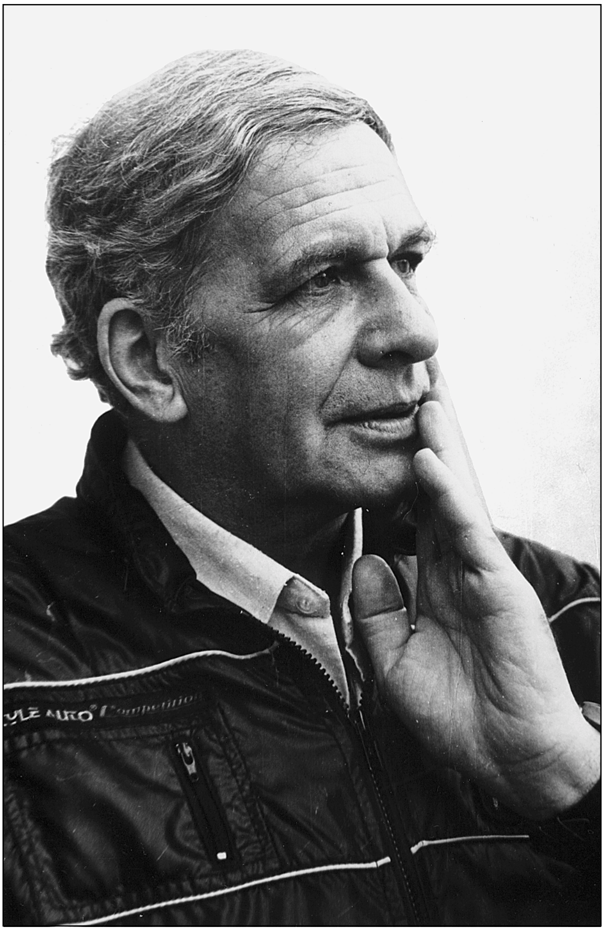
The Innovation **Algorithm**

TRIZ, Systematic Innovation and Technical Creativity



Genrich Saulovich Altshuller
October 15,1926 to September 24, 1998

"A person accupied with creativity cannot be a bad person.
He has no interest in being a bad person —it only consumes valuable time.
I saw this in the Gulag Camp. . . ."

The Innovation **Algorithm**

TRIZ, Systematic Innovation and Technical Creativity

By Genrich Altshuller

Translated, edited and annotated by
Lev Shulyak and Steven Rodman

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Preface: by Way of Introduction

There have been many milestones in the development and spread of TRIZ since we published our last translation, *40 Principles*, early in 1998. But they all pale beside one event:

> On September 24, 1998, Genrich Saulovich Altshuller, after a prolonged illness, passed away.

This news shocked everyone who knew him personally, and knew of him through his work. We take some heart in knowing that the Master got to see the emergence of his brainchild from the Russian "underground" into the seeds of a world-wide phenomenon. Our first Altshuller translation, *And Suddenly the Inventor Appeared,* in less than five years, has been translated into Spanish, Japanese, Chinese and Korean. It has been reprinted around the world, and is about to enter its fourth printing in America. In the meantime, knowledge of TRIZ has spread throughout the world, and the word "TRIZ" itself has become synonymous with contemporary innovation. And, significantly, the Altshuller Institute for TRIZ Studies is now a reality —something that greatly pleased its namesake.

Today, thousands of people are learning TRIZ, opening many new avenues for application to all areas of human activity. Besides its traditional technological use, TRIZ is entering management, marketing, art, education, psychology, and other diverse fields. As it grows, TRIZ can provide unprecedented opportunities to solve the problems most threatening to our species and our planet.

Thankfully, the founder of this phenomenal science lived to see these results of his heroic life's effort. We are confident that someday Genrich Altshuller's name will be carved among those of all the great individuals who shaped human destiny.

* * *

As the story of TRIZ continues to spread, Western readers are demanding more of Altshuller's original writings, particularly his fundamental texts created during that period when TRIZ philosophy began taking shape as a science. In response, we have committed the Technical Innovation Center to continue translating and publishing as much of his work as possible.

The book you hold in your hands, *The Innovation Algorithm,* is a landmark TRIZ text. First published in 1969, a second highly-reworked edition followed in 1973. With this book Altshuller lays-out the foundation of TRIZ theory and methodology, and walks the reader through ARIZ, the carefully crafted algorithm for realizing TRIZ's immense problem-solving powers.

While translating this edition, we were fascinated —and astonished — by the depth and philosophical foundation of Altshuller's work. Thirty-five years after its first appearance, his concept of technical creativity has not only continued to be applicable, but has become a more powerful tool for the rapid and efficient solving of technical problems. This proves the strength of the foundation Altshuller constructed with ARIZ in this book.

The Innovation Algorithm is divided into three sections. In the first, "Technology of Creativity," Altshuller analyzes different existing methods of technical creativity along with their supporting philosophies. He concludes that humanity needs new, more effective tools and guidance for innovation. He proposes that, since people can be trained to become doctors or musicians, they can also be trained to be innovative. Analyzing huge quantities of available data, Altshuller determines that there are fundamental, typical tools and principles that everyone can learn to assist them in creativity and innovation. With these initial skill-sets, humanity can achieve increasing innovative abilities. The first section ends with his vision of the Ideal System, and the types of contradictions that always arise blocking the achievement of its Ideal Final Result. The key is to learn how to overcome these typical, ubiquitous road blocks.

In the second section, "Dialectics of Invention," Altshuller provides us with that key —a new approach to solving inventive problems —called ARIZ (the Russian acronym for, 'Algorithm of Inventive Problem Solving'). This step-by-step process provides precise problem definitions while guiding the user towards an ideal solution concept. In addition, Altshuller explains the 40 Principles that can resolve many technical contradictions without compromise.

The last part of the book, "Man and Algorithm," describes the main obstacles to creativity —psychological barriers —and how to overcome them through cultivating "TRIZ mind"—a higher creative consciousness.

This, in our opinion, all adds up to a book which is a scientific marvel of the 20th Century.

◆

Translation of the text from Altshuller's native Russian was a somewhat difficult task. Altshuller's writing style is more like that of a novelist than a scientist. His text is packed with idioms whose meanings are mainly understood only in Russian. In fact, some Russian TRIZ experts expressed the view that it is impossible to translate Altshuller into other languages. We took the challenge while attempting to preserve the original flavor of Altshuller's writing. However, this was a lengthy and exacting process that took over a year to complete.For those interested in such things, we divided the process into the following steps:

1. Lev made a rough translation.
2. Steve rewrote this into as close an English interpretation as possible.
3. Lev verified the accuracy of Steve's interpretation, making corrections when needed.
3. Together, both retranslated questionable passages to ensure their proper meaning.
4. Steve produced a final edited draft.
5. Richard Langevin read this draft for "errors in logic."
6. Robyn Cutler performed extensive proofreading.
7. Both Lev and Steve reviewed the final document.

Consequently, all credit for what *does* work should go directly to Mr. Altshuller; all responsibility for what *does not* must revert to Mr. Shulyak and Mr. Rodman.

Finally, we all hope that the reader will thoroughly enjoy this book, and become ignited by the power of this new process for mastering technical creativity.

Lev Shulyak & Steve Rodman
January, 1999

* * *

We would like to express our deepest gratitude to the following people:

Robyn Cutler, Lidya Shulyak, Victor Fey, Simon Litvin, Boris Zlotin, Leonid Lerner, Richard Langevin, Isak Bukhman, Larry Abramoff, Jampa Dhondup, Thinley Dhargay, and Peter Thuse (Commonwealth Printing), Peter Geraty (Praxis Bindery), & Bookcrafters, Inc.

For the Master (1926-1998)

Three Questions

A Short Interview with Genrich Altshuller, Summer, 1998

While preparing our translation of this book, we approached Genrich Altshuller with a proposal that he submit a special introduction for inclusion in the book. This would give him the opportunity to personnally address his many new readers in the west, and perhaps express to them his hopes —and concerns —for the future development of his brainchild, TRIZ.

Mr. Altshuller enthusiastically agreed. However, because of his ill health, he indicated that we should write the introduction for him. We were both dubious about this until it was proposed that an interview with Mr. Altshuller be conducted, and an introduction composed from his responses. The tone would be humanistic and philosophical, rather than technical, in keeping with the direction of his later work.

So, about mid-summer 1998, we sent Mr. Altshuller three general questions. The plan was to propose broad topics for his consideration and response. Then, subsequent question and answer sessions would flesh-out his ideas.

