.

For example, in the evolution of aircraft, landing gear became retractable, the aerodynamic profile of wings became adjustable, wings with variable sweep angles were introduced, and engines were put on swivels to produce vertical thrust.

Principle of Psychological Inertia

This principle states the well-known tendency of human beings to resist change, to get "stuck in a rut," to be unable to see or think "outside the box," etc. One corollary of this principle is that when technological change does occur, or when new ideas are tried out, it often tends to happen hesitantly and in small increments. A striking example seen in the pictures of early automobiles, upon which papier-mâché horse heads were attached. Another example is given in *figure 4*, which shows the evolution of sea craft from single to multiple oars, to oared vessels with sail assist, to sail vessels with oar assist, to sail only, to sail with engine assist, to engine with sail assist, and finally to engine only.

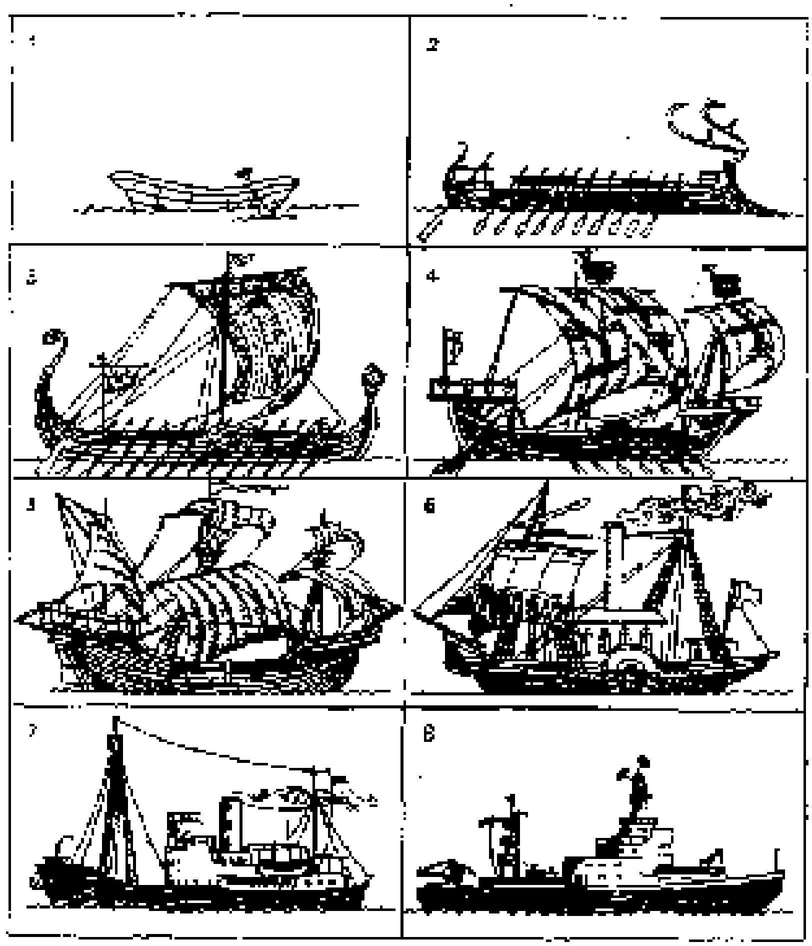

Figure 4

Another example of psychological inertia occurred during the design of the Soviet lunar exploration module. The designers wanted to include a light on this module so that TV images could be transmitted to Earth when the module was on the dark side of the moon. But a problem was encountered with the light bulbs which, under the vibration of flight, tended to fail where the bulb joined the metal socket. The module designers were unable to find or build a reliable bulb. This problem remained for months, threatening the schedule of the module, until someone asked the question: "What is the purpose of the glass bulb?"

Comment:

At this point let us call attention to an interesting subtlety. The above regularities, or "laws" as we have called them, have been presented here as purely empirical in nature. Thus they are laws in the same sense that Darwin's laws were simply summary descriptions of his observations of biological species.

In the case of technical systems, however, the above laws can be given another, more prescriptive "thou shalt" type of meaning, in the sense of the "law of the land." Thus, if we want to improve a particular technological system and stay ahead of our competition, build patent fences, etc., the above laws tell us that we should think about ways to improve the energy conductivity, the harmonization, the transition to a micro-level, etc. Viewed this way, these laws become powerful guides for forecasting and accelerating the evolution of a technical system.

5. How Does TRIZ Work?

Accepting the assertions of the Russian scientists that a theory of inventive problem solving has in fact been developed and productively applied to a wide range of problems in the Soviet Union, Finland, Israel, and other countries, and for the past decade in the United States as well, we now turn our attention to the question of understanding how such a theory works. For this purpose let us recall how we were taught to solve quadratic equations.

5.1 Solving Quadratic Equations

Let us suppose we are asked to solve the following equation, i.e., find the values of x for which the following equation is satisfied:

$$3x^2 + 5x + 2 = 0$$

If we know nothing about algebra we would proceed using the trial-and-error method, guessing and trying values of x. If we have studied algebra we can proceed in a much more powerful way as shown in *figure 5*. In this case, our first step is to recognize that our equation, shown in the lower-left box, is a special case of the equation in the upper-left box. Our algebra book now tells us that every equation having the form of the equation in the upper-left box has two solutions of the form shown in the upper-right box. This form, of course, is the familiar quadratic formula. All that remains is to plug into this formula our specific values, a=3, b=5, and c=2, and we obtain the specific solutions to our problem, as shown in the lower-right box.

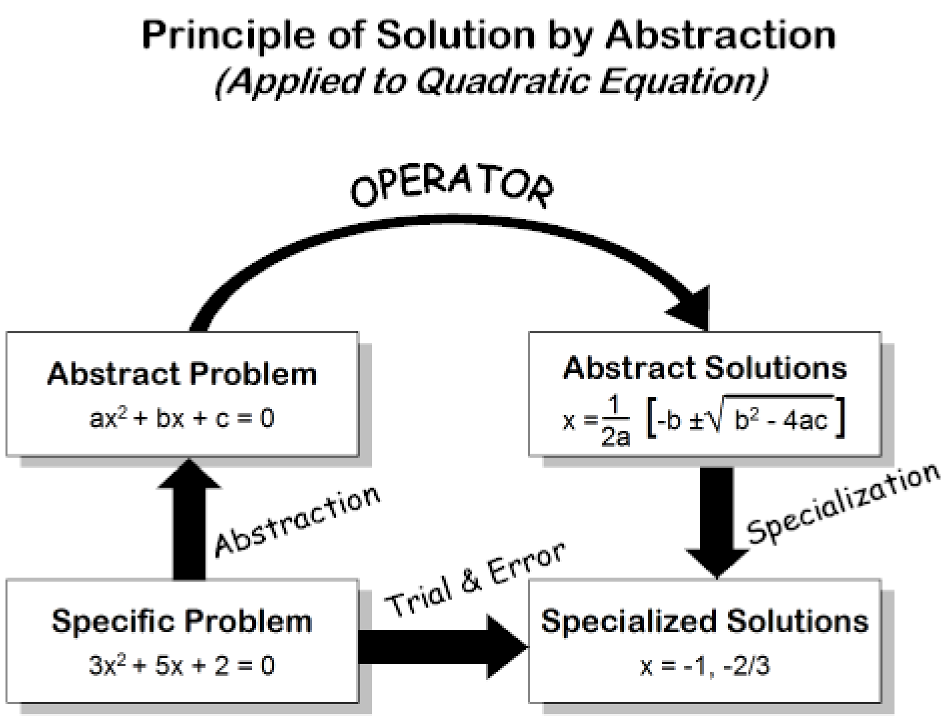

Figure 5

5.2 Reflections on the Solution Process

What we have just done, though simple and familiar, is also very important and far reaching. Therefore, let us pause to reflect on it and view it in a more general context. The upper-left equation in *figure 5* shows the general form of a quadratic equation. We could say that it *abstracts* or lifts out that form from the specific equation shown to the lower left. Thus we could also call it the "abstract form," the "abstract equation," or the "abstract problem."

Note also that this abstract equation can be thought of as defining a *set* of quadratic equations as we let the parameters a, b, and c vary over their ranges. So when we say that our equation in the lower left is a special case of the abstract equation, it is equivalent to saying that our specific equation is one member of the set of equations defined by the abstract equation.

Thus we see that the step of *abstracting the form* from our specific problem is equivalent to defining a whole class of problems, of which our specific problem is one member.

Now, what is the class of solutions to this class of problems? A solution to a quadratic equation is, in general, a complex number. Therefore, we could say that the set or "space" of solutions to a quadratic equation is the space of complex numbers. The quadratic formula in the upper right box can be thought of as an *operator* in the mathematical sense. That is, it describes a "mapping" or correspondence from the space of problems to the space of solutions. Therefore, to obtain the solutions to our specific equation, we simply need to specialize this mapping to that equation.

5.3 The Principal of Solution by Abstraction

This process we have just used in solving our quadratic equation is an example of a fundamental and immensely powerful process that we call the *Principle of Solution by Abstraction*. The basic idea, once again, is to abstract the forms or, equivalently, to identify categories of problems within the given subject. Then, for each category, we work out the general solutions, i.e., the operators. The set of categories and operators thus identified can be thought of as constituting a "theory" of the solution of problems within this subject.

Once this theory has been documented, to solve a specific problem within the subject, the user of the theory needs only to identify into which category his problem falls, look up the operators for that category, and specialize them to his particular case.

If we think about it, this process is used not only in mathematics and engineering but in, for example, medicine, and in all problem-solving subjects. Altshuller's inspiration was to recognize that this same familiar process could also apply to the solution of inventive problems. This is the basic idea behind TRIZ.

5.4 Application to Inventive Problems

To develop a theory for the solution of inventive problems, then, what needs to be done, and what Altshuller has done, is the same thing that has been done for algebraic and medical problems, etc.; namely, to establish one or more classification systems for inventive problems, and for each category of problems thus established, to identify one or more operators that lead to solutions.

This done, the process of solving an inventive problem would follow the schema shown in *figure 6*. Beginning at the lower left with a specific inventive problem, we abstract its form and thus recognize it as a member of a category of inventive problems shown at the upper left. We then look up, in the books of the theory, the operator(s) applicable to this category. This gives us one or more solutions in abstract form, represented by the upper-right box. So, having gone up and over, it remains only to specialize the abstract solution and thus move down to the particular solution of our specific problem.

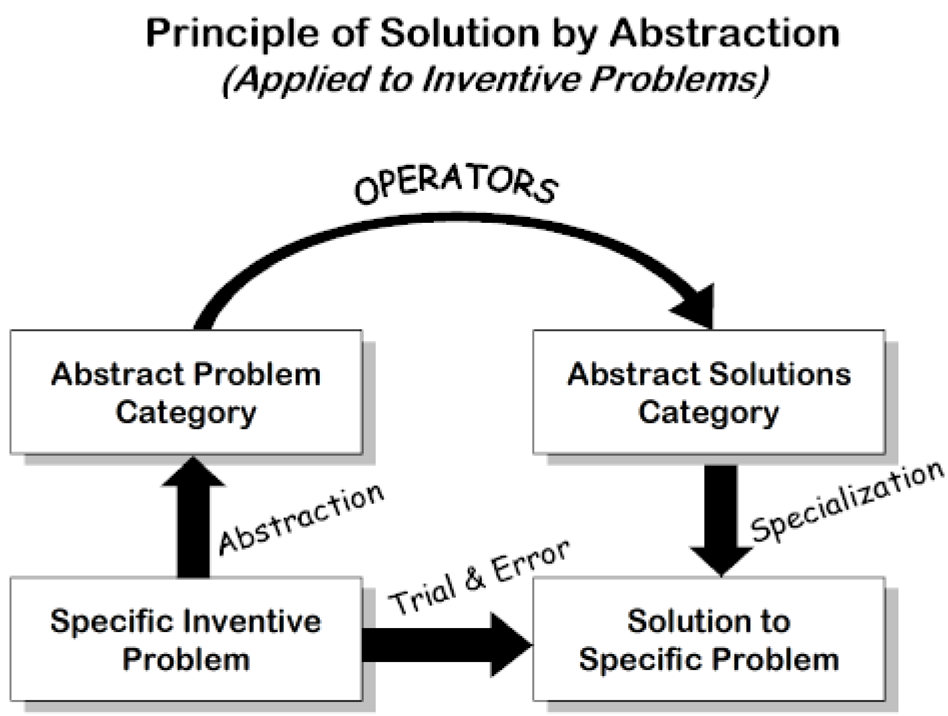

Figure 6

Of course, solving an inventive problem using this process is not quite as simple as solving an algebraic problem. The space of inventive problems is much larger and more varied than the space of algebraic problems. A specific inventive problem may fall into several different abstract categories; a given category may have many different operators; a particular operator acting on a specific problem may lead to a whole class of solutions rather than a single solution; and finally, the step of specializing the abstract solution to a particular one still requires creativity, though not nearly as much as if we had tried to solve the problem by the usual trial-and-error method.