Unfortunately, the universe had other plans.

All that exists now is his initial response to our first broad-topic questions. Out of deep respect and affection for Mr. Altshuller, they are printed here.

❧

Question 1: What do you think the long-term effect of TRIZ might be on the wellfare of humanity?

> "Of course, I would like to answer this in an optimistic spirit. However, the history of science and technology does not give us a very consoling forecast. The social well-being, the social relationship between good and evil, has little to do with levels of science and technology —even if this may seem paradoxical."

Question 2: What are some important future applications of TRIZ beyond technical systems?

> "This is a very interesting question. Scientists and inventors hold onto their illusions for a long time. Sometimes, a new search is only made in

> areas where conventional science and technology spin their wheels. The same happened a while back with the Great Breakthrough to the Poles. 'What can we gain from reaching the North Pole? It is just an empty place.' It is just an empty place with worthless ice. However, almost all technology —along with a significant amount of scientific research —is connected, in one way or another, to the Great Breakthrough to the Poles. Later, many of these 'worthless' discoveries and inventions were used in general technology."

Question 3: Widespread application of TRIZ will undoubtably lead to a technological explosion. Is this good, or bad?

> "This is neither good nor bad. It is inevitable. If people can create a strong theory that allows for understanding the "technological explosion," then they will live in a crazy, but exciting and interesting world. If the "technological explosion" becomes uncontrollable — mankind will face a sad epoch."

Three tributes

Victor Fey, Boris Zlotin and Simon Litvin were all designated "TRIZ Masters" in September, 1998 by TRIZ's father, Genrich Altshuller. They were three of Mr. Alshuller's closest associates, and were all profoundly influenced by *The Innovation Algorithm* upon first encountering it in their native Russian.

We asked them each to submit a brief essay on the meaning of this book to their lives. As both a tribute to this book and its author, their responses follow:

Boris Zlotin

The history of the human race is the history of men who take control over their lives and destiny.

Agriculture provides enough food for constantly growing populations. Industry helped reduce dependence upon climate and natural disasters. The ability to write and publish, and now computers, provides an effective knowledge exchange and utilization. Today, there are many effective means to satisfy all the basic requirements of the human race except the most important one — forecasting the future of technical evolution. For thousands of years people have tried to control their destiny, to shape it by their vision. However, they were missing the knowledge to forecast what would happen, to overcome contradictions, to solve scientific and technical problems for the realization of their vision.

Control of the future becomes possible through development of the Theory of Solving Inventive Problems (TRIZ), created by Genrich Altshuller — the genius of such a level that is born only once in each Century.

More than 50 years ago, in 1946, at the age of 20, Genrich decided to think-out a methodology of inventiveness that would give any person the ability to become more creative. His name for this methodology constantly changed. At first, Altshuller called it "Algorithm of Innovation," then "The Algorithm of Solving Inventive Problems," then the "Theory of Solving Inventive Problems" (TRIZ). Its contents constantly expanded. Today, TRIZ is the theory of the evolution of technical and non-technical systems, where inventiveness is one important part together with the methodology of forecasting, solution of scientific problems, methodology of creativity training, and so on. Today, thousands of people around the world use TRIZ. This snowball effect (a human avalanche) was triggered by one person — Genrich Altshuller.

The book you are holding in your hands became a milestone in TRIZ development. This is not the first, nor the last, book written by Altshuller on the subject of inventiveness. However, this is a very special book. Many tools described in it have been surpased. It does not have the laws of technical system evolution, S-Field analysis, standard solutions, and many other tools that round-out TRIZ today. However, it contains the core ideas that always will be part of the golden fund of TRIZ. This book is to the Theory of Solving Inventive Problems what Newton's *Phylosophiae Naturalis Principia Mathematica* is to Physics. Everyone who wants to become a TRIZ expert, and really understand Ideality, Technical Contradictions, Evolution of Technical Systems, and many other things, must first read this book.

There is one more thing I would like to say:

This is a very special book for me personally.

The first time I read this book was in 1974 and, like the magic flute of Hamlin's Pied Piper, it carried me away. I left my job, my PhD unfinished, and successfully started a career becoming a professional TRIZ master and inventor. This road led me to meet, and later create a friendship with, Genrich Altshuller, the most unusual person I have ever known. This book led me to have a close working relationship with Altshuller, training people and further developing TRIZ. It led me to later form the Kishinev Scientific School of TRIZ, to participate in solving more than 6,000 problems in different areas of technology and business, and later to form several companies in Russia, and now, the USA (Ideation International, Inc.).

I have never regreted following my commitment to advance and disseminate TRIZ.

Boris Zlotin is Chief Scientist of Ideation International, Inc. He is the author of ten books on TRIZ, including three published together with G. Altshuller. He has written more than 100 papers in the area of TRIZ. He is also a member of the Committee of the International TRIZ Association.

* * *

Simon Litvin

The Word that Became Action: About G. Altshuller's *The Innovation Algorithm*

"In the beginning was the word . . . ."

In 1969, while still a student, I accidentally bought a book with a flashy title. It was devoted to a new area of knowledge —the methodology of innovation.

About 15 years later, Genrich Altshuller offered his *Scale of Fantasy* that provides an objective system for grading literary writings and books. One criteria that Altshuller used for this evaluation was the degree of influence a book had on a reader. The highest grade, in his opinion, must be given to a book that changed the life of its reader. For me, *The Innovation Algorithm* was such a book.

Its first edition of 100,000 copies sold-out immediately. This was very surprising considering that it was a technical book. The book is saturated with thoughts, ideas and convincing examples about his theory of inventiveness. Besides, it was created by the hands of a brilliant writer, and possessed charm and an unusual attractive force. Even the titles of its sections and chapters could be put together like elements of a jigsaw puzzle, creating a picture of the theory of innovation. Titles like:

Inventing Methods of Inventing
Through Knowledge, not Numbers
Step-by-Step
An Alloy Made of Logic, Intuition, and Skills
How the Algorithm Works
Breaking an Old Structure
Over the Barriers

Today, TRIZ is accepted all over the world. New tools to improve technology have become part of TRIZ's system, along with collected examples of practical utilization of these tools. New TRIZ software has been created and successfully used, and yet the main ideas in Altshuller's *The Innovation Algorithm* have not lost their significance. Those ideas are: **The process of creativity can be learned; the process of creativity can be detected and become accessible to those who want to solve creative problems; there exists an "algorithm" for invention.**

Simon Litvin is Vice President of Pragmatic Vision, Inc., and a Member of the Committee of the International TRIZ Association. He is the author of six books and 80 papers on TRIZ, FSA and DCI (Development of Creative Imagination). He has participated in 12 seminars with Genrich Altshuller. Their close association lasted until Altshuller's last days.

* * *

Victor Fey

I once asked Altshuller what helped him endure the years of horrifying and humiliating conditions in the GULAG's concentration camps: 12-hour working days, starvation, cold weather, lack of elementary sanitary settings, diseases, taunts by wardens.

Altshuller responded that there were three kinds of people who managed to survive not only physically, but also, which was more important, as individuals: The profoundly pious, high-ranking servicemen, and "crazy inventors."

He considered himself belonging to the latter group. Altshuller was developing TRIZ, and this gave him the necessary strength to keep his spirit up. In the foundation of Altshuller's philosophy is a reverence for the creative individual. Quite often TRIZ is perceived as a set of powerful tools for solving engineering problems. Albeit true, TRIZ is much more than that. First, and foremost, it is a new way of thinking. TRIZ is a tool for developing skills for what Altshuller called *Strong Thinking* (this is a literal translation from Russian; another possible rendition would be *Analytical Independent Thinking*).

Altshuller held that the well-being (both ethically and economically) of any society depends to a large extent on the proportion of creative individuals in that society. A creative individual, according to Altshuller, is a person pursuing a major noble goal (some examples are: Allen Bombard, Albert Schweitzer, Albert Einstein, etc.). A creative individual has to be able to think freely (creatively); i.e., analytically, holistically and independently. Altshuller also believed that many acute problems that mankind faces, and will inevitably confront in the future, could be eliminated/prevented if not for our inability to think logically and independently. Man's only means of understanding and changing reality is reason. We cannot survive unless we fully develop and employ our intellectual power to achieve ethical and material goals that can assure the continual evolution of the human race. Hence, among such fundamental rights of an individual as the right to life, work, liberty, freedom of conscience, freedom of opinion, and others, there should also be an inalienable right to develop skills of *Strong Thinking*. TRIZ is an instrument for developing the basics of such thinking. Besides its immense importance for society, *Strong Thinking* has a more intimate appeal: it is a source of the joy of creativity which, equally with a passionate love, is the most potent human emotion.

Thanks to TRIZ, the excitement of discovery and invention, and the thrilling sensation of the beauty of an original thought, can be experienced not only by the lucky few who inherited the inborn ability to create, but by many more who want to engage themselves in the search for new ideas. In the evening of September 28, 1998 my friend and I were sitting across from each other in a sleeping car of the St. Petersburg —Petrozavodsk train. The next morning, in a small Russian city of Petrozavodsk we would say the last goodbye to our Mentor, Genrikh Saulovich Altshuller. Saddened and downhearted, we kept silence listening to the rumble of the wheels and beating of the rain against the window. My friend broke the silence:

"You know, when life sometimes gets to me, and it looks like there is no ray of hope ahead, I pick a book by Altshuller from the shelf — any book — open it to any page, and start reading. This proved to be the best elixir for me, for in a short while I begin feeling hope and faith in myself coming back."

As he spoke, I remembered the thoughts and feelings that overwhelmed me after reading my first book on TRIZ — the very same book you are holding in your hands. I was seventeen years old and was astounded by the singularity and colossal scale of the main idea of TRIZ — to make that rarest gift, talented thinking, available to everybody. This awe has stayed with me ever since then. I wish you every success in making TRIZ your best guide into the daring world of creativity.

Victor R. Fey is a Managing Partner of The TRIZ Group, and Adjunct Professor of Mechanical Engineering at Wayne State University. From 1978 through 1990 he was a close associate, and friend, of Genrich Altshuller, and performed basic research in the areas of the laws of technological system evolution, laws of societal system evolution, and in the principles of solving scientific problems. He was also Altshuller's personal representative in the U.S. from 1991 until Altshuller's death in 1998.

Section 1

Technology of Creativity

One person gropes through the dark labyrinth —
perhaps he will find something useful, or maybe he will just crack his skull.
Another carries a small lamp to shine through the darkness and,
during his journey, his lamp shines brighter and brighter.
It finally becomes an electric sun illuminating everything and revealing all.
Now I ask: "Where is your lamp?"

D. I. Mendeleyev

Part 1-1

A Needle in a Hay Stack

How an inventor works and how late an invention appears

Any theory of invention must study innovative creativity for the purpose of developing effective methods for solving inventive problems.

This implies an idea that may seem, at first glance, heretical: existing methods of inventing are so bad that they should be replaced. Yet, people have made great inventions with these old methods! All invention today is based upon these methods, producing thousands of new technical ideas every year. How can these existing methods be wrong?

Let's not rush to an answer. Let's begin by examining how inventive problems have been solved traditionally.

As a rule, inventors have no desire to discuss the ways in which they developed new technical ideas. In his book *The Secret of NSE*, author and talented inventor, B. S. Egorov, is an exception.[1] He describes in detail how he invented a winding device mechanism.

Let's follow this inventor's thought process.

Here is how Egorov states the problem:

> *"Imagine a big computer with several thousand tiny toroidal transformers. Each transformer has a center opening only 2mm in diameter. Through this is wound a wire thinner than a human hair. The wire is coated with silk. The winding of each transformer is laboriously done by hand so as not to damage the fragile insulation."*

The problem is clear. A ring made of ferrite must be wound quickly and accurately with thin insulated wire. Egorov had successfully solved a similar problem several years earlier. At that time, it was necessary to mechanize the winding of telephone inductor coils. At first glance, both problems seem alike —both problems involve a ring that needs a wire wound around it. However, in the new problem, the tiny ferrite ring is significantly smaller than the ring of the telephone inductor. This fundamentally changes the problem.

> *"I must say that the problem did not initially appear complex," Egorov writes. "However, my opinion changed as I analyzed the problem more thoroughly. The difficulty was in winding the wire over a ring only 2mm in diameter."*

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[1] B. S. Egorov, *Secret NSE*, M., Profizdat (Union Publisher), 1961.

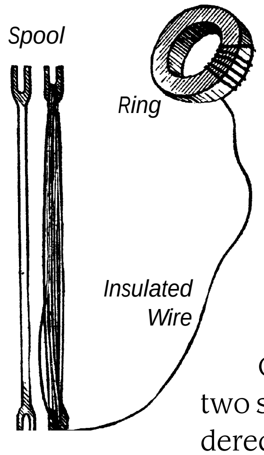

Figure 1. *Winding wire over the ring was done by hand.*

For instance, the ferrite toroid K-28 —used in Soviet BESM-2 computer systems —has similar dimensions: 3.1mm outside diameter, 2.0mm inside diameter and 1.2mm thickness. Even smaller miniature toroids are used inside the memory device of BESM-2.

The windings of these rings were also done by hand using a spool. The spool acts as a "needle," carrying the wire. The ring and spool are shown magnified in *Figure 1*. The cross-sectional shape of the ring is not significant. It can be square, rectangular or round.

Of course, the problem would be simpler if the ring could be made of two separate C-shaped halves. But the ferrite toroids are made with a powdered metallurgy process —the powder is compressed and then baked. No windings can withstand this high temperature and pressure. Therefore, the wire must be wound onto the finished ring. Egorov explains:

> *"How big should the spool be? How big should the needle ring be? Immediately it becomes clear that the spool I used to wind the wire on the first device cannot be used here. This spool will be too small, complicating the situation. Can the wire be wound without the spool? Can we find a completely new concept of winding? What kind of concept would it be? These questions destroyed my peace of mind.*
>
> *"Can, perhaps, a pendulum be used? This idea was offered by many of my friends with whom I consulted. So I decided to solve the problem using pendulums. The concept was simple —begin with two pendulums and the ring located between them. The pendulum on the right has a needle that draws the wire through the ring, bringing it to the left pendulum. The ring is then lifted and the needle returns to the right pendulum bringing the string under the ring. Then the process starts all over again. This is amazingly simple. Everything is done without the spool."*

A model of this machine was built; however, testing yielded a negative result. The wire was tightened only when the needle was in its extreme positions. When the wire was in motion, it sagged, making the windings non-uniform.

> *"I doubled my effort and started all over again. First, I positioned the pendulums differently. Next, I changed the position of the ring. Then I tried altering the pendulum's swing. Nothing helped. The wire still sagged. I made over three hundred experiments. Finally, I concluded that pendulums were not a good solution.*
>
> *"At this time, it became clear that I should seek a new concept. But what kind? I analyzed several variants. Nothing was satisfying. An idea entered my mind: wind the wire with compressed air in place of the pendulum. The air will push the needle through the ring."*

Egorov built another experimental model. The compressed air did not help —the wire still sagged.

> *"Suddenly a thought struck me: the whole concept of winding the wire* ***around*** *the ring is wrong. Such a concept includes the idea that the needle must travel* ***through*** *the ring. It is the needle's movement that causes the wire to become slack. Therefore, I must reject any concept that includes the needle. I had to find a completely new method."*

As time passed, Egorov continued to think about the problem. One day another idea struck him while he was traveling in a train:

> *"As I was sitting on the bench looking around, my eye stopped on an old woman weaving a hat. She had a hook in her hand. She made a motion with her hand and the hook made a ring. Another motion, another ring. I stared at the hands of this knitter and repeated her movements in my mind. One ring, another ring, another and another. . . . I then imagined the movement of the hook —not in the hands of the knitter, but in my machine.*
>
> *"What if I replace the spool and pendulum in my machine with hooks? The hook will pick up the wire and pull it through the ring. A spring can keep the wire tight. I began with a needle and thread, then transformed the needle into a hook while trying to repeat the gesture of the old woman's hands. One gesture followed by another. I could not believe that, in this simple hook, lay hidden the secret of the winding machine. Was it possible that I had found the secret to a problem that had seemed to have no answer? Yes. Now the windings were placed perfectly. This was exactly the concept for which I had searched so long. With the help of these hooks it was possible to make tight windings around the ring."*

And this is how a new winding machine emerged.

What can we now say about the roads an inventor follows to invent?

First, the search for a solution is performed randomly —by "trial-and-error," as psychologists say. Eventually, an idea emerges: "What if we do it like *this*?" Then, theoretical and practical testing of the idea follows. Each unsuccessful idea is replaced with another, and so on.