6. Technical Contradictions and the Contradiction Matrix: Altshuller's First Solution System

Figure 6 is all well and good as a general schema, but how does one actually do it? How does one go about defining categories of inventive problems and identifying the operators for each? A good way to begin is by studying the existing patent literature. This is what Altshuller and his followers have been doing since 1946.

6.1 Technical Contradictions

The first big breakthrough came when Altshuller observed that all inventive problems involved what he called a *technical contradiction*. A technical contradiction exists when, in attempting to improve one parameter (say, parameter A) of a technological system, another parameter (B) deteriorates. Thus if we attempt to make a product stronger by making it thicker, it also gets heavier. If we use stronger materials, the cost increases, and so on *(see figure 7)*.

TECHNICAL CONTRADICTION

$A\uparrow$ $B\downarrow$

Parameter A improves

Parameter B deteriorates

Examples: strength vs. weight, reliability vs. cost

- **Common engineering approach: design compromise. Not considered an invention in TRIZ**
- **Invention surmounts the contradiction, achieving both $A\uparrow$ and $B\downarrow$**

Figure 7

The typical engineering approach to dealing with such contradictions is to "trade off," i.e., to compromise. In TRIZ, such a compromise is not considered an invention. An invention is an idea that surmounts the contradiction, moving both parameters in a favorable direction.

6.2 The Technical Contradiction Matrix and the Inventive Principles

Altshuller used his observation about technical contradictions to develop his first classification system for inventive problems. As he studied each patent he identified the underlying technical contradiction resolved by the patent, as well as the principle, i.e., the operator, used to resolve the contradiction. By amassing these results for many patents, he was able to identify 39 engineering parameters (such as speed, force, strength, etc.) and 40 operators, which he called *Inventive Principles*. The parameters are listed in *figure 8* and the inventive principles in Appendix 1. Altshuller then created a 39x39 table with these parameters as the row and column headings, as shown in *figure 9*. (The full table is given in Appendix 2.) We shall call this table, now of mainly historical interest, the *Contradiction Matrix*.

ALTSHULLER'S PARAMETERS

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

Figure 8

Consider the box in this matrix formed by the intersection of row *i* and column *j*. This box represents a category of inventive problems, namely, the category of all problems in which the *ith* parameter and the *jth* parameter form a contradiction. The set of boxes, i.e., the table itself, therefore constitutes a categorization schema for inventive problems.

In box *i,j* Altshuller listed the identification numbers of the inventive principles that inventors had used to resolve problems in the *i,j* category. Therefore, the table containing these identification numbers (Appendix 2) along with the corresponding set of operators (Appendix 1) constitutes a solution system according to the schema of *figure 6.*

6.3 Using the Solution System

To use this solution system to solve a given problem we follow the procedure illustrated in *figure 9*. We begin by identifying the technical contradiction present in that problem. We then locate the appropriate box in the table and find there the identification numbers for the operators that other inventors have used to resolve technical contradictions of that type. By looking in Appendix 1 we find the descriptions of these operators. We then think about how each operator might be applied to our specific problem. This may lead to a number of inventive ideas out of which at least one, hopefully, will yield a satisfactory solution.

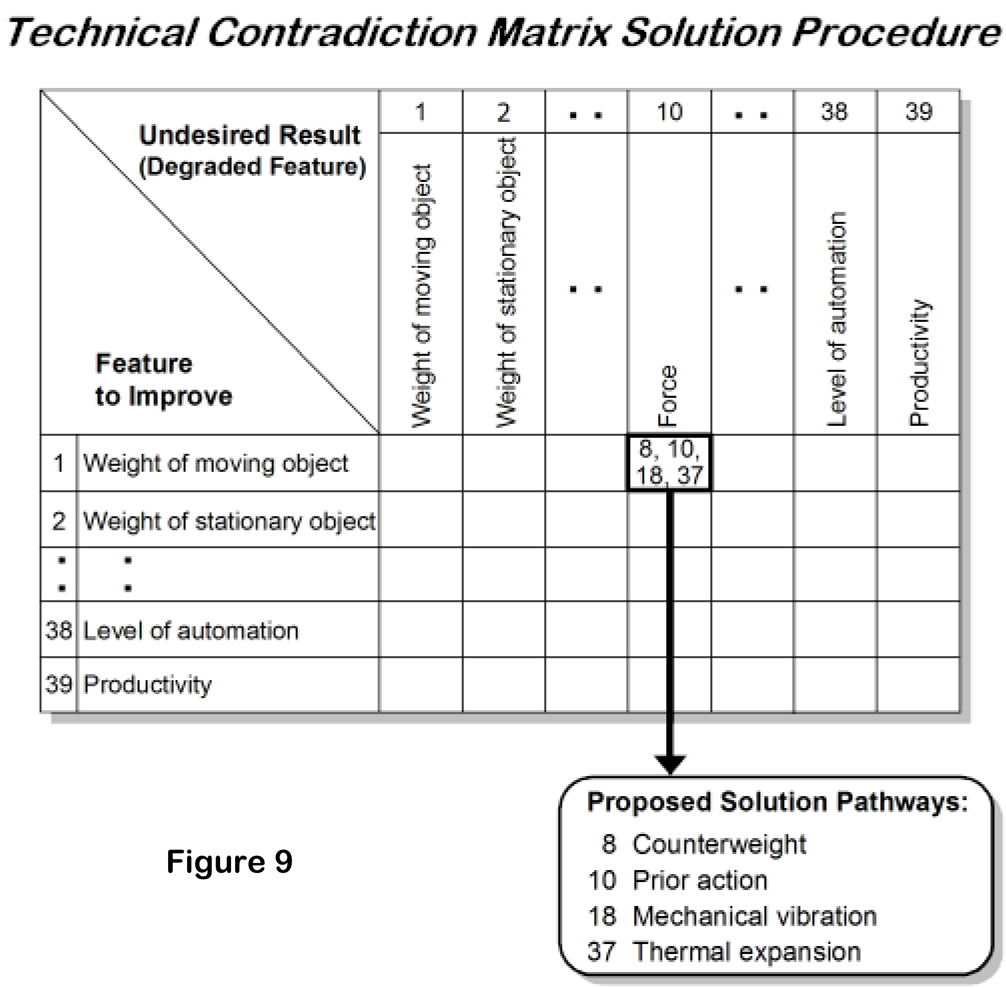

Figure 9

7. Centrifugal Governor Example

As an example, consider the problem of a centrifugal governor *(figure 10)* used in early helicopters to control the speed of blade rotation. Since weight is always an important factor in aircraft, it is desirable to reduce the mass, *m*, of the rotating balls. If we do this, however, the centrifugal force decreases as well, impairing the effectiveness of the governor. Thus we have a technical contradiction between the weight of the moving object and its resultant force. Referring to row 1, column 10 of the contradiction matrix, we find as the first recommendation inventive principle (operator) 8. Looking this up in Appendix 1, we obtain:

8. Counterweight Principle

a. *Compensate for the object's weight by joining with another object that has a lifting force.*

b. *Compensate for the weight of an object by interaction with an environment providing aerodynamic or hydrodynamic forces.*

Item *b* prompts the idea of replacing the rotating balls by airfoils which provide a lifting force proportional to the angular velocity. Thus we can reduce the weight without diminishing the governing action, and the contradiction is surmounted.

Centrifugal Governor

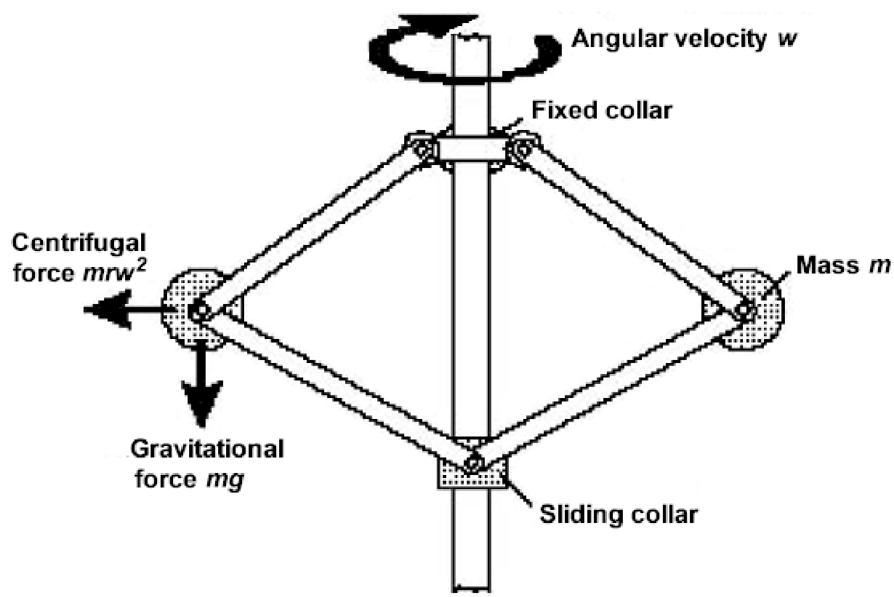

Figure 10

8. Summary of the Technical Contradiction Method

The technical contradiction method is our first concrete example of the schema of *figure 6*. Let us trace the centrifugal governor through this schema. We began with our specific problem in the box at the lower left in *figure 6*. By identifying the technical contradiction, we moved to the upper-left box; that is, we put our centrifugal governor in the category of inventive problems in which the weight of a moving object is in contradiction to its force. The upper-right box in *figure 6* now represents the abstract set of all solutions to this category of inventive problems.

We then entered the contradiction matrix and found there, in box (1,10), the identifiers of four operators used by previous inventors to solve problems in this category. The first of these, operator *8b*, suggested a solution to our specific problem, bringing us down to the lower-right box in *figure 6*.

9. Physical Contradictions

In section 6.1 we defined a technical contradiction as a situation wherein if we increase parameter A, representing a favorable change, then parameter B decreases, representing a deterioration. Now suppose that we had a single parameter, C, which for some reason we want to increase and for another reason we want to decrease. Altshuller called this situation, where a parameter is in contradiction to itself, a *physical contradiction*.

For example, consider again our centrifugal governor problem. The weight of the balls should be high to generate centrifugal force, and it should be small to increase the payload of the aircraft. This is a physical contradiction. Again, the typical engineering approach is to compromise, but that approach does not lead to an invention. An invention surmounts the contradiction.

It turns out, as we will show, that from every technical contradiction can be identified at least one physical contradiction. In terms of our schema of *figure 6*, identifying the physical contradiction in a problem is a way of moving to the upper-left box, i.e., a way of abstracting the form of the problem. For problems abstracted in this way, in terms of physical contradictions, Altshuller has identified a set of particularly powerful operators known as the *separation principles*.

10. Separation Principles

The three most important separation principles are given in *figure 11:* separation in time, separation in space, and separation in scale, i.e., between parts and the whole.

10.1 Separation in Time — *Siberian Pile Driving Example*

Separation Principles

1. Separation in TIME

2. Separation in SPACE

3. Separation in SCALE

Figure 11

This problem arose during construction of large buildings upon permanently frozen ground, where piles were being driven to form the foundation. It was desirable that the piles be pointed at the bottom so that they were easier to drive into the ground *(figure 12)*. On the other hand, for maximum load bearing capacity and for resistance to settling, it was desirable that the piles be blunt. Hence a physical contradiction: the piles should be pointed and the piles should be blunt.

A solution to this problem was obtained by including a hollow chamber in the pointed pile and filling it with wire, concrete rubble, and an explosive charge. After the pile was driven to its final position the charge was detonated, forming a blunt footing *(figure 13)*. Thus we have an instance of separation in time: the pile was pointed while being driven, and blunt when carrying load.

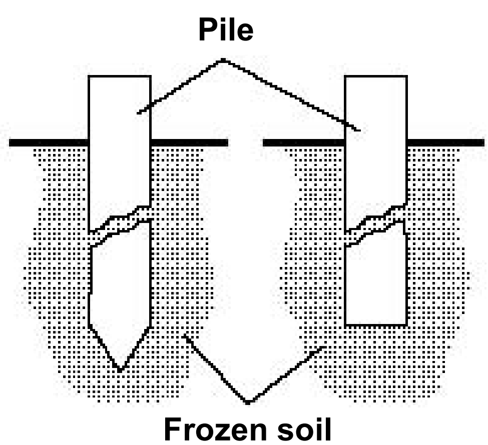

Figure 12

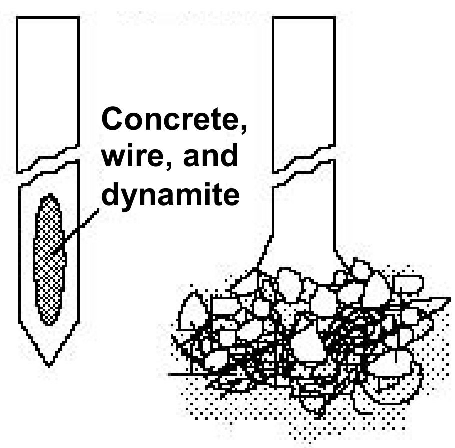

Figure 13

10.2 Separation in Space — *Metal Coating Example*

Metal parts are coated by being immersed in a bath of coating solution. The coating proceeds more quickly if the temperature of the solution is high, but the solution tends to decompose and precipitate out at such a temperature. Hence the physical contradiction: the temperature of the bath should be high for production rate, and it should be low for stability of the solution.