A diagram of this method is shown in *Figure 2*. An inventor needs to get from the point we call **Problem** to the point **Solution,**

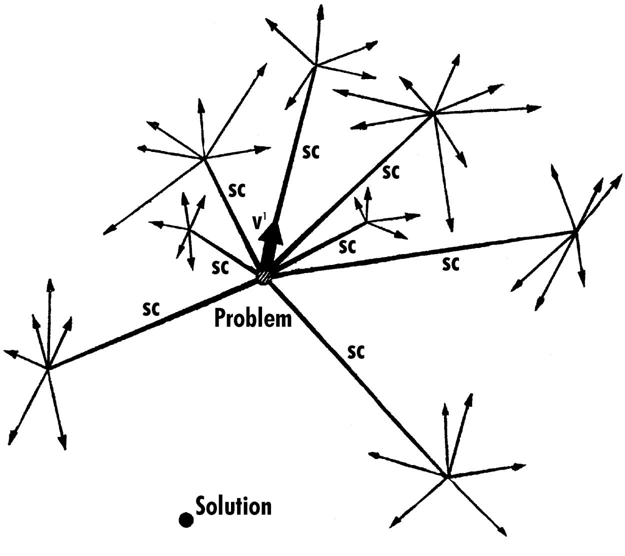

Figure 2. *Diagram of a trial-and-error search method.*

whose final location is unknown. The inventor develops a searching concept (**SC** in *Figure 2*) along with a direction — *"I decided to solve the problem using pendulums."* The attack on the problem (shown on *Figure 2* by arrows) begins in this direction —" *What if we do it this way?"* Later, it becomes obvious that the whole concept is wrong —"I concluded that pendulums were not a good solution."

The inventor returns to the original problem and introduces a new searching concept — *"An idea entered my mind: wind the wire with compressed air in place of the pendulum."* The inventor now starts a new series of attacks.

In reality, there are usually many more trials than is shown on the illustration. Egorov mentioned about 300 modifications of only the first model of his machine. During the process of solving an inventive problem with the trial-and-error method, the number of trials is very large. It requires thousands —maybe even tens of thousands —of "what ifs. . ." to find a satisfying solution.

There is another distinct characteristic of this method. In the previous diagram, a cluster of arrows point in the direction opposite **Solution**. This is no accident. Usually, trials are not as chaotic in the beginning as they appear. An inventor begins the search with a concept in mind based upon previous experience. Egorov had already developed a machine to wrap coils of wire for telephone inductors. When he began working on the new problem, his mind immediately turned to his previous experience: "It must require a spool. However, this spool must be very thin. Or, it can be a thin needle with a wire reserve."

Nearly all the trials were unsuccessful because of the inventor's attachment to the concept of *needle*. The initial tendency, as shown in *Figure 2* as the Inertia Vector (V^I), is to start from **Problem** and head in the opposite direction away from **Solution**. The main step is finished when the inventor finally rejects the concept of using a needle as the means to wind the wire.

Later in this book we will discuss the trial-and-error method in greater detail. The reader will now have a chance to personally test this method.

* * *

Problem 1

Egorov's invention manages to coil the wire over the ferrite ring very well —as long as the internal diameter of the ring is not less then 2mm. However, miniaturized electronics require smaller transformers with smaller rings. Again, as always, this work must be done by hand. How can we automate this process?

Try spending some time attempting to solve this problem without using any inventive methodology.

The problem is clear. There is a ring made out of ferrite. It has an internal diameter of, for example, 0.5mm. There is also an insulated, thin wire. The wire must be coiled around the ring. How can we automate this process?

The number of loops in the coil is dependent upon the design of the transformer, and thus can vary. There can be several hundred loops in a toroidal transformer, or there may only be two or three, as in the case of a computer memory toroid. Let us say that we need twenty loops of wire.

We also have two additional considerations: first, because this is a practice problem, it cannot be changed —i.e., there can be no solutions that remove the ferrite rings altogether. Second, any solution can be offered if it provides high productivity because millions of these transformers are required for computer memory.

One does not need special knowledge in order to solve this problem. It is doubtful, however, that even experienced inventors will find good solutions through the trial-and-error method alone. In fact, I am positive that the reader will not solve this problem. Suppose that you are as talented as Thomas Edison. Did you know that Edison, as he confesses, worked on each of his inventions an average of seven years before reaching a solution? One third of that time was spent searching for solution concepts.

Nicola Tesla, who at one time worked with Edison, wrote:

> *"If Edison had the task to find a needle in a haystack, he would not lose time determining the most probable location of it. He would immediately, with the diligence of a bee, begin picking up straw after straw until he found the object of his search.*
>
> *"His methods were very inefficient. He would spend a lot of time and energy reaching nothing —unless luck was with him. In the beginning, it was sad watching him work, knowing that just a little theoretical knowledge and a few calculations could save him at least 30% of his time. He despised education from books, and especially the knowledge of mathematics, trusting completely to his inventive intuition and American common sense."*

Even though I doubt you will solve the problem of the transformer, I recommend you make several attempts. Later, we will see how this problem can be solved with the help of inventive methodologies. Then, based on your experience, you can compare the trial and error search for a solution to the algorithmic method described in this book.

* * *

The winding machine was developed by a Egorov, a talented worker who was also an inventor. What if such a search was to be performed by a scientist? Does more knowledge improve the efficiency of the trial-and-error method?

Some time ago, the magazine *Inventor and Innovator* published a paper by E. Veretennikov (Ph.D., Technical Science). This is another rare case where an inventor has described how he found a new idea. The problem solved by Veretennikov is not complex, and his higher scientific education does not make this case unusual. Here is the story described by Veretennikov:

> *"Our Kuibushev Industrial Institute collaborates with the Kuibushev manufacturing plant that makes auger bits for well-drills. Everyone entering the assembly station of this plant asks the same question: 'Can't this assembly be done differently?'*
>
> *"The scene inside the plant is unpleasant. The shank of each auger is coated with thick graphite grease acting as glue. The grease holds the rollers on two horizontal planes. Without the grease, the rollers would scatter all over the place. As soon as two rows of bearings are set, the cutterhead is placed over the assembly. This whole process is done by hand —and graphite grease is harmful to human skin. Besides, small metal chips can cut into the hands of the assembler. The work is hard and requires high levels of skill.*
>
> *"This type of assembly, requiring that parts be held in a certain position, is common. All kinds of clamping devices —soldering, welding, glue and sticky substances —are used to hold the parts in place temporarily. This particular auger assembly process forced me to rethink how rollers can be temporarily held against shanks."*

The problem looks like this:

To assemble a section of an auger, it is required to first place two rows of roller bearings on the surface of the shank. There are 20-30 rollers in each row. It is clearly impossible to hold all of them by hand. A method must be developed that allows the rollers to be held (without grease) on the surface of the shank until the cutter is placed over the assembly. The concept must be simple, efficient, and allow for further automation.

> *"The first thing that came to my mind was, of course, a rope to secure the rollers. The next thought followed immediately: 'How can I remove the rope after assembly?' We could use film, instead of the rope, which could be melted away later by oil. This might have been the correct solution —except that the manufacturing process became more complex. Further thinking led to better solutions. Other means could be used to hold the bearings, like magnetic forces."*

Let's say that Veretennikov produced a really good invention. The story of his arrival at this invention is like a bad novel with a good ending.

This problem appeared a long time ago when the means to resolve it existed. Unfortunately, the inventive solution appeared at least 20-30 years later! Veretennikov emphasized that everybody coming to the assembly section of the plant noticed the necessity to improve this part of the operation. The problem screamed: "Please pay attention to me!" It is very important to resolve this problem, and it is not so difficult to do.

But people walked by without paying attention.

This is not an isolated case. In every industry there are many inventions that must be made —and utilize knowledge from contemporary science and technologies. However these inventions are never made.

Let's see how the inventor worked out this problem:

His first thought: "Of course, a rope." Notice the " *of course*." The starting point of his thinking process related to an already existing mechanism —rope. It is impossible to use a metal rope as a yoke, so he thought of using a normal rope.

The *rope* idea dominated the inventor's imagination so much that he did not want to part with it. The next step includes *rope* again —so goes the Vector of Inertia. This time the *rope* consists of plastic film. Analysis indicated that this concept, though more contemporary, would also not lead to a successful solution. Finally, further thought did bring the correct solution: A magnetic force must be used.

This problem belongs to that type which is solved automatically as soon as the problem's formulation is stated precisely. **Creativity here resides in the skill to state the problem correctly.** Let's repeat: *It is required that roller bearings placed upon a shank will not fall down before a cutter head can be placed over it.* In other words, one metal part has to be temporarily attached to another metal part.

It is enough merely to state the problem like this, and five out of ten people with a simple sixth-grade scientific knowledge will immediately solve it —a magnet.

We can further specify the problem: *A metal part has to be attached to another metal part without the use of any other substance (like grease).* Not much force is needed —only enough to compensate for the part's own weight. Now eight out of ten answers will be correct.

Later, as we learn more about methods of inventing, other mistakes made during the process of solving this problem will become obvious. But even now we can draw some conclusions:

1. The inventor's thoughts moved from a known concept to an unknown one. An already existing device (a metal band) was used as a prototype that the inventor tried to modify. This produced a number of unsuccessful solutions.

The same thing happened with Egorov. The **Vector of Inertia** always leads away from the solution.

2. The inventor is forced to choose a completely different road toward the correct solution. This road was initially unknown to him. He can explain logically and confidently how he moves down this road — from one unsuccessful idea to another. Then, abruptly, the road ends. Instead of a logical explanation, there are only his meaningless words: "Further thinking brought me to. . . ."

Remember that Egorov cannot explain why a good idea did not pop into his mind earlier.

3. Although the final solution was successful, the inventor's search was far from perfect.

A magnetic assembly could have been developed much earlier. Economic necessity for this invention appeared a long time ago, and the necessary technology was available at the time. Either inventors did not want to see the problem, or they did not attack the problem seriously enough. Inventors let this problem stand still. The price for that was very high — years of hard and dirty manual labor.

If we consider long historical periods, we see that inventions appear in accordance with certain laws of evolution. For instance, the steamship could not appear before the steam engine was invented. The steam engine could not appear earlier than economy demanded. However, inventions often come late without valid reasons — objective conditions to invent something are present, yet that something is not invented.

Logical directions in the evolution of technology do not mean that inventions will emerge by themselves and all we need do is sit and wait for something to happen. Our present "Invention Industry" produces the most valuable product of all — new technical ideas — but still uses conventional methods that result in lower production and lesser quality than might be achieved otherwise.

Sometimes, it is difficult to understand why a different invention did not appear significantly earlier. For instance, at the dawn of the automobile era fans were installed to cool engines. Even then, every driver knew that, at low outside temperatures, there was no need to cool the engine. Furthermore, it was harmful to overcool the engine — also consuming more energy. However, a magnetic clutch to disengage the fan at lower outside temperatures was not invented until 1951. "Stand-still" time stretched over almost half a century, and a heavy price was paid — rivers of wasted gasoline.

* * *

Let's see what kind of "Technology of Creativity" is used in more complex problems. Let's take, for example, the history of the development of meniscus-lens telescopes.

Before the Second World War, the Leningrad optician D. D. Maksutov was working on the development of an educational telescope. His goal was to develop a simple and inexpensive —yet high quality —device capable of withstanding abusive classroom conditions. Existing telescopes were complex and expensive, requiring careful handling. All attempts to simplify and economize telescopes led to the worsening of their optical quality. Maksutov could not superimpose that which is not superimposable.

Maksutov wrote in his book *Astronomical Optics*:

> *"Meniscus telescopes were invented by myself in the beginning of August, 1941, during my evacuation from Leningrad. I left Leningrad, and with it all the preparations for the production of school telescopes that I had spent half of my life working on. My invention was a dubious success, and I envisioned a sad fate for my 'baby.' During this period I found myself with something rare for a busy person —time with nothing to do but reflect upon the subject that most interested me.*
>
> *"Was everything correct in the design of my telescope reflector? No. In particular, the aluminum-plated mirrors will rapidly lose their quality. The reflector, which rests in an open tube, will not live long in a school environment. Even if a janitor wipes the dust from the mirror only once, it will be destroyed. Can we cover the mirror with glass? Of course, this will protect the mirror. What kind of material can we use for the glass? Regular glass is inexpensive; however, it absorbs a lot of light. Optical glass is much better, but much more expensive.*
>
> *"How can I improve the design? It seems like there is only one solution — make the design more complex by installing a parallel-plane protective glass window in the front of the tube. Installation of such a window, made, as it must be, from optical glass, will significantly increase the cost of the telescope system. . . ."*

The inventor thought about this for many years. Every time he faced the fact that ordinary glass wasn't good enough, and an optical glass was too expensive. Once, while riding on a train, Maksutov, as he points out, was daydreaming. In other words, he stepped aside from his Vector of Inertia and examined variants that were previously considered inappropriate. He opened to the possibilities of fantasy and allowed himself to imagine the following: *suppose optical glass should become very inexpensive*. It would then be possible to use it as the reflector's protective window, sealing the telescope. Now, what would this accomplish? First, of course, it would extend the life of the mirror.

He continued, finding other advantages derived from the protective glass:

> *"A hermetically sealed tube has an additional advantage: convection airflow is eliminated. It is possible to attach a diagonal mirror to the glass window by drilling a hole in the glass and setting the connecting rod of the mirror frame in it. By doing this, the supporting frame that usually holds the mirror, absorbing light and adding additional interference, would be eliminated."*

It is here where Maksutov makes his initial step towards making an invention. An optical glass is initially held as some kind of inevitable evil. "But this is okay," the inventor says. "Let's have an optical glass. If the glass has to be there, why not get additional advantages from it as compensation?"

It was enough to merely make this statement. Anyone with a knowledge of telescope construction — not just experts — could now find the correct answer. A flat mirror [the secondary mirror] should be placed at the entrance of the telescope. This mirror will bounce light rays from the primary mirror back to the eye of the observer. Originally, the fixture holding the secondary mirror absorbed a lot of light. Now, it can be attached directly to the protective glass window.

His train of thought proceeds further: *Why not make the protective window in the shape of a* ***meniscus*** *instead of a parallel-plane disk — and made in such a way that its aluminized center will play the role of secondary mirror?* In this case, not only does the secondary mirror's mechanical fixture disappear, but the *mirror itself* disappears. The function of the secondary mirror can now be performed by the center portion of the protective glass window.

> *"This design is very good. There is no framework for the secondary mirror, so deflection becomes minimal. But, now another concern appears: can the meniscus lens cause harmful optical aberrations? It probably will — not achromatic aberrations, but simultaneous positive and negative spherical aberrations.*
>
> *"Here I almost missed an important discovery — that a meniscus can be designed to be 'aberration-free.'"*

Please read the following lines carefully. The inventor has overcome two barriers. The first barrier is that the protective glass window can only be made of expensive optical glass. It later became clear that the high-cost of this glass can be compensated for by an additional function the glass will provide. This means that it is no longer necessary to jump over this barrier — we can simply step around it.

The inventor now reaches the second barrier. There is a necessity to eliminate the distortions produced by the meniscus lens. Now is the time to utilize our newly discovered concept of "compensation." Let the aberration from the lens stay — it's just one more inevitable evil. We can *compensate* for this evil, and extract something useful from it, instead of eliminating it.

The weakness of the trial-and-error method is clear in this example. At first, it seems that the method is chaotic. This is not true. There is a definite system to it. Trials are made along the direction of least resistance. After all, it is much easier to pursue a familiar direction. The inventor follows this same route subconsciously —therefore, the odds are against him discovering anything new. There are only the same repeated attempts at "jumping over" barriers. And, as we have just learned, it is not necessary to jump over what one can merely walk around.

Maksutov continues:

> *"I spent several hours mulling over these thoughts. Then I figured it out: Choose a meniscus lens that introduces a positive aberration, which compensates for any negative aberration of the spherical mirror, or mirrors. It was precisely at this moment that the meniscus telescope was invented."*

So, the second barrier was overcome by the same compensation method. A meniscus lens distorts light rays, and the inventor understood that there was no need to fight this distortion. Instead, it's better to utilize these distortions to compensate for those distortions produced in the main mirror-reflector during its manufacture.

It is complex and laborious work to manufacture a parabolic reflector. Maksutov's invention allows replacement of the parabolic reflector with spherical mirrors that are simpler to manufacture. Originally, it was impossible to use a spherical mirror because it produced visual distortion. Now, it becomes possible to compensate for a reflector's distortion with distortion produced by the meniscus. An optically imperfect reflector — and an imperfect meniscus —working together provide a completely perfect optical system!