The inventive solution was to raise the temperature of the metal part by passing current through it. Thus the temperature of the bath in the vicinity of the part was high but through its bulk it was low, hence a separation in space.

10.3 Separation Between a Whole System and its Parts — *Bicycle Chain Example*

A bicycle chain must be flexible to traverse a loop and rigid to accept high loads from the pedals. The solution, a chain of links, is rigid on the small scale but flexible on the large scale.

11. Relation Between Physical and Technical Contradictions

The physical contradiction and the separation principles together constitute Altshuller's second actualization of the schema of *figure 6* (the technical contradiction matrix and the inventive principles constituted the first). To discuss the relationship between these two, let us first observe, as was noted at the end of section 9, that from every technical contradiction can be identified at least one physical contradiction.

This observation is explained in *figure 14*. In order to improve property or parameter A of our system we must change some other parameter. Let's refer to this other parameter as the *control parameter*, C. Thus to improve the strength, A, of our system we can increase its thickness. Thickness is thus the control parameter. When we increase C, however, the weight, parameter B, deteriorates. Thus we want C to be high to provide strength, and we want C to be low to keep the weight down: a physical contradiction.

In this way we see that for every inventive problem in which we have identified a technical contradiction, we can further identify a specific physical contradiction in terms of the control parameter. In making this identification we place our specific problem into the abstract set of all inventive problems having physical contradictions. Having placed our problem into this set, we now have available to us the known operators acting on this set.

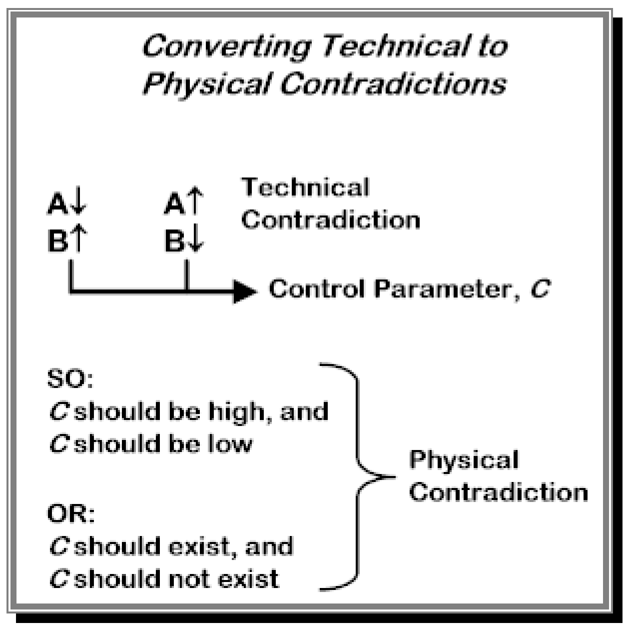

Figure 14

In this case the operators are the separation principles, and they have particularly great heuristic power (i.e., power to stimulate inventive ideas), much more so than the inventive principle operators acting at the level of technical contradictions. The source of this greater power lies in the fact that the space of physical contradictions is a higher level abstraction than the spaces represented by the boxes in the technical contradiction matrix.

This notion of *levels of abstraction* pervades all of TRIZ. To illustrate what we mean by this notion we next consider an example from the mathematics of heat conduction.

12. Levels of Abstraction — *Heat Conduction Example*

In connection with the general schema of *figure 6*, we now observe that when abstracting, it is possible to go to various levels of abstraction. As an example of this, consider the one-dimensional heat conduction problem shown at the bottom left in *figure 15*. We seek to determine the steady-state temperature distribution, T(x), in a cylindrical bar having internal heat generation. Our specific problem, defined by the length, b, the conductivity, k, and the heat generation function, Q(x), is represented by the lower-left box.

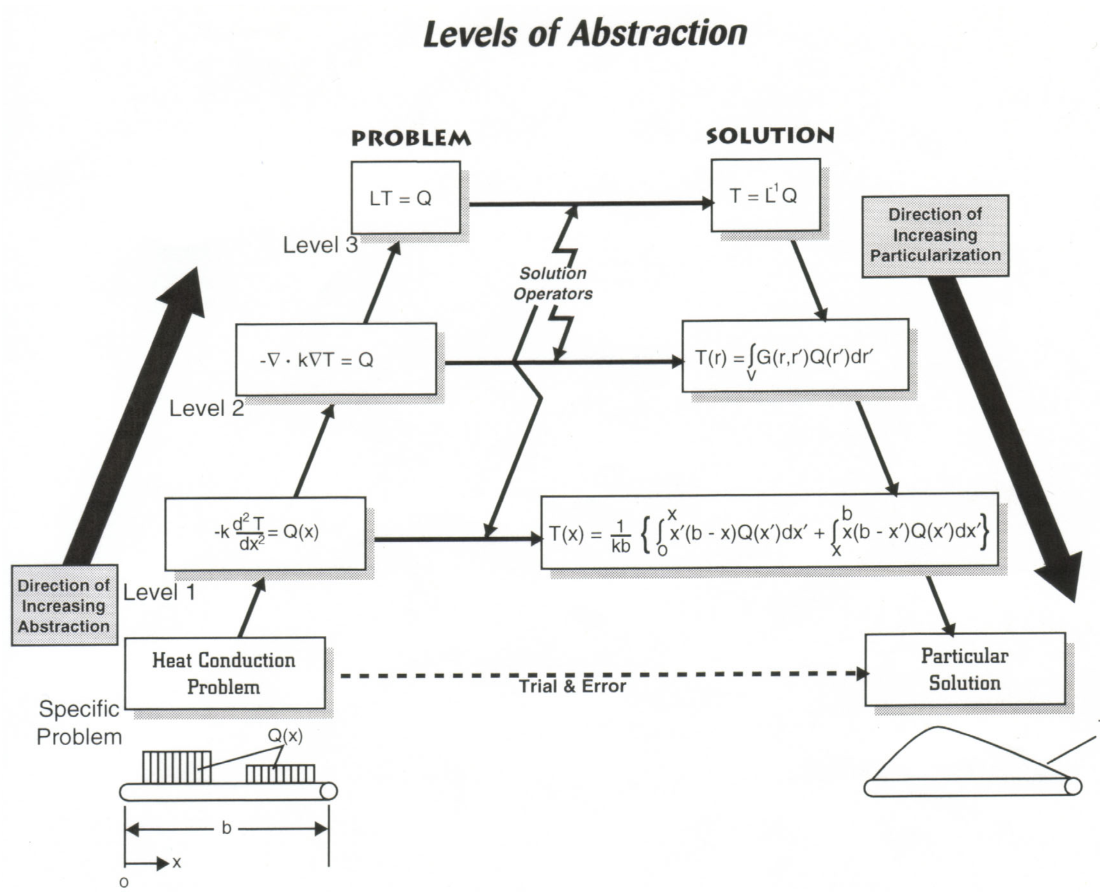

Figure 15

To attempt to solve the problem directly by trial and error would be very awkward. To solve it by abstraction at the first level, we would write the one-dimensional heat conduction equation shown at level 1 on the left. At this level the solution operator is known, and is written in the box at level 1 on the right. To specialize this to our specific problem we need only enter k, b, and Q, and then perform the quadrature.

We can abstract to a higher level by writing the general three-dimensional heat conduction equation shown at level 2 on the left. At this level the solution operator is expressed by the integral on the right involving the Green's function G(r,r′). To obtain our particular solution we must again carry out the quadrature. We can do this in steps by first specializing the Green's function to its one-dimensional form. This moves us back down the ladder of abstraction to the box at level 1 on the right.

We can abstract to a still higher level by recognizing that our three-dimensional heat conduction equation is a special case of the more general class of equations known as Linear Operator Equations. These are shown in the top box on the left, with L representing the linear operator. The solution to this equation is written in terms of the inverse operator L^{-1}, as shown in the top box on the right.

The level of abstraction here is so high that no information about L^{-1} is given other than that it is also a linear operator. But this fact alone is sufficient to allow us to move back down the ladder of abstraction, specializing first to the Green's function integral at level 2, then to the one-dimensional form, and finally to the particular solution represented at the bottom right.

In the same way, we can think of the boxes in the technical contradiction matrix as being a first-level abstraction, and the inventive principles as the operators at this level. The set of inventive problems having physical contradictions is a much higher abstraction. Indeed, it may be the highest possible level of abstraction, since one can argue that all inventive problems have physical contradictions.

The separation principles are operators at this high level. In what follows, we shall give examples of other operators, other levels, and other ways of abstracting inventive problems.*

* It is interesting also to observe in figure 15 that the form of the operators gets drastically simpler as we move up the ladder of abstraction. We see a similar effect in the simplicity of Separation Principles as compared with the 40 Inventive Principles. This increasing simplicity is inherent in the abstraction process itself which, by definition, drops out the complications of complications of the specific details as it lifts out the basic essence.

13. Su-Field Theory

Altshuller gave us a third system for classifying inventive problems and operators. He called this *Substance and Field Theory*, or “Su-Field” for short. The basic ideas of this theory are as follows:

1) In every technological system one can discern two objects or *substances*, S_1 and S_2. These could be, for example:

a) Two parts of the system

b) The system itself and its product, i.e., what it acts upon

c) The system and its environment

2) These substances interact or communicate through a *field*, F. Examples of the various types of fields are:

a) Mechanical

b) Acoustic

c) Thermal

d) Chemical

e) Electric

f) *Magnetic*

and so on.

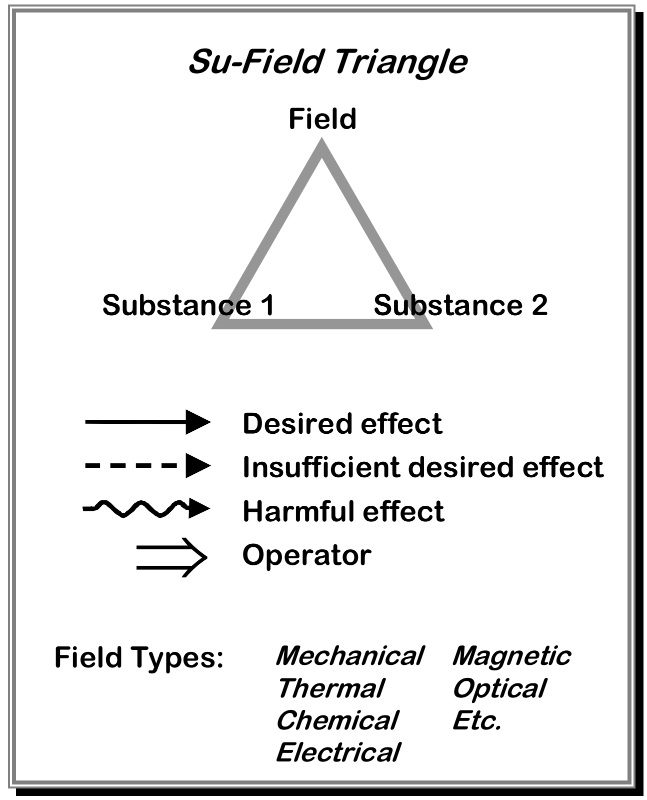

Figure 16

3) The relationship between the field and the two substances can be expressed in a *Su-Field triangle*, as shown in *figure 16*.

4) This triangle diagram may be thought of as a model of the technological system. It is of course a very simple (i.e., abstract) model. More detailed models can be made by adding more nodes, linking triangles together, etc.

5) These diagrams can be made more informative by introducing different line symbols for the connections between nodes, as shown in *figure 16*. Thus a solid line indicates a desired effect, a dashed line indicates a desired but insufficient effect, and a wavy line indicates an undesired effect. Arrowheads can be added to the links to indicate directionality, i.e., one node having an effect on another.

6) If a Su-Field diagram contains dashed or wavy lines, then the system it represents needs improvement. Such a diagram therefore represents an inventive problem.

7) The solution to this inventive problem may also be represented by a Su-Field diagram, which would be a modification of the original diagram.

8) The connection between the original diagram and the solution diagram is denoted by a double arrow, as shown in *figures 17a* and *17b*.

9) This connection may be regarded as an *operator* in the sense of *figure 6*. Thus, the Su-Field diagram representing the problem is an abstraction representing the whole set of inventive problems having the structure shown in that diagram. This set corresponds to the upper left box in *figure 6*. Similarly, the Su-Field diagram representing the solution corresponds to the upper-right box in *figure 6*. It expresses the structure of the solution in exactly the same way that the quadratic formula does in *figure 5*. The connection or correspondence between the two sets is, by definition, an operator.

In the next section we illustrate these ideas with examples.