Maksutov writes:

> *"Working on the theory of the meniscus system, and understanding its advantages, I involuntarily remembered the thorny road of the optical industry history. How many lances were broken during the battles between advocates of reflectors and refractors? How much energy was wasted to perfect methods to manufacture and investigate precise spherical surfaces and resolving, on the other hand, problems of achromatic glass? How much flintglass and other complex, labor-intensive kinds of glass were manufactured and were eventually not needed? And finally, how many expensive, bulky, imperfect telescopes (with equally bulky and expensive mechanisms, as well as buildings with huge rotating domes) were built?!*
>
> *"If, at the dawn of astronomical optics, the simple concept of the compensating meniscus was known (it was available to contemporaries of Descartes and Newton), then astronomical optics would have progressed in entirely*

> *new directions, and achromatic short focus optics with spherical surfaces based only on a single kind of optical glass could have been developed without regard to their properties."*[1]

Invention, in this case, came 250-300 years too late.

What was the fate of this invention?

After constructing his telescope, Maksutov decided to develop meniscus microscopes, binoculars, and other optical devices. Even in the field of optics, Maksutov's idea was used only to solve tasks similar to his original one. If the problem was slightly different, it was not solved —or, if people tried to solve it, they followed the same trial-and-error road as Maksutov had before.

Here is the story of one such invention. Pay close attention to the thinking process and the solution. Both are strikingly reminiscent of the invention of the meniscus telescope.

> *"An idea appeared accidentally. I knew a person, an amateur diver, who wore eyeglasses for many years. He had a problem wearing his glasses underwater. I suggested he make a mask out of Plexiglas, milling the lenses the same as his glasses. The idea was enticing, although not everyone could do it.*
>
> *"Suddenly, it became clear that the real solution lay in the water itself. If the mask's parallel-plane glass is made convex, the boundary between two substances —water and air —becomes concave, diffusing light rays just like concave lenses. The swimmer wore eyeglasses with lenses of -2 to -3 dioptry (curvature). As experiments revealed, this is the equivalent of a mask with a convex radius of 10-15 centimeters. Here I realized that eyeglasses have nothing to do with underwater vision. Distant objects under water seem distorted —much larger and closer. If the convex radius of the glass were 20-35 centimeters, then the magnification produced by the water would disappear, and the underwater world would appear its natural size while being much clearer."*[2]

Just like Maksutov, this inventor began with the idea of attaching optical lenses to the swim mask window. Then he surmised that he could eliminate the lenses altogether by making the window convex —transforming it into a meniscus. However, this meniscus could also perform another function. It could eliminate distortions produced by the parallel glass of the mask window. Thus, a new technical idea was born.

The most important idea contained in Maksutov's invention is to accept that which had been previously unacceptable —and then *compensate* for

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[1] D. D. Maksutov, "New Catadioptical Meniscus Systems," V. XVI, Issue 124, L., 1944, page 15.

[2] V. Maslaev, "Mask-glasses," *Technology —to Youth* magazine, July 1962, page 27.

it. We can confidently affirm that, among many unsolved problems, there are those that can be solved by this compensation method. However, this method is not widely known. Meniscus-lens telescopes were described a hundred times, but no papers said: "This is a successful method for solving different inventive problems. It can be used not only in the optical industry, but in other industries as well."

* * *

So far we have talked about inventors who solve problems individually. Perhaps conditions are different in large organizations with more resources at their disposal, and with more effective technologies for creativity.

Here is a story told by the aviation designer and business executive Oleg Konstantinovich Antonov:

> *"There was a very complex problem with the concept of the empennage [aircraft tail section containing vertical fin and horizontal stabilizer] during the design stage of the "Antey" [a large Russian airliner]. A simple, tall, vertical fin with an upper-stabilizer was difficult to make —although this idea was tempting and recommended by an aerodynamic laboratory. The fuselage of the airplane, having a large cutout area for cargo 4.4 meters wide and 17 meters long, would be smashed and twisted like a paper bag by such a high empennage.*
>
> *"It was also impossible to segment this vertical empennage and place round vertical plates —"washers" —on each end of the stabilizer. This could drastically reduce critical vibrations in the empennage. Time passed, and still no workable concept of the empennage was found."*

A contemporary aviation company is an organization working steadily on common problems. A general designer, thinking about a project, is not alone. A group of talented engineers is assigned to each system of an airplane. These people have the most recent information about everything relative to their profession. When one group is slack, it affects the working rhythm of the whole organization. It is not so difficult to imagine the cost of the phrase: "Time passed and still no workable concept of the empennage was found."[1]

Antonov continues:

> *"Once, waking in the middle of the night, I began, by force of habit, to think about what worried me most. If "half-washers" on the empennage's horizontal stabilizer produce flutter due to their weight, then "washers" may be positioned in such a way that their masses' negative effect becomes positive. Therefore, it is necessary to move them to the front of the neutral axis of the horizontal stabilizer.*

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[1] *Literature Newspaper*, August 14, 1968.

> *"How simple this was!*
>
> *"I stretched out my hand to the night stand, found a pencil and notebook, and in complete darkness diagrammed my newfound concept. Feeling complete relief, I immediately fell to sleep."*

In the beginning, Antonov, just like Maksutov, unsuccessfully tried to remove one harmful factor. In Maksutov's case, the harmful factor was an aberration; Antonov had some mass as his harmful factor. Yet, their solution concepts were the same — it wasn't necessary to remove the harmful factor, just to modify it somehow to make it useful.

Perhaps today, in some engineering firm, engineers are trying to eliminate some harmful factor. They bang their heads against the wall, unaware that a door exists.

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It is no longer difficult to answer the question stated in the beginning of this chapter. A methodology of inventing is needed to:

- Bring problems that are stagnant, waiting for innovative solutions, immediately to the attention of inventors.
- Solve inventive problems efficiently.
- Repeatedly utilize new-found methods to solve other technical problems, and relieve inventors from the necessity to laboriously search for new solutions.

Part 1-2

Levels of Creativity

Inventing is the oldest human activity. Strictly speaking, the humanization of our predecessors begins with the invention of the first tools. Since that time millions of inventions have been made. What is surprising is that, as inventive problems became more complex, the methods for solving these problems underwent almost no improvement. As a rule, inventors have continued to proceed toward their goals using the trial-and-error method.

"The inventor possesses neither reasoning nor foresight —nor even their younger sister, patience," French scientist Charles Nicolle wrote. "He does no research, nor does he follow his active imagination. Instead, he immediately throws himself into the unknown —and by this act, conquers. The problem, obscured in smoke where common light cannot penetrate, is suddenly illuminated as if by lightning. A new creation is born. This act is indebted neither to logic nor to intellect."[1]

"It would be nice if inventions were the result of a logical and systematic process," says American inventor John Rabinov. "Unfortunately, this is usually not the case. They are the product of what psychologists call 'intuition' —a sudden burst of inspiration; a process hidden inside the human mind."[2]

Rabinov, like Nicolle, does not consider the creative process to be logical. However, Rabinov does differ from Nicolle's opinion that one may make an invention by simply attacking a problem and eventually conquering it. Rabinov paints a less rosy picture —one closer to reality. Success is possible only after attacking the problem and then sorting out all possible variants.

There are many similar quotations —all the results of somewhat unrealistic thinking.

Prominent Soviet inventor G. Babat compared creativity to climbing a steep mountain:

> *"You wander around searching for a footpath. You go down a dead end, approach the cliff, and return. Finally, after much distress, you reach the summit and look back down. It is then that you see how chaotic and disorderly was your trek. Meanwhile you notice that, all the while, a straight, wide*

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1. Charles Nicolle, *Biology De L'Invention,* Paris, 1932, p.5.

2. John Rabinov, "Why Do People Invent," *Inventor and Innovator*, USSR, 1966, Issue #7, Page 15.

> *road lay near your path. It would have been much easier and faster to reach the summit had you only known about this road in advance."*[1]

Here Babat has precisely described the nature of the creative process. A high price in energy and time is paid for such a chaotic and disorderly search. Not surprisingly, the realization eventually arose for the necessity to develop some kind of orderly search process with rules —a map pointing to the "straight, wide road" leading to the summit. A science for solving creative problems was needed: Heuristics.

The word *heuristic* first appeared in the work of Greek mathematician Alexandria, who lived in the second half of the third century. Later, many prominent scientists, including Leibnitz and Decartes, expressed the necessity to study the process of creative thinking itself. Gradually, large numbers of observations were collected confirming the existence of several heuristic rules. Confidence in this understanding of the creative process has increased —yet inventors continue utilizing the trial-and-error method even to this day.

Why has Heuristics, after seventeen centuries, not produced any effective method for solving inventive problems? From its onset, Heuristics set a somewhat general goal: find universal rules, applicable to every area of human activity, for solving any creative task. Ancient Greek philosophers tried to find a small number of "basic elements" to explain a wide variety of phenomena. Aristotle taught that any substance consists of five elements (fire, air, water, earth, and ether). So, the common elements of creativity were presented in much the same way.

Certainly, all kinds of creativity possess some common attributes. However, by limiting ourselves only to the analysis of universal elements, it is difficult to move beyond base concepts. In this respect, Engelmeyer's work is notable. Utilizing rich factual material, this talented Russian scientist offered the following model of the creative process:

First Action:	**Second Action:**	**Third Action:**
Intuition and desire.	Knowledge and analysis.	Know-how.
Creation of an idea.	*Development of concept and plans.*	*Engineering implementation of invention.*

Generally speaking, everything here is correct. Each creative process includes a plan (*statement of problem*), a search for a new idea (*solution to problem*) and a development of the idea (*engineering implementation*). However, this concept is so vague that it cannot actually help inventors invent.

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1. G. Babat, *Roads into the Unknown*, 1962, page 581.

In fact, Engelmeyer —as well as other researchers —did not set as a goal the development of a real, workable methodology for solving inventive problems. Until recently it was believed that the present "inventing industry" satisfied all existing demands for innovation. The number of trials and errors made no difference as long as the problem was eventually solved successfully. The "inventing industry" appeared to work, satisfying the world's demands while still using grandfather's methods. No wonder development of Heuristics was slow.

This situation was further complicated because the subject was approached from positions of narrow specialization. Historians of technology, as a rule, completely ignore the psychological aspect of the creative process. Psychologists, in turn, do not consider objective laws of evolution in science and technology. They are interested only in the individual creative characteristics of prominent scientists and inventors.

In 1926, the American psychologists L. Termen and S. Cox published *On the Early Years of the Mental Characteristics of 300 Geniuses*. For the next 25 to 30 years, Terman and M. Eden studied the lives of 1,000 gifted students, and published the three-volume book *Genetic Studies of Genius*.

Inventors themselves made no attempt to clarify the creative process. There were only a few inventors, and most found the aura of exceptionality flattering. Early in this century, the American psychologist Rossman asked many inventors to fill out a questionnaire. One of the questions was, "Do you consider that inventive ability is innate, or can it be learned?" Seventy-percent of the inventors answered: "It is impossible to learn to invent. One has to have natural ability to become an inventor." However, nobody taking the poll could explain what "natural ability" meant.

In 1931, soon after the poll was taken, Rossman published *Psychology of an Inventor*. In this book he states:

> *"At this time, we have practically no knowledge about the psychological process leading up to an invention. We know neither what conditions are favorable for developing an invention, nor the specific characteristics of the inventor himself."*

Although he gathered many interesting facts, Rossman didn't reveal the essence of inventive creativity. He made modest conclusions that provided only a rough schematic of the creative process. It looked like this:

1. Identification of needs and/or problems.
2. Analysis of these needs and/or problems.
3. Review of existing information.
4. Formulation of all possible solutions.
5. Analysis of those solutions.
6. Birth of a new idea.
7. Experimentation and confirmation of new concept.

After Julius Caesar conquered the Gauls, he sent Rome the news in these words: "I came. I saw. I conquered." Imagine somebody who, based on this historical fact, describes the principle of military strategy thus: "First phase —arrive; second phase —see; third phase —conquer." Rossman's concept looks very much like this. It states no more than the chronologically arranged basic steps for working with an invention without distinguishing one step over another by importance. For instance, the search for information and the creation of an idea were considered of equal importance. Information can be easily obtained in a library —but how can one "deliver" a new idea that is "healthy" and valuable? Rossman could not answer this question. The technology of inventing remained undiscovered.

In 1934, the Soviet psychologist P. Jacobson published the first volume of his book, *The Process of an Inventor's Creativity*. Analyzing Rossman's conclusions, Jacobson offered his own concept of the creative process, also consisting of seven steps:

1. Period of intellectual/creative readiness.
2. Finding a demand.
3. Birth of the task and/or idea.
4. Searching for the solution.
5. Creating an inventive concept.
6. Transition of the concept into a schematic format.
7. Technical implementation and development of the idea.

It's easy to see that this concept is reminiscent of Rossman's ideas. However, Jacobson clearly expresses the thought that it is necessary to reveal the underlying laws of technical creativity and develop a scientifically based method for solving inventive problems. He planned on laying out this method in the second volume of his work. That volume, however, was never written, even though Jacobson continued publishing other works in psychology.

In the mid-1930's, millions of patents were stored on the shelves of patent libraries. Inventing had become increasingly wide spread. The need for scientific methodologies of creativity became more apparent. Nevertheless, new works on an "inventing technology" were not published for the following 20 years for various reasons. At the same time, the old vague and unworkable concepts were useless. They are all the more useless today in this period of vigorous scientific-technological development. The Central Committee of the Soviet Communist Party reported at their 24th convention: "Our weakest links are the connections between a scientific achievement and its introduction into mass-manufacturing." Does not a scientific achievement enter industry by way of an invention?

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In 1944, the American mathematician D. Poia wrote of Heuristics that ". . . its name belongs a little with logistics, somewhat with philosophy, and a bit to psychology —and has no clearly defined research area of its own. It was often generalized, seldom described in detail, and is, as a matter of fact, forgotten today."[1] The history of Heuristics consists of short periods of high tide divided by long periods of low tide. Each high tide enriched Heuristics with new hope and new terminology. However, it would soon become clear that these great promises were not rushing toward fulfillment. Old and vague ideas were discovered lurking behind the new terminology. And then a period of low tide would begin.

The appearance of Cybernetics prolonged the next low tide for Heuristics. Computer software technology is dominated by the methodology of consecutively sorting through variants. Thus, popular —and superficially convincing —analogies between computers and the brain reinforced the opinion that inventive problems must be solved by the trial-and-error method.

Computer technology continued improving until, at the end of the 1950's, it became clear that constantly sorting through variants —even with enormous computer processing speed —could not be used to solve creative problems. It became necessary to recall Heuristics. The new idea of heuristic programming appeared; let the computer not sort through *all* variants, but pre-select small numbers of variants by certain rules. This select group of variants alone should be adequate to solve a problem.

In 1957, the American scientists A. Newell, J. Show and G. Simon published the heuristic program called *General Problem Solver*. The terminology was brand-new, with a cybernetic accent, but the idea was old — develop universal rules to solve creative problems. However, the determinant of these problems was very specific, and generally useful only for proving mathematical theorems. Newell tried to utilize *General Problem Solver* to play chess —and nothing happened. It was useless to talk about solving inventive problems. They were too difficult for the *General Problem Solver* program to solve.

Later, Newell, Show and Simon developed a special program to play chess. However, this time they gave up the traditional heuristic search rules. Scientists had turned to studying objective laws for playing chess. A very good, previously developed chess theory became the core of this program.

It seems that a right direction was found. In order to develop heuristic programs, it was necessary to have a foundation of objective laws acting upon a given area. However, contemporary Heuristics accepts this idea without great enthusiasm. The fact is that a theory in chess existed, as did chess textbooks with rules, generalizations, and advice. There existed a large body

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1. D. Poia, *How to Solve a Problem*, Moscow, Uchpedgiz, 1961, page 200.

of analysis of previously played games. If all these had not already existed, work thousands of times more complex would have been required. First, develop the theory, and then develop a heuristic program based on that theory. This is why contemporary Heuristics offers nothing to inventors.

* * *

Rossman and other researchers, dividing the creative process into separate stages, did not consider that each stage could proceed on quantitatively different levels.

This is typical for investigations into inventive creativity. Inventions are considered in general —although they represent, in reality, a variety of distinct objects.

Let's compare two specific inventions:

> ***Author's Certificate #166,584***
> *A device to open bottles is comprised of a handle and claw. This invention is new because it opens bottles sealed with polyethylene caps. The claw is horseshoe-shaped, with a lip along its inside edge to grip the bottle cap.*
>
> ***Author's Certificate #123,209***
> *A method to amplify electromagnetic radiation, (ultraviolet, visible, infrared and radio waves). Amplified radiation is passed through a medium that, with the help of auxiliary radiation or other means, creates an excessive (in comparison with its equilibrium state) concentration of atoms, other particles, or their systems. This acts to "amplify" the electromagnetic radiation by exciting it to a higher energetic level.*

In each case, the creative process must follow the same steps: beginning, middle, and end. However, there is a quantitative difference between finding the necessity to remove a plastic cork and the necessity to develop an induction emitter (laser). The same obvious difference has to be present in the delivery mechanism for new ideas for these inventions.