14. Su-Field Examples

Figure 17a shows a Su-Field operator applicable to inventive problems in which the desired interaction between the two substances is present but insufficient. To strengthen the interaction, the operator suggests the addition to S_2 of a third substance, S_3, and possibly changing the field. The following examples demonstrate the use of this operator and suggest the wide range of its applicability.

14.1 Finding Refrigerant Leaks

A maintenance worker attempting to find a small leak in a refrigeration system is hindered by poor lighting. *Figure 17a* shows a Su-Field diagram for this situation. S_1 represents the maintenance worker, S_2 the leak, and F_1 the light (an optical field). As the dashed line shows, the interaction between the leak and the maintenance worker is insufficient. The suggested solution is to add a small amount of a fluorescent substance, S_3, to the refrigerant, and to look for it using ultraviolet light, F_2.

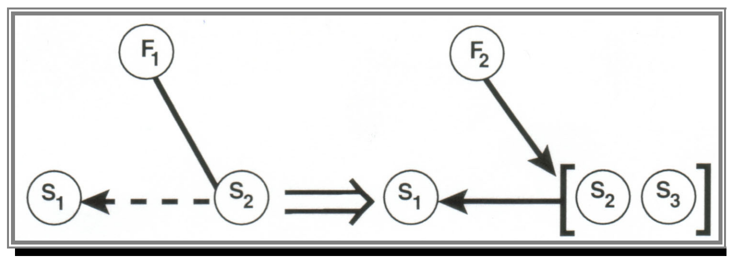

Figure 17a

14.2 Ink Eraser

A Japanese patent describes an ink eraser made by mixing small capsules of ink solvent into the rubber. The mechanical action of rubbing breaks the capsules, releasing the solvent. S_1 represents the ink, S_2 the rubber, S_3 the capsules, and $F_1 = F_2$ is the mechanical field of rubbing.

14.3 Polymer Hardening

When making large items out of polymers it is often desirable to measure the degree of hardening of the polymer mass. For this purpose iron filings are added to the polymer mix. As the polymer hardens, the mobility of the filings, and thus the magnetic permeability of the polymer mass, changes. This change can be measured non-destructively.

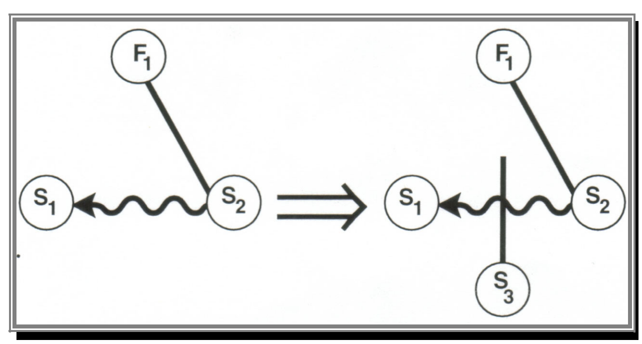

Figure 17b

In *figure 17b*, the interaction between S_1 and S_2 is harmful. In this case, the operator suggests interposing a third substance between them. This operator works especially well if the third substance is a modified form of S_1 or S_2. The following are two examples of the use of this operator.

14.4 Preventing the Hardening of Slag Clinker

As a byproduct of making steel, large amounts of molten slag, S_2, are produced. The slag is towed in large cauldrons to slag piles where it is dumped. During this transport, air, S_1, cools the surface of the slag. If the journey is too long or the air too cold, the surface of the slag freezes solid, preventing the vats from emptying. In accord with *figure 17b*, the problem is solved by creating a slag foam on the surface, which insulates the hot slag from the cold air.

14.5 Protecting Pipes from Steel Shot

In a steel shot factory, the shot is transported pneumatically through pipes. Where a pipe bends, the shot impinges on and erodes the pipe metal, necessitating frequent repair. In accord with *figure 17b*, the problem is solved by applying magnetism to the outside of the pipe at the bend. This creates a static layer of shot on the inside of the pipe, which shields the pipe wall from the impact of the moving shot.

Many additional operators have been identified in terms of Su-Field theory. We shall leave this subject for now, however, and proceed to a fourth way of realizing the schema of *figure 6*.

15. SUH Method

What we call here the *SUH method* is the author's interpretation, in light of the abstrcation principle, of what is now known as the *Modern TRIZ,* or *Ideation Methodology*, was developed by Alla Zusman and Boris Zlotin. This method is yet another entirely different and more comprehensive approach to defining categories of inventive problems, and to identifying operators acting on those categories. In terms of *figure 15*, this approach might be thought of as a "top down" approach in the sense that it starts at the top level of abstraction and moves down the pyramid.

The SUH method begins with the observation that every engineering system, S, has useful output, U, and harmful output, H. This is expressed in the diagram of *figure 18*, which we might characterize as the ultimate abstraction of a technological system. Similarly, the ultimate abstract statement of an inventive problem would be: "increase the *ideality* of the system."

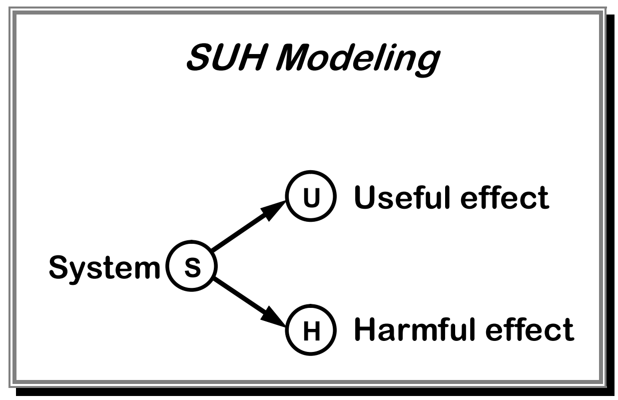

Figure 18

For an inventive problem stated in this way, *figure 18* suggests two operators:

(1a) increase U

(1b) decrease H

These are so obvious, however, that they hardly seem to warrant the term "operators." Recall that we had a similar situation at the top of *figure 15*, where the solution operator L^{-1} seemed abstract to the point of being trivial. Yet the structure of L^{-1}, simple as it is, is enough (as was noted in Section 12) to allow us to work down the ladder of abstraction to the specific solution.

A similar thing is true of the operators 1a and 1b above. They are one level more specific than the statement "increase ideality," and to this extent they focus our attention and stimulate our creativity. Moreover, they set the stage for further stepwise descent along the ladder of abstraction. For example, the next step down from operators (1a) and (1b), according to the SUH method, are the operators:

(2a) Given S, find a way to eliminate (or reduce) H

(2b) Find a way to modify S that eliminates H while still yielding U

(2c) Find a way to obtain U without using S

(2d) Find a way to modify S that improves U without worsening H

These operators, as simple as they are, have distinctly greater heuristic power than operators (1a) and (1b). They cause us to focus and perhaps think differently about the problem, thus helping us to break our psychological inertia and think “outside the box.” Indeed, when one uses these operators frequently, they become a mental habit. The neural networks in the brain become flexible and accustomed to thinking about a problem from many different angles. This is what creativity is, and it is learnable. TRIZ shows how.

16. Moving Down the Ladder of Abstraction

From the operators (2a) through (2d), one may now work downward to operators of greater specificity. Indeed, Zusman, Zlotin and their associates (hereafter ZZA), have written a computer software system in which, along with the *problem formulator*, they have organized over 400 operators into a branching structure that works from very abstract *universal operators* down through *general operators* and on to very *specialized operators*.

16.1 Detailing H

For example, starting with (2a), we might take a further step towards specificity by asking "What kind of H do we have?"

ZZA suggest we distinguish two types of H:

Undesired Action

High Expense Attribute

Suppose our H is of the High Expense Attribute type. We can detail this further by indicating the type of attribute. For example, ZZA identify the following types of attributes:

TABLE 1

Types of High Expense Attribute

- ***Weight***
- ***Overall dimensions***
- ***Energy required***
- ***Energy wasted***
- ***Time wasted***
- ***System complexity***
- ***Monetary cost***

and give operators for each.

Alternately, suppose our H is of the Undesired Action type. ZZA then suggest a number of operators, among which are:

TABLE 2

Operators for Eliminating Indesired Action

- ***Eliminate the cause of the undesired action***
- ***Exclude the source of the undesired action***
- ***Make use of the culprit of the undesired action***
- ***Substitute by using a model***
- ***Eliminate obstacles***
- ***Impact on the undesired action***
- ***Isolate the undesired action***
- ***Counteraction (compensation)***
- ***Parallel restoration***
- ***Anti-action***
- ***Vaccination***
- ***Use of feedback***

In the ZZA software, each of these operators is explained, and a number of examples are given. The operator *counteraction (compensation*), for example, is illustrated by a description of the tactic "fighting fire with fire," well known among those who fight forest fires. The operator *make use of the culprit* is illustrated by the steel shot example of Section 14.5.

As a matter of principle, every operator can be broken down into sub-operators. Thus, continuing down the ladder, the operators of *Table 2* can be further broken down into more specific operators. For example, the operator *impact on the undesired action* contains the following sub operators:

TABLE 3

Sub-operators of "Impact on the Undesired Action"

- ***Drawing off the undesired action***
- ***Changing direction of the undesired action***
- ***Switching off the undesired action***
- ***Hyper-enforcement of the undesired action***
- ***Local slackening of the undesired action***
- ***Prolonging the undesired action***

As an example of the operator *drawing off the undesired action*, ZZA discuss the case of larvae of the potato nematode, who spend the winter underground in cocoons which protect them from chemicals and other eradication methods. In the spring, after potatoes are sown, the larvae perceive the potato smell. They then emerge and migrate to the tubers, drawn by the smell. If even a small percentage of the larvae reach the tubers the harvest will be destroyed.

The inventive solution suggested was to introduce an extract containing potato "smell" (water in which rotten potatoes had been stored) into the soil a few weeks before sowing. This caused the larvae to emerge and, being unable to find food, die in two to three days, leaving the soil clear for sowing.

16.2 Detailing U

In the same way as, in Section 16.1, we started from operator (2a) and detailed H, we can start from (2d) and detail U. For this purpose we ask "What aspect or characteristic of U do we want to improve?" ZZA offer the following list:

TABLE 4

Aspects of Characteristics of U

- ***Reliability***
- ***Longevity***
- ***Mechanical strength***
- ***Speed of action***
- ***Stability of composition***
- ***Convenience***
- ***Productivity***
- ***Accuracy***
- ***Form***
- ***Universality***
- ***Degree of automation***
- ***Degree of adaptation***

Again, these can be further broken down and operators identified. For example, under *accuracy* is the sub-characteristic *dosage accuracy*, for which the operator *form transformation* is identified. Illustrating this is the solution to the problem of slicing eggs for sandwiches, where the diameter of the slices varies. The solution given was a machine that breaks the eggs, separates the whites and yolks, and puts the egg whites into a rotating metal cylinder. By centrifugal force, the whites become evenly spread over the surface of the cylinder, which is then heated, causing the whites to solidify. The yolks are then poured into the center and the assembly heated again, producing a sausage-shaped egg which can be cut into uniform slices.

16.3 Using the Substructures of H, U, and S

Another approach to moving down the ladder is to use the substructures of H, U, and S. For example, *figure 19* shows a case in which the harmful effect, labeled H_n, emerges as the end result of a chain of effects, H_1, H_2, etc. H_n can be eliminated by interdicting the chain at any point; that is, by eliminating either H_1, H_2, etc.

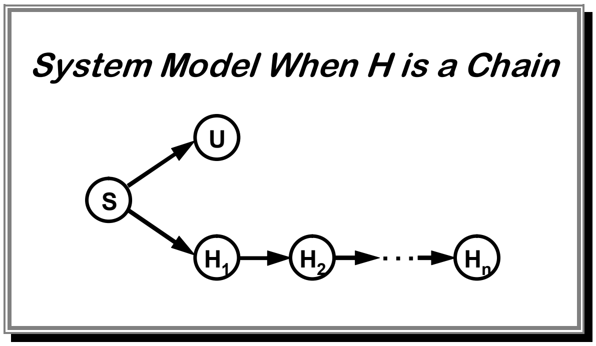

Figure 19

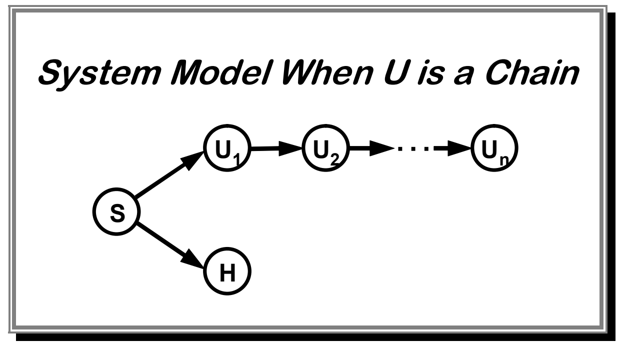

Figure 20

Similarly, in *figure 20*, the desired effect U_n emerges as the result of a chain of intermediate effects U_i. Enhancing any of the intermediate effects will result in the enhancement of U_n.

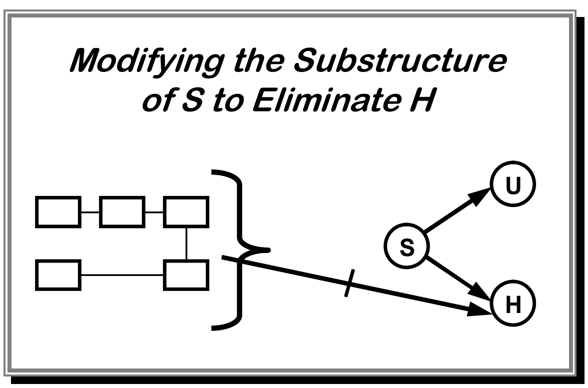

Figure 21

In *figure 21*, the substructure of S is examined to identify the particular part of the system which leads to the harmful (or useful) effect. This part can then be modified to diminish H or enhance U.

16.4 Adding Corrective Systems

Figure 22 shows the typical engineering approach to eliminating a harmful effect (H_0), which is to add to the basic system S_0 another system S_1 whose useful output U_1 is the negation of H_0 (negation is indicated by a barred arrow). Usually, however, perhaps inevitably, this new system also has a harmful output (H_1), as shown. Still another system, S_2, can then be added to negate H_1, and so on.

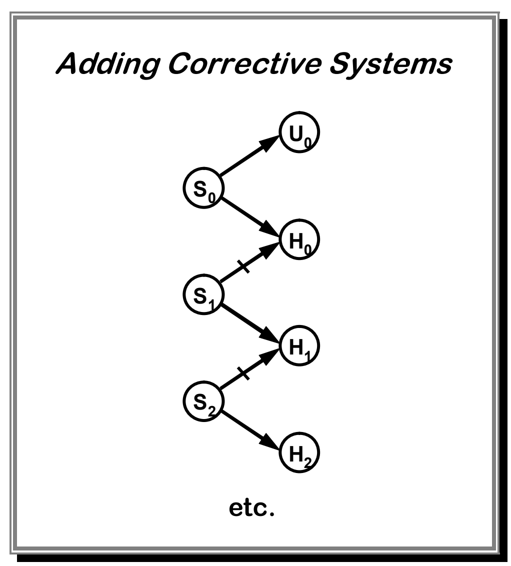

Figure 22

An example of this approach arose in a manufacturing operation in which angular copper contacts were silvered. In the original system the contacts were simply immersed in a silver bath. This had the harmful outcome of wasting silver, since only a part of each contact required silvering. Therefore, a lid with slits was added to the system as shown in *figure 23a*, so that only the desired portions of the contacts were immersed. This additional system, however, also had an undesired effect – the level of the silver bath fluctuated with time. Thus another system was added to detect and control these fluctuations; the harmful outcome of this was the cost and complication of the control system.

Silvering of Contacts

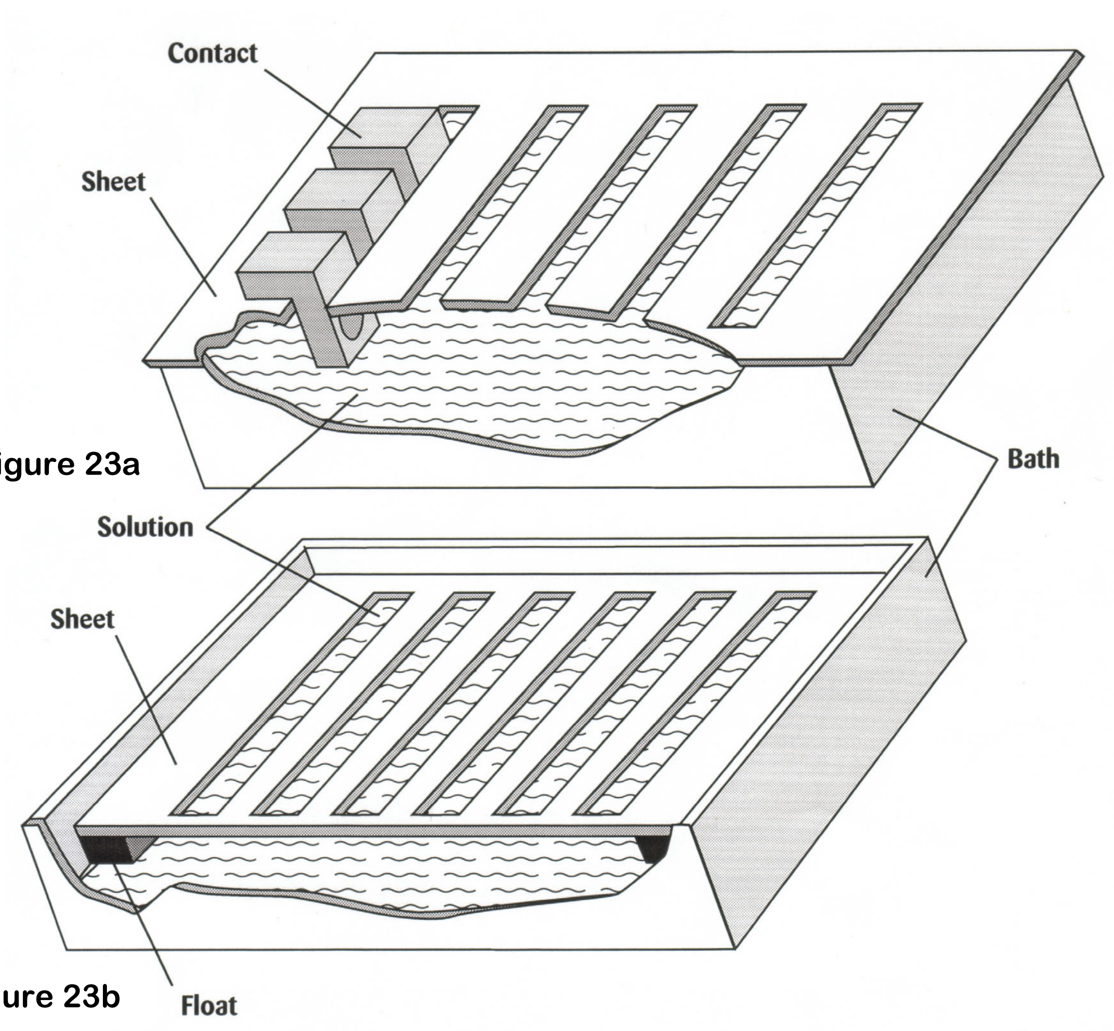

Figure 23a

Figure 23b

The TRIZ solution was to float the lid on the silver bath itself as shown in *figure 23b*, so that the contacts maintained a fixed distance from the silver solution even though its level fluctuated.

17. Nickel Production Example

To pull together some of the preceding ideas we present one more example:

Refined and processed nickel is typically supplied in the form of small granules or pellets. To produce these, drops of molten nickel are poured into water from a substantial height. As they fall toward the water, the drops are cooled by the air and solidify, while remaining hot. Upon entering the water they are cooled further and become the final granular product.

As designed, this system worked well. In an attempt to increase production, however, the rate at which the drops were released into the cooling tower was increased, resulting in a harmful side effect: the increased density of the drops heated the air, reducing the heat transfer from the drops. As a result, the drops entered the water at a higher temperature, causing thermal shock, damage, and disintegration of many of the granules. This in turn led to the production of a substantial amount of nickel powder, which then had to be recovered.

17.1 Applying the SUH Approach. Solution 1

Applying the SUH approach to this problem, we produce the model shown in *figure 24*. The basic system, S_0, in which drops of nickel fall through air into water, produces the useful outcome of the desired nickel granules. When the system is modified by increasing the rate of nickel feed (shown as S_1), the useful outcome of high production rate is added.

There is now a chain of harmful effects, however. The drops are overcooled by the water, resulting in thermal shock, disintegration of the granules, and production of nickel powder.

To eliminate the powder, system S_2 was added, which recovered the nickel powder and fed it into the furnace for remelting. This produced the harmful effect H_4, however, as a large fraction of the powder burned upon entering the furnace and went up the stack.

To counteract this burning, a system (S_3) was proposed whereby the powder was placed into a box before feeding it into the furnace. This also had an undesirable side effect: the material of which the box was constructed would pollute the melt.

At this point TRIZ was applied. Having identified H_5 as an undesired action of the kind "pollution," the specialized TRIZ operator *masking a substance* was applied. This operator suggests combining the powder with a substance which, after performing its function, becomes indistinct from the material already present in the furnace. Three possibilities then became immediately apparent: nickel, ore and slag. Producing boxes from nickel was considered too costly. The powder could be mixed with the incoming ore, but it was not certain if this would prevent it from burning. However, mixing the powder with slag and then solidifying it and feeding it back into the furnace proved to be an acceptable solution.

Nickel Production Example

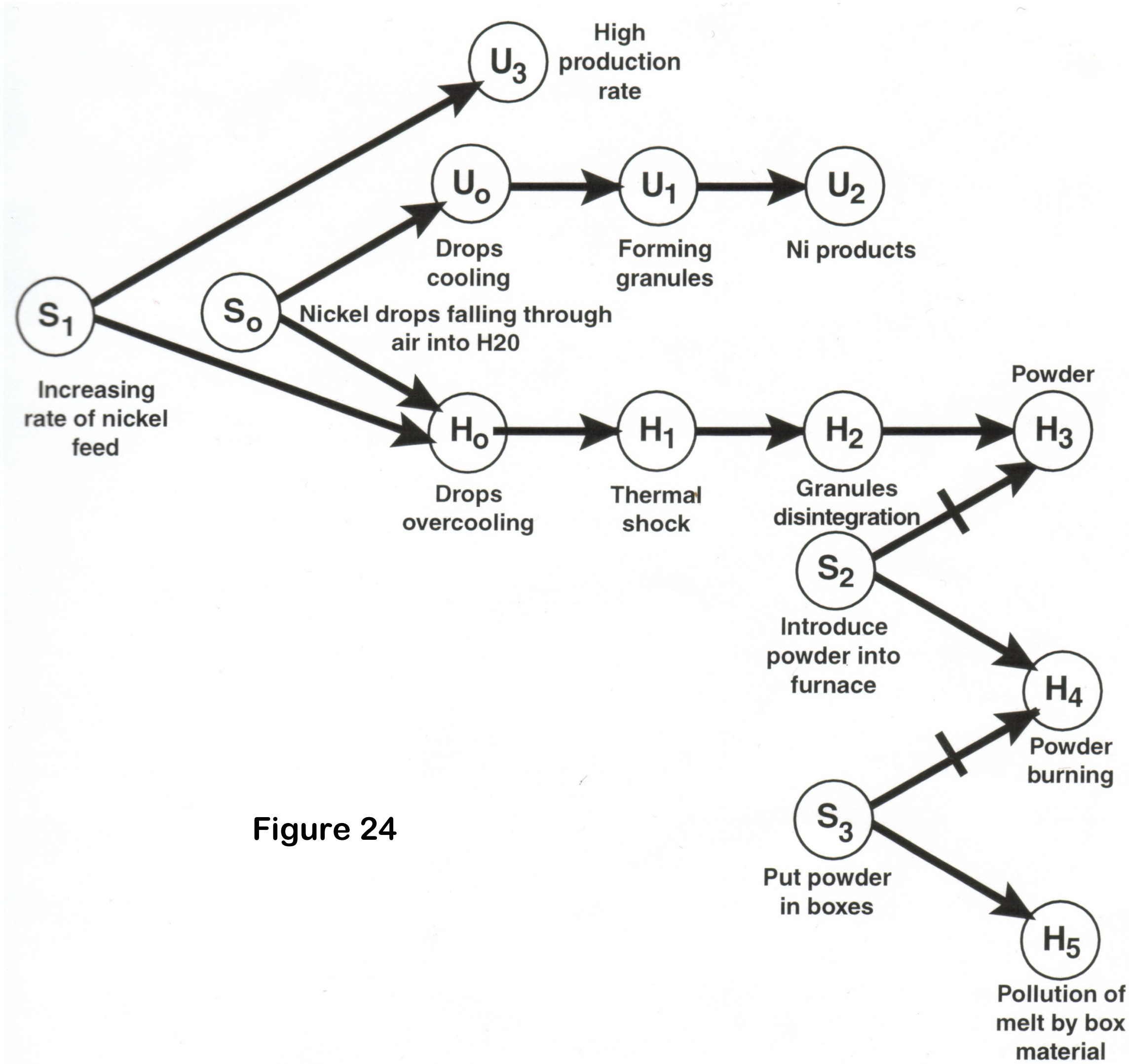

Figure 24

17.2 Solution 2

Although finding a way to reintroduce the powder was a good solution, a better solution would be to eliminate the production of powder, H_3, in the first place. For this purpose, the operator *drawing off the undesired action*, *(listed in Table 3)* was used. Continuing down the abstraction ladder, this operator contains the sub-operator *introduce a mediating substance*, which in turn contains the sub-operator *application of void or foam*. This suggests the solution that was finally implemented, namely, to add soap to the water and bubble air through the mixture. These, together with the churning of the falling drops, produced a foam layer which cooled the drops before they entered the water, thus reducing thermal shock sufficiently to eliminate the production of powder.

18. Conclusion

We began this book by stating that our purpose was to present a point of view from which at least a large portion of the TRIZ theory could be apprehended by an English-speaking audience. We believe we have accomplished this, but we must hasten to add that, as large a portion as this is, it is only a small part of what TRIZ has become. TRIZ is a system for creative thought which has grown to include applications to management sciences, education, business, marketing, social and political issues, pure science, biology, etc. It includes methods for forecasting the future development of technologies, building patent fences, uncovering the causes of past disasters as well as identifying and eliminating potential causes for would-be disasters. We hope we have given the reader enough to convey the enormous value of TRIZ, and we invite him/her to look further.

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APPENDIX 1 — 40 Inventive Principles

1. Segmentation

a. Divide an object into independent parts.

b. Make an object sectional.

c. Increase a degree of an object's segmentation.

Examples:

1. Sectional furniture, modular computer components, folding wooden ruler.
2. Garden hoses can be joined together to form any length needed.

2. Extraction

a. Extract (remove or separate) a "disturbing" part or property, from an object, or

b. Extract the only necessary part or property.

Example:

To scare birds from the airport, reproduce the sound known to excite birds using a tape recorder. The sound was separated from birds.

3. Local Quality

a. Transition from a homogeneous structure of an object or outside environment (outside action) to a heterogeneous structure.

b. Have different parts of the object carry out different functions.

c. Place each part of the object under conditions most favorable for its operation.

Examples:

1. To combat dust in coal mines, a fine mist of water in a conical form is applied to working parts of the drilling and loading machinery. The smaller the droplets, the greater an effect in combating dust, but fine mist hinders the work. The solution is to develop a layer of coarse mist around the cone of fine mist.
2. A pencil and an eraser in one unit.

4. Asymmetry

a. Replace a symmetrical form with an asymmetrical form of the object.

b. If an object is already asymmetrical, increase the degree of asymmetry.

Examples:

1. One side of the tire is stronger than the other to withstand impact with the curb.

2. While discharging wet sand through a symmetrical funnel the sand forms an arch above the opening, causing irregular flow. A funnel of asymmetrical shape completely eliminates the arching effect.

5. Combining

a. Combine in space homogeneous objects or objects destined for contiguous operations.

b. Combine in time homogeneous or contiguous operations.

Example:

The working element of a rotary excavator has special steam nozzles to defrost and soften the frozen ground in a single step.

6. Universality

a. Have the object perform multiple functions, thereby eliminating the need for some other objects.

Examples:

1. Sofa which converts from a sofa in the daytime to a bed at night.
2. Minivan seat which adjusts to accommodate seating, sleeping or carrying cargo.

7. Nesting

a. Contain the object inside another which in turn is placed inside a third object.

b. An object passes through a cavity of another object.

Examples:

1. Telescoping antenna.
2. Stacking chairs (on top of each other for storage).
3. Mechanical pencil with lead stored inside.

8. Counterweight

a. Compensate for the object's weight by joining with another object that has a lifting force.

b. Compensate for the weight of an object by interaction with an environment providing aerodynamic or hydrodynamic forces.

Examples:

1. Boat with hydrofoils.
2. A rear wing in racing cars to increase the pressure from the car to the ground.

9. Prior counter-action

a. If it is necessary to carry out some action, consider a counter-action in advance.

b. If by the problem statement an object has to have a tension, provide anti-tension in advance.

Examples:

1. Reinforced concrete column or floor.
2. Reinforced shaft – in order to make a shaft is stronger the shaft made out of several pipes that have been previously twisted to a calculated angle.

10. Prior action

a. Carry out the required action in advance in full, or at least in part.

b. Arrange objects so they can go into action without time loss waiting for action (and from the most convenient position).

Examples:

1. Utility knife blade made with a groove allowing the dull part of the blade to be broken off, restoring sharpness.
2. Rubber cement in a bottle is difficult to apply neatly and uniformly. Instead, it is formed into a tape so that the proper amount can be more easily applied.

11. Cushion in advance

Compensate for the relatively low reliability of an object by countermeasures taken in advance.

Example:

To prevent shoplifting the owner of the store attaches a special tag containing a magnetized plate. In order for the customer to carry out the merchandise, the plate is demagnetized by the cashier.

12. Equipotentiality

Change the condition of work so that an object need not be raised or lowered.

Example:

Automobile engine oil is changed by workers in a pit (so that expensive lifting equipment is not needed).

13. Inversion

a. Instead of an action dictated by the specifications of the problem, implement an opposite action.

b. Make a moving part of the object or the outside environment immovable and the non moving part moveable.

c. Turning the object upside down.

Example:

Abrasively cleaning parts by vibrating the parts instead of the abrasive.

14. Spheroidality

a. Replace linear parts or flat surfaces with curved ones, cubical shapes with spherical shapes.

b. Use rollers, balls, spirals.

c. Replace a linear motion with rotating movement, utilize a centrifugal force.

Example:

Computer mouse utilizes ball construction to transfer linear two axis motion of into vector.

15. Dynamicity

a. Make characteristics of an object, or outside environment automatically adjust for optimal performance at each stage of operation.

b. Divide an object into elements able to change position relative to each other.

c. If an object is immovable, make it movable or interchangeable.

Examples:

1. A flashlight with a flexible gooseneck between the body and the lamp head.
2. A transport vessel with the body of a cylindrical shape. To reduce the draft of a vessel under full load the body, comprised of two hinged half-cylindrical parts that can be opened.

16. Partial or overdone action

a. If it is difficult to obtain 100% of a desired effect, achieve somewhat more or less to greatly simplify the problem.

Examples:

1. A cylinder is painted by dipping into paint, but contains more paint than desired. Excess paint is then removed by rapidly rotating the cylinder.
2. To obtain uniform discharge of a metallic powder from a bin, the hopper has a special internal funnel which is continually overfilled to provide nearly constant pressure.

17. Moving to a new dimension

a. Remove problems in moving an object in a line are by two dimensional movement (along a plane). Similarly, problems with moving an object in a plane are removed if the object can be changed to allow three-dimensional space.

b. Use a multilayer assembly of objects instead of a single layer.

c. Incline the object or turning it "on its side."

d. Project images onto neighboring areas or onto the reverse side of the object.

Example:

A greenhouse which has a concave reflector on the northern part of the house to improve illumination of that part of the house by reflecting the sun light during the day.

18. Mechanical vibration

a. Set an object into oscillation.

b. If oscillation exists, increase its frequency, even as far as ultrasonic.

c. Use the frequency of resonance.

d. Instead of mechanical vibrations, use piezovibrators.

e. Use ultrasonic vibrations in conjunction with an electromagnetic field.

Examples:

1. To remove a cast from the body without skin injury, a conventional hand saw was replaced with a vibrating knife.
2. Vibrate a casting mold while it is being filled to improve flow and structural properties.

19. Periodic action

a. Replace a continuous action with a periodic one, or impulse.

b. If an action is already periodic, change its frequency.

c. Use pauses between impulses to provide additional action.

Examples:

1. An impact wrench loosens corroded nuts using impulses rather than a continuous force.
2. A warning lamp flashes so that it is even more noticeable than if continuously lit.

20. Continuity of useful action

a. Carry out an action without a break – all parts of an object should be constantly operating at full capacity.

b. Remove an idle and intermediate motions.

Example:

A drill with cutting edges which permit cutting process in forward and reverse directions.

21. Rushing through

a. Perform harmful or hazardous operations at very high speed.

Example:

A cutter for thin wall plastic tubes prevents tube deformation during cutting by running at a very high speed (cuts before the tube has a chance to deform).

22. Convert harm into benefit

a. Utilize a harmful factors or harmful effect of an environment to obtain a positive effect.

b. Remove a harmful factor by adding it with another harmful factor.

c. Increase the amount of harmful action until it ceases to be harmful.

Examples:

1. Sand or gravel freezes solid when transported through cold climates. Over freezing (using liquid nitrogen) embrittles the ice, permitting pouring.
2. When using high frequency current to heat metal, only the outer layer was heated. This negative effect was later used for surface heat treating.

23. Feedback

a. Introduce feedback.

b. If feedback already exists, reverse it.

Examples:

1. Water pressure from a well is maintained by sensing output pressure and turning on a pump if pressure is too low.
2. Ice and water are measured separately but must be combined to an exact total weight. Because it is difficult to precisely dispense the ice, it is measured first and the weight is fed to the water control, which precisely dispenses the needed amount.
3. Noise canceling devices sample noise signals, phase shift them and feed them back to cancel the effect of the noise source.

24. Mediator

a. Use an intermediary object to transfer or carry out an action.

b. Temporarily connect an object to another one that is easy to remove.

Example:

To reduce energy loss when applying current to a liquid metal, cooled electrodes and intermediate liquid metal with a lower melting temperature used.

25. Self-service

a. Make the object service itself and carry out supplementary and repair operations.

b. Make use out of waste of material and energy.

Examples:

1. To distribute an abrasive material evenly on the face of crushing rollers and to prevent feeder from wearing, its surface made out of the same abrasive material.
2. In an electric welding gun, the rod is advanced by a special device. To simplify the system, the rod is advanced by a solenoid controlled by the welding current.

26. Copying

a. Use simple and inexpensive copy instead of an object which is complex, expensive, fragile or inconvenient to operate.

b. Replace an object or a system of objects by their optical copy, optical image. A scale can be use to reduce or enlarge the image.

c. If visible optical copies are used, replace them with infrared or ultraviolet copies.

Example:

The height of tall objects can be determined by measuring their shadows.

27. Use an inexpensive short-lived object instead of an expensive, durable one

Replace an expensive object by a collection of inexpensive ones, compromising other properties (longevity, for instance).

Examples:

1. Disposable diapers.
2. A single usage mousetrap consisting of a plastic tube with bait. A mouse enters the trap through a cone-shaped opening; the walls of the opening are angled and do not allow the mouse to get out.

28. Replacement of a mechanical system

a. Replace a mechanical system by an optical, acoustical or odor system.

b. Use an electrical, magnetic or electromagnetic field for interaction with the object.

c. Replace fields:

1. Stationary fields with moving fields
2. Fixed to those changing in time
3. From random to structured

d. Use a field in conjunction with ferromagnetic particles.

Example:

To increase a bond of metal coating to a thermoplastic material the process is carried out inside an electromagnetic field to apply force to the metal.

29. Use a pneumatic or hydraulic construction

Replace solid parts of an object by gas or liquid – these parts can use air or water for inflation or use air or hydrostatic cushions.

Examples:

1. To increase the draft of an industrial chimney a spiral pipe with nozzles was installed. When the air starts flowing through the nozzles, it creates an air like wall, reducing drag.
2. For shipping fragile products air bubble envelopes or foam like materials are used.

30. Flexible film or thin membranes

a. Replace customary constructions with flexible membranes and thin film.

b. Isolate an object from outside environment with thin film or fine membranes.

Example:

To prevent the loss of water evaporating from the leaves of plants, polyethylene spray was applied. After a while the polyethylene hardened and plant growth much improved because the polyethylene film passes oxygen better than water vapor.

31. Use of porous material

a. Make an object porous or use additional porous elements (inserts, covers etc.).

b. If an object is already porous fill the pores in advance with some substance.

Example:

To avoid pumping coolant to a machine, some of the parts of the machine are filled with porous material (porous powdered steel) soaked in coolant liquid which evaporates when the machine is working, providing short-term uniform cooling.

32. Changing the color

a. Change the color of an object or its surroundings.

b. Change the degree of translucency of an object or surroundings.

c. Use colored additives to observe objects or processes which are difficult to see.

d. If such additives are already used, employ luminescent traces or tracer elements.

Examples:

1. A transparent bandage enabling a wound to be inspected without the dressing being removed.
2. In steel mills a water curtain was designed to protect workers from overheating. But this curtain only protects from infrared rays, so the bright light from the melted

steel can easy get through the curtain. A coloring was added to the water to create a filter effect while remaining transparent.

33. Homogeneity

Make objects interacting with a primary object out of the same material or material that is close to it in behavior.

Example:

The surface of a feeder for abrasive grain is made of the same material that runs through the feeder – allowing to have a continuous restoration of the surface without being worn out.

34. Rejecting and regenerating parts

a. After it has completed its function or become useless reject or modify (e.g., discard, dissolve or evaporate) an element of an object.

b. Restore directly any used up parts of an object.

Examples:

1. Bullet casings are ejected after the gun fires.
2. Rocket boosters separate after serving their function.

35. Transformation of physical and chemical states of an object

Change an aggregate state of an object, concentration of density, the degree of flexibility, the temperature.

Example:

In a system for brittle friable materials, the surface of the spiral feedscrew was made from an elastic material with two spiral springs. In order to control the process the pitch of the screw could be changed remotely.

36. Phase transition

Implement an effect developed during the phase transition of a substance. For instance, during the change of volume, liberation or absorption of heat.

Example:

To control the expansion of ribbed pipes, they are filled with water and cooled to a freezing temperature.

37. Thermal expansion

a. Use expansion or contraction of material by heat.

b. Use various materials with different coefficients of heat expansion.

Example:

To control the opening of roof windows in a greenhouse, bimetallic plates are connected to the windows. With a change of temperature, the plates bend and make the window open or close.

38. Use strong oxidizers

a. Replace normal air with enriched air.

b. Replace enriched air with oxygen.

c. Treat in air or in oxygen with ionizing radiation.

d. Use ionized oxygen.

Example:

To obtain more heat from a torch, oxygen is fed to the torch instead of atmospheric air.

39. Inert environment

a. Replace the normal environment with an inert one.

b. Carry out the process in a vacuum.

Example:

To prevent cotton from catching fire in a warehouse, it is treated with inert gas during transport to the storage area.

40. Composite materials

a. Replace a homogeneous material with a composite one.

Example:

Military aircraft wings are made of composites of plastics and carbon fibers for high strength and low weight.

APPENDIX 2 — Contradiction Matrix

Undesired Result (Conflict) / Feature to Improve		1 Weight of moving object	2 Weight of stationary object	3 Length of moving object	4 Length of stationary object	5 Area of moving object	6 Area of stationary object	7 Volume of moving object	8 Volume of stationary 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 stationary 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 stationary 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 stationary 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 stationary 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, 6, 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 stationary 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, 26								
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 stationary object		19, 9, 6, 27								36, 37			27, 4, 29, 19

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

Feature to Improve \ Undesired Result (Conflict)		27 Reliability	28 Measurement accuracy	29 Manufacturing accuracy	30 Harmful factors acting on object	31 Harmful side effects	32 Manufacturability	33 Convenience of use	34 Repairability	35 Adaptability	36 Device complexity	37 Complexity of control	38 Level of automation	39 Productivity
1	Weight of moving object	3, 11, 1, 27	28, 27, 35, 26	28, 35, 26, 18	22, 21, 18, 27	22, 35, 31, 39	27, 28, 1, 36	35, 3, 2, 24	2, 27, 28, 11	29, 5, 15, 8	26, 30, 36, 34	28, 29, 26, 32	26, 35, 18, 19	35, 3, 24, 37
2	Weight of stationary object	10, 28, 8, 3	18, 26, 28	10, 1, 35, 17	2, 19, 22, 37	35, 22, 1, 39	28, 1, 9	6, 13, 1, 32	2, 27, 28, 11	19, 15, 29	1, 10, 26, 39	25, 28, 17, 15	2, 26, 35	1, 28, 15, 35
3	Length of moving object	10, 14, 29, 40	28, 32, 4	10, 28, 29, 37	1, 15, 17, 24	17, 15	1, 29, 17	15, 29, 35, 4	1, 28, 10	14, 15, 1, 16	1, 19, 26, 24	35, 1, 26, 24	17, 24, 26, 16	14, 4, 28, 29
4	Length of stationary object	15, 29, 28	32, 28, 3	2, 32, 10	1, 18		15, 17, 27	2, 25	3	1, 35	1, 26	26		30, 14, 7, 26
5	Area of moving object	29, 9	26, 28, 32, 3	2, 32	22, 33, 28, 1	17, 2, 18, 39	13, 1, 26, 24	15, 17, 13, 16	15, 13, 10, 1	15, 30	14, 1, 13	2, 36, 26, 18	14, 30, 28, 23	10, 26, 34, 2
6	Area of stationary object	32, 35, 40, 4	26, 28, 32, 3	2, 29, 18, 36	27, 2, 39, 35	22, 1, 40	40, 16	16, 4	16	15, 16	1, 18, 36	2, 35, 30, 18	23	10, 15, 17, 7
7	Volume of moving object	14, 1, 40, 11	25, 26, 28	25, 28, 2, 16	22, 21, 27, 35	17, 2, 40, 1	29, 1, 40	15, 13, 30, 12	10	15, 29	26, 1	29, 26, 4	35, 34, 16, 24	10, 6, 2, 34
8	Volume of stationary object	2, 35, 16		35, 10, 25	34, 39, 19, 27	30, 18, 35, 4	35		1		1, 31	2, 17, 26		35, 37, 10, 2
9	Speed	11, 35, 27, 28	28, 32, 1, 24	10, 28, 32, 25	1, 28, 35, 23	2, 24, 35, 21	35, 13, 8, 1	32, 28, 13, 12	34, 2, 28, 27	15, 10, 26	10, 28, 4, 34	3, 34, 27, 16	10, 18	
10	Force	3, 35, 13, 21	35, 10, 23, 24	28, 29, 37, 36	1, 35, 40, 18	13, 3, 36, 24	15, 37, 18, 1	1, 28, 3, 25	15, 1, 11	15, 17, 18, 20	26, 35, 10, 18	36, 37, 10, 19	2, 35	3, 28, 35, 37
11	Tension, pressure	10, 13, 19, 35	6, 28, 25	3, 35	22, 2, 37	2, 33, 27, 18	1, 35, 16	11	2	35	19, 1, 35	2, 36, 37	35, 24	10, 14, 35, 37
12	Shape	10, 40, 16	28, 32, 1	32, 30, 40	22, 1, 2, 35	35, 1	1, 32, 17, 28	32, 15, 26	2, 13, 1	1, 15, 29	16, 29, 1, 28	15, 13, 39	15, 1, 32	17, 26, 34, 10
13	Stability of object		13	18	35, 24, 30, 18	35, 40, 27, 39	35, 19	32, 35, 30	2, 35, 10, 16	35, 30, 34, 2	2, 35, 22, 26	35, 22, 39, 23	1, 8, 35	23, 35, 40, 3
14	Strength	11, 3	3, 27, 16	3, 27	18, 35, 37, 1	15, 35, 22, 2	11, 3, 10, 32	32, 40, 28, 2	27, 11, 3	15, 3, 32	2, 13, 28	27, 3, 15, 40	15	29, 35, 10, 14
15	Durability of moving object	11, 2, 13	3	3, 27, 16, 40	22, 15, 33, 28	21, 39, 16, 22	27, 1, 4	12, 27	29, 10, 27	1, 35, 13	10, 4, 29, 15	19, 29, 39, 35	6, 10	35, 17, 14, 19
16	Durability of stationary object	34, 27, 6, 40	10, 26, 24		17, 1, 40, 33	22	35, 10	1	1	2		25, 34, 6, 35	1	10, 20, 16, 38
17	Temperature	19, 35, 3, 10	32, 19, 24	24	22, 33, 35, 2	22, 35, 2, 24	26, 27	26, 27	4, 10, 16	2, 18, 27	2, 17, 16	3, 27, 35, 31	26, 2, 19, 16	15, 28, 35
18	Brightness		11, 15, 32	3, 32	15, 19	35, 19, 32, 39	19, 35, 28, 26	28, 26, 19	15, 17, 13, 16	15, 1, 1, 19	6, 32, 13	32, 15	2, 26, 10	2, 25, 16
19	Energy spent by moving object	19, 21, 11, 27	3, 1, 32		1, 35, 6, 27	2, 35, 6	28, 26, 30	19, 35	1, 15, 17, 28	15, 17, 13, 16	2, 29, 27, 28	35, 38	32, 2	12, 28, 35
20	Energy spent by stationary object	10, 36, 23			10, 2, 22, 37	19, 22, 18	1, 4					19, 35, 16, 25		1, 6

Feature to Improve / Undesired Result (Conflict)		1 Weight of moving object	2 Weight of stationary object	3 Length of moving object	4 Length of stationary object	5 Area of moving object	6 Area of stationary object	7 Volume of moving object	8 Volume of stationary object	9 Speed	10 Force	11 Tension, pressure	12 Shape	13 Stability of object
21	Power	8, 36, 38, 31	19, 26, 17, 27	1, 10, 35, 37		19, 38	17, 32, 13, 38	35, 6, 38	30, 6, 25	15, 35, 2	26, 2, 36, 35	22, 10, 35	29, 14, 2, 40	35, 32, 15, 31
22	Waste of energy	15, 6, 19, 28	19, 6, 18, 9	7, 2, 6, 13	6, 38, 7	15, 26, 17, 30	17, 7, 30, 18	7, 18, 23	7	16, 35, 38	36, 38			14, 2, 39, 6
23	Waste of substance	35, 6, 23, 40	35, 6, 22, 32	14, 29, 10, 39	10, 28, 24	35, 2, 10, 31	10, 18, 39, 31	1, 29, 30, 36	3, 39, 18, 31	10, 13, 28, 38	14, 15, 18, 40	3, 36, 37, 10	29, 35, 3, 5	2, 14, 30, 40
24	Loss of information	10, 24, 35	10, 35, 5	1, 26	26	30, 26	30, 16		2, 22	26, 32				
25	Waste of time	10, 20, 37, 35	10, 20, 26, 5	15, 2, 29	30, 24, 14, 5	26, 4, 5, 16	10, 35, 17, 4	2, 5, 34, 10	35, 16, 32, 18		10, 37, 36, 5	37, 36, 4	4, 10, 34, 17	35, 3, 22, 5
26	Amount of substance	35, 6, 18, 31	27, 26, 18, 35	29, 14, 35, 18		15, 14, 29	2, 18, 40, 4	15, 20, 29		35, 29, 34, 28	35, 14, 3	10, 36, 14, 3	35, 14	15, 2, 17, 40
27	Reliability	3, 8, 10, 40	3, 10, 8, 28	15, 9, 14, 4	15, 29, 28, 11	17, 10, 14, 16	32, 35, 40, 4	3, 10, 14, 24	2, 35, 24	21, 35, 11, 28	8, 28, 10, 3	10, 24, 35, 19	35, 1, 16, 11	
28	Measurement accuracy	32, 35, 26, 28,	28, 35, 25, 26	28, 26, 5, 16	32, 28, 3, 16	26, 28, 32, 3	26, 28, 32, 3	32, 13, 6		28, 13, 32, 24	32, 2	6, 28, 32	6, 28, 32	32, 35, 13
29	Manufacturing accuracy	28, 32, 13, 18	28, 35, 27, 9	10, 28, 29, 37	2, 32, 10	28, 33, 29, 32	2, 29, 18, 36	32, 28, 2	25, 10, 35	10, 28, 32	28, 19, 34, 36	3, 35	32, 30, 40	30, 18
30	Harmful factors acting on object	22, 21, 27, 39	2, 22, 13, 24	17, 1, 39, 4	1, 18	22, 1, 33, 28	27, 2, 39, 35	22, 23, 37, 35	34, 39, 19, 27	21, 22, 35, 28	13, 35, 39, 18	22, 2, 37	22, 1, 3, 35	35, 24, 30, 18
31	Harmful side effects	19, 22, 15, 39	35, 22, 1, 39	17, 15, 16, 22		17, 2, 18, 39	22, 1, 40	17, 2, 40	30, 18, 35, 4	35, 28, 3, 23	35, 28, 1, 40	2, 33, 27, 18	35, 1	35, 40, 27, 39
32	Manufacturability	28, 29, 15, 16	1, 27, 36, 13	1, 29, 13, 17	15, 17, 27	13, 1, 26, 12	16, 40	13, 29, 1, 40	35	35, 13, 8, 1	35, 12	35, 19, 1, 37	1, 28, 13, 27	11, 13, 1
33	Convenience of use	25, 2, 13, 15	6, 13, 1, 25	1, 17, 13, 12		1, 17, 13, 16	18, 16, 15, 39	1, 16, 35, 15	4, 18, 39, 31	18, 13, 34	28, 13, 35	2, 32, 12	15, 34, 29, 28	32, 35, 30
34	Repairability	2, 27, 35, 11	2, 27, 35, 11	1, 28, 10, 25	3, 18, 31	15, 13, 32	16, 25	25, 2, 35, 11	1	34, 9	1, 11, 10	13	1, 13, 2, 4	2, 35
35	Adaptability	1, 6, 15, 8	19, 15, 29, 16	35, 1, 29, 2	1, 35, 16	35, 30, 29, 7	15, 16	15, 35, 29		35, 10, 14	15, 17, 20	35, 16	15, 37, 1, 8	35, 30, 14
36	Device complexity	26, 30, 34, 36	2, 36, 35, 39	1, 19, 26, 24	26	14, 1, 13, 16	6, 36	34, 25, 6	1, 16	34, 10, 28	26, 16	19, 1, 35	29, 13, 28, 15	2, 22, 17, 19
37	Complexity of control	27, 26, 28, 13	6, 13, 28, 1	16, 17, 26, 24	26	2, 13, 15, 17	2, 39, 30, 16	29, 1, 4, 16	2, 18, 26, 31	3, 4, 16, 35	36, 28, 40, 19	35, 36, 37, 32	27, 13, 1, 39	11, 22, 39, 30
38	Level of automation	28, 26, 18, 35	28, 26, 35, 10	14, 13, 17, 28	23	17, 14, 13		35, 13, 16		28, 10	2, 35	13, 35	15, 32, 1, 13	18, 1
39	Productivity	35, 26, 24, 37	28, 27, 15, 3	18, 4, 28, 38	30, 7, 14, 26	10, 26, 34, 31	10, 35, 17, 7	2, 6, 34, 10	35, 37, 10, 2		28, 15, 10, 36	10, 37, 14	14, 10, 34, 40	35, 3, 22, 39

#	Feature to Improve \ Undesired Result (Conflict)	14 Strength	15 Durability of moving object	16 Durability of stationary object	17 Temperature	18 Brightness	19 Energy spent by moving object	20 Energy spent by stationary object	21 Power	22 Waste of energy	23 Waste of substance	24 Loss of information	25 Waste of time	26 Amount of substance
21	Power	26, 10, 28	19, 35, 10, 38	16	2, 14, 17, 25	16, 6, 19	16, 6, 19, 37			10, 35, 38	28, 27, 18, 38	10, 19	35, 20, 10, 6	4, 34, 19
22	Waste of energy	26			19, 38, 7	1, 13, 32, 15			3, 38		35, 27, 2, 37	19, 10	10, 18, 32, 7	7, 18, 25
23	Waste of substance	35, 28, 31, 40	28, 27, 3, 18	27, 16, 18, 38	21, 36, 39, 31	1, 6, 13	35, 18, 24, 5	28, 27, 12, 31	28, 27, 18, 38	35, 27, 2, 31			15, 18, 35, 10	6, 3, 10, 24
24	Loss of information		10	10		19			10, 19	10, 19			24, 26, 28, 32	24, 28, 35
25	Waste of time	29, 3, 28, 18	20, 10, 28, 18	28, 20, 10, 16	35, 29, 21, 18	1, 19, 26, 17	35, 38, 19, 18	1	35, 20, 10, 6	10, 5, 18, 32	35, 18, 10, 39	24, 26, 28, 32		35, 38, 18, 16
26	Amount of substance	14, 35, 34, 10	3, 35, 10, 40	3, 35, 31	3, 17, 39		34, 29, 16, 18	3, 35, 31	35	7, 18, 25	6, 3, 10, 24	24, 28, 35	35, 38, 18, 16	
27	Reliability	11, 28	2, 35, 3, 25	34, 27, 6, 40	3, 35, 10	11, 32, 13	21, 11, 27, 19	36, 23	21, 11, 26, 31	10, 11, 35	10, 35, 29, 39	10, 28	10, 30, 4	21, 28, 40, 3
28	Measurement accuracy	28, 6, 32	28, 6, 32	10, 26, 24	6, 19, 28, 24	6, 1, 32	3, 6, 32		3, 6, 32	26, 32, 27	10, 16, 31, 28		24, 34, 28, 32	2, 6, 32
29	Manufacturing accuracy	3, 27	3, 27, 40		19, 26	3, 32	32, 2		32, 2	13, 32, 2	35, 31, 10, 24		32, 26, 28, 18	32, 30
30	Harmful factors acting on object	18, 35, 37, 1	22, 15, 33, 28	17, 1, 40, 33	22, 33, 35, 2	1, 19, 32, 13	1, 24, 6, 27	10, 2, 22, 37	19, 22, 31, 2	21, 22, 35, 2	33, 22, 19, 40	22, 10, 2	35, 18, 34	35, 33, 29, 31
31	Harmful side effects	15, 35, 22, 2	15, 22, 33, 31	21, 39, 16, 22	22, 35, 2, 24	19, 24, 39, 32	2, 35, 6	19, 22, 18	2, 35, 18	21, 35, 2, 22	10, 1, 34	10, 21, 29	1, 22	3, 24, 39, 1
32	Manufacturability	1, 3 10, 32	27, 1, 4	35, 16	27, 26, 18	28, 24, 27, 1	28, 26, 27, 1	1, 4	27, 1, 12, 24	19, 35	15, 34, 33	32, 24, 18, 16	35, 28, 34, 4	35, 23, 1, 24
33	Convenience of use	32, 40, 3, 28	29, 3, 8, 25	1, 16, 25	26, 27, 13	13, 17, 1, 24	1, 13, 24		35, 34, 2, 10	2, 19, 13	28, 32, 2, 24	4, 10, 27, 22	4, 28, 10, 34	12, 35
34	Repairability	11, 1 2, 9	11, 29, 28, 27	1	4, 10	15, 1, 13	15, 1, 28, 16		15, 10, 32, 2	15, 1, 32, 19	2, 35, 34, 27		32, 1, 10, 25	2, 28, 10, 25
35	Adaptability	35, 3, 32, 6	13, 1, 35	2, 16	27, 2, 3, 35	6, 22, 26, 1	19, 35, 29, 13		19, 1, 29	18, 15, 1	15, 10, 2, 13		35, 28	3, 35, 15
36	Device complexity	2, 13, 28	10, 4, 28, 15		2, 17, 13	24, 17, 13	27, 2, 29, 28		20, 19, 30, 34	10, 35, 13, 2	35, 10, 28, 29		6, 29	13, 3, 27, 10
37	Complexity of control	27, 3, 15, 28	19, 29, 39, 25	25, 24, 6, 35	3, 27, 35, 16	2, 24, 26	35, 38	19, 35, 16	19, 1, 16, 10	35, 3, 15, 19	1, 13, 10, 24	35, 33, 27, 22	18, 28, 32, 9	3, 27, 29, 18
38	Level of automation	25, 13	6, 9		26, 2, 19	8, 32, 19	2, 32, 13		28, 2, 27	23, 28	35, 10, 18, 5	35, 33	24, 28, 35, 30	35, 13
39	Productivity	29, 28, 10, 18	35, 10, 2, 18	20, 10, 16, 38	35, 21, 28, 10	26, 17, 19, 1	35, 10, 38, 19	1	35, 20, 10	28, 10, 29, 35	28, 10, 35, 23	13, 15, 23		35, 38

Feature to Improve / Undesired Result (Conflict)		27 Reliability	28 Measurement accuracy	29 Manufacturing accuracy	30 Harmful factors acting on object	31 Harmful side effects	32 Manufacturability	33 Convenience of use	34 Repairability	35 Adaptability	36 Device complexity	37 Complexity of control	38 Level of automation	39 Productivity
21	Power	19, 24, 26, 31	32, 15, 2	32, 2	19, 22, 31, 2	2, 35, 18	26, 10, 34	26, 35, 10	35, 2, 10, 34	19, 17, 34	20, 19, 30, 34	19, 35, 16	28, 2, 17	28, 35, 34
22	Waste of energy	11, 10, 35	32		21, 22, 35, 2	21, 35, 2, 22		35, 22, 1	2, 19		7, 23	35, 3, 15, 23	2	28, 10, 29, 35
23	Waste of substance	10, 29, 39, 35	16, 34, 31, 28	35, 10, 24, 31	33, 22, 30, 40	10, 1, 34, 29	15, 34, 33	32, 28, 2, 24	2, 35, 34, 27	15, 10, 2	35, 10, 28, 24	35, 18, 10, 13	35, 10, 18	28, 35, 10, 23
24	Loss of information	10, 28, 23			22, 10, 1	10, 21, 22	32	27, 22				35, 33	35	13, 23, 15
25	Waste of time	10, 30, 4	24, 34, 28, 32	24, 26, 28, 18	35, 18, 34	35, 22, 18, 39	35, 28, 34, 4	4, 28, 10, 34	32, 1, 10	35, 28	6, 29	18, 28, 32, 10	24, 28, 35, 30	
26	Amount of substance	18, 3, 28, 40	13, 2, 28	33, 30	35, 33, 29, 31	3, 35, 40, 39	29, 1, 35, 27	35, 29, 25, 10	2, 32, 10, 25	15, 3, 29	3, 13, 27, 10	3, 27, 29, 18	8, 35	13, 29, 3, 27
27	Reliability		32, 3, 11, 23	11, 32, 1	27, 35, 2, 40	35, 2, 40, 26		27, 17, 40	1, 11	13, 35, 8, 24	13, 35, 1	27, 40, 28	11, 13, 27	1, 35, 29, 38
28	Measurement accuracy	5, 11, 1, 23			28, 24, 22, 26	3, 33, 39, 10	6, 35, 25, 18	1, 13, 17, 34	1, 32, 13, 11	13, 35, 2	27, 35, 10, 34	26, 24, 32, 28	28, 2, 10, 34	10, 34, 28, 32
29	Manufacturing accuracy	11, 32, 1			26, 28, 10, 36	4, 17, 34, 26		1, 32, 35, 23	25, 10		26, 2, 18		26, 28, 18, 23	10, 18, 32, 39
30	Harmful factors acting on object	27, 24, 2, 40	28, 33, 23, 26	26, 28, 10, 18			24, 35, 2	2, 25, 28, 39	35, 10, 2	35, 11, 22, 31	22, 19, 29, 40	22, 19, 29, 40	33, 3, 34	22, 35, 13, 24
31	Harmful side effects	24, 2, 40, 39	3, 33, 26	4, 17, 34, 26							19, 1, 31	2, 21, 27, 1	2	22, 35, 18, 39
32	Manufacturability		1, 35, 12, 18		24, 2			2, 5, 13, 16	35, 1, 11, 9	2, 13, 15	27, 26, 1	6, 28, 11, 1	8, 28, 1	35, 1, 10, 28
33	Convenience of use	17, 27, 8, 40	25, 13, 2, 34	1, 32, 35, 23	2, 25, 28, 39		2, 5, 12		12, 26, 1, 32	15, 34, 1, 16	32, 26, 12, 17		1, 34, 12, 3	15, 1, 28
34	Repairability	11, 10, 1, 16	10, 2, 13	25, 10	35, 10, 2, 16		1, 35, 11, 10	1, 12, 26, 15		7, 1, 4, 16	35, 1, 13, 11		34, 35, 7, 13	1, 32, 10
35	Adaptability	35, 13, 8, 24	35, 5, 1, 10		35, 11, 32, 31		1, 13, 31	15, 34, 1, 16	1, 16, 7, 4		15, 29, 37, 28	1	27, 34, 35	35, 28, 6, 37
36	Device complexity	13, 35, 1	2, 26, 10, 34	26, 24, 32	22, 19, 29, 40	19, 1	27, 26, 1, 13	27, 9, 26, 24	1, 13	29, 15, 28, 37		15, 10, 37, 28	15, 1, 24	12, 17, 28
37	Complexity of control	27, 40, 28, 8	26, 24, 32, 28		22, 19, 29, 28	2, 21	5, 28, 11, 29	2, 5	12, 26	1, 15	15, 10, 37, 28		34, 21	35, 18
38	Level of automation	11, 27, 32	28, 26, 10, 34	28, 26, 18, 23	2, 33	2	1, 26, 13	1, 12, 34, 3	1, 35, 13	27, 4, 1, 35	15, 24, 10	34, 27, 25		5, 12, 35, 26
39	Productivity	1, 35, 10, 38	1, 10, 34, 28	18, 10, 32, 1	22, 35, 13, 24	32, 22, 18, 39	35, 28, 2, 24	1, 28, 7, 19	1, 32, 10, 25	1, 35, 28, 37	12, 17, 28, 24	35, 18, 27, 2	5, 12, 35, 26	

About the Author

Stan Kaplan is one of the early practitioners of the discipline now known as Quantitative Risk Assessment (QRA), and a major contributor to its theory, language, philosophy and methodology. His ideas and methods are widely used in the international risk and reliability community, and in regulatory agencies worldwide. In 1996, he received the Society for Risk Assessment's Distinguished Achievement Award.

Dr. Kaplan's main focus in QRA has been the handling of uncertainty -- how to quantify and express it. He uses an "evidence-based" approach, which strives to "let the evidence speak, as opposed to the personalities, positions, opinions, politics and wishful thinking involved." He points out that this approach "brings about clarity, communication, decision, and action where before there was confusion, conflict, waste, delay, and litigation. In other words, it creates order out of chaos."

The evidence-based approach is made possible by a mathematical principle called Bayes Theorem, which Dr. Kaplan describes as "not only the fundamental law of logical inference, but actually the very definition of logic. It is what we mean by logical, rational thinking." He is a founder and chairman of Bayesian Systems, Inc., a Washington, D.C.-based company that develops diagnostic, decision, simulation, and business management software and applications based on the Bayes Theorem.

Stan is one of the first American scientists to become interested in the Russian theory of inventive thinking, TRIZ. In addition to its evident practical value, what attracted him to this theory was the thought that "just as the structure of logical thinking is the same whatever we're thinking about, might it also be true that the structure of creative thinking is the same, whether one is thinking about engineering inventions, business strategies, political and social organization, pure science, or even artistic expression? And, if so, could this structure be identified, abstracted, and taught to people of varied backgrounds and ages, including children?"

This thought drove him to try to understand "what makes TRIZ work?" *An Introduction to TRIZ* is the result. Ideation International Inc. hope you enjoy it, profit from it, and come back for more.