I randomly questioned 29 people between the ages of 12 and 40. During the first two to five minutes, all of them found an idea to mechanize the cork removing process.

Here is one recording from this survey. It was done with my 12 year-old son.

Author: It is necessary to conceive a new kind of opener for plastic corks. The standard corkscrew isn't good enough. A sharp knife for opening cans isn't good either. A different kind of opener has to be made specifically for plastic corks.

Son: Mother uses a kitchen knife.

Author: It is not convenient to use a knife. A special opener is required.

Son: You can use scissors.

Author: Why are scissors better?

Son: A knife picks up the cork from one side; scissors pick it up from two sides.

Author: How can we make this even better?

Son: *(Enthusiastically)* We can pick the cork up from three sides! (Note. This is exactly how it was written in the Author's Certificate #166,584 —a bracket in the shape of a horseshoe.)

Author: It is still required that we develop a special opener.

Son: A special blade that lifts the cork from three sides (demonstrates with his fingers).
And with its handle on the top.

In order to understand the technique of the inventive process it is necessary to consider inventive activity from multiple levels during each stage of the creative process.

And this is exactly what we are going to do.

Table 1 is a structured diagram of the creative process. Letters A, B, C, D, E, and F represent different *stages* of the process. Numbers 1, 2, 3, 4, and 5 represent *levels* of the process. Each stage can be worked out on each of the Five Levels.

Later we shall discuss in more detail the differences between these levels. At this time we can define the following characteristics of the creative process:

Level One: Utilization of one existing object without consideration of other objects.
Level Two: Choosing one object out of several.
Level Three: Making partial changes to the selected object.
Level Four: Development of a new object, or the complete modification of a chosen one.
Level Five: Development of a completely new complex of systems.

Table 1

Levels	*Choosing the task*	*Choosing search concept*	*Gathering data*	*Searching for idea*	*Idea found*	*Practical implelmentation*
	A	**B**	**C**	**D**	**E**	**F**
1	Utilize an existing task	Utilize an existing search concept	Utilize existing data	Utilize an existing solution	Utilize ready design	Manufacture an existing design
2	Choose one task out of several	Choose one search concept out of several	Gather data from several resources	Choose one idea out of several	Choose one design out of several	Manufacture a modification of an existing design
3	Change original task	Modify search concept suitable to new task	Modify gathered data suitable to new task	Change existing solution	Change existing design	Manufacture new design
4	Find new task	Find new search concept	Gather new data relative to new task	Find new solution	Develop new design	Utilize design in a new way
5	Find new problem	Find new method	Gather new data relative to new problem	Find new concept (principle)	Develop new constructive concepts	Modify all systems in which new concept is implemented

Below are several examples of what belongs to different levels. [Note: these are actual examples from Soviet Authors' Certificates, the rough equivalent of American Patents.]

Level One Examples:

Authors Certificate #157,356.

A protective cap for the storage of compressed, liquid, or dissolved gases. The cap is made out of plastic with internal ribs for increased strength. This allows for cost reduction and savings of metal.

A common problem (*saving metal*) existed. An existing search concept (*replace metal with something less expensive*) was used. Finally, an existing solution (*make cap out of plastic*) is designed. This design is trivial –ribs inside the cup. Therefore, there was no need for a research or debugging process.

> ***Author's Certificate #362,335.***
> *A siphon for pumping liquid metal consists of a "u-shaped" tube, with a gas-permeable ceramic plug connected though a nipple to a vacuum pump with an intake from a horizontal pipe. This device allows for increased purity of pumped metal because a siphon is positioned with a stop-rod above the level of the container's sediment.*

To prevent the siphon from sinking into the sluggish sediment, the siphon has a support (*stop-rod*) —trivial task, trivial solution. [1]

Level Two Example:

> ***Author's Certificate #210,662.***
> *An induction-type electromagnetic pump. The pump consists of a body, an inductor and a canal. This pump is new because its inductor can move along the canal's axis.*

Electromagnetic pumps have been known for a long time. These consist of a pipe with a ring-type inductor placed over it. During work, one end of the pipe is immersed in the liquid metal. Usually an inductor is positioned above the level of the liquid metal. For the pump to start operating, metal has to be sucked to the inductor's level. There are several different solutions to this problem:

a. Place a starter inductor at the low end of the suction pipe.
b. Pour metal from the top, before the pump is started.
c. Lower the inductor, not the pipe.

Here, one solution (quite probably the best) was chosen —lower the inductor at the beginning of the work process without lowering the pipe itself. Then, raise the metal to the level of the working position of the inductor. From the Table, this is a Second Level, Stage D invention (*Choose one idea out of several*).

Level Three Examples:

> ***Author's Certificate #163,487.***
> *A method for interrupting a light beam by utilizing an explosion-driven shutter (for example, when making high-speed motion pictures). This*

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[1] Let me emphasize here that I am not saying that patents should *not* be issued on Level One inventions. Legal protection of such low-level inventions may have validity. We are talking about a different subject: from the psychological perspective, there is no creativity in inventions of this level.

invention is different because it proposes a "reusable shutter" by implementing a spark-discharge in liquid placed between two protective sheets of glass in such a way that their surface, in neutral conditions, touches the light beam of the optical system.

Previous methods for the instant interruption of a light ray depended upon destroying the glass; thus, making it a one-time shutter. Changing the physical state of the shutter gives it a new property. The liquid "shutter" is reuseable. Here we have Stages D and E worked out on Level Three.

Author's Certificate #256,956.
A method for removal of internal fish organs. This method is new because it proposes freezing the organs by inserting a device with a temperature below -5°C that will also preserve the quality of the fish.

Level Four Examples:

Author's Certificate #163,559.
A method to control the state of earth drilling tools while in use (i.e., while drilling wells). This invention is different from others because it proposes using a strong odor as an indicator of severe wear conditions of the drilling tool. This is accomplished by placing chemical ampoules inside the drill.

This is a Level Four invention because it proposes a new method for controlling the wearing process rather than modifying the existing process.

Author's Certificate #187,135.
An evaporative cooling system for electric motors. To eliminate a separate cooling system for electric motors, this new system proposes utilization of porous powdered steel impregnated with a liquid cooling agent for different working elements of motors. During activity, the cooling agent evaporates providing a short-term intensive and uniform cooling action.

Conventional cooling systems act from the *outside* —therefore they are cumbersome and ineffective. This invention proposes a pre-stored cooling agent *inside* the metal.

Level Five Examples:

Author's Certificate #70,000.
A method for producing powdered metals, alloys and other conductive materials. This method is different because electrodes made from these materials are connected in an oscillating circuit tuned in such a way that electrical sparks discharge and disperse the electrode material as powder.

This method became the starting point for electro-discharge technology for processing materials.

* * *

Of course, each stage and level can be broken down even further. However, qualitative differences between levels are more important than quantitative differences within each level.

Let me explain this through an analogy. It is impossible to study a substance (like water) *in general*. There are *qualitative* levels of water —ice, liquid, and steam. These substances have different characteristics and regularities. There are differences inside each level: Water at 4° is different from water at 99° and steam at critical temperatures is different from steam at temperatures below the critical point. However, interlevel differences do not play significant roles in the first step of structural analysis.

Perhaps the reader wonders what the relationship is between inventions of the First and Fifth Levels?

I have analyzed 14 classes of inventions from 1965 to 1969 revealing the following dispersal:

Level One	32.0%
Level Two	45.0%
Level Three	19.0%
Level Four	below 4.0%
Level Five	below 0.3%

Therefore, 77% (Levels One and Two) of registered inventions represent only new designs. In general, every engineer should know how to invent on these first two levels. There is no need to choose new tasks, new technical ideas, and so on throughout the range of these levels. There is enough knowledge and skills possessed by every engineer to provide effective solutions. On the other hand, there are sub-levels of Level Five, and the higher ones are involved with the utilization of new discoveries. It is typical[1] that today's inventive creativity belongs in the range between the Third and mid-Fifth Levels.

Quantitatively, this is less than ¼ of all registered inventions. However, it is precisely these inventions that provide *qualitative* changes in technology.

Differences between the levels in Stage D can be characterized by the number of trials and errors made by the average engineer while searching for a solution:

Level One:	1 to 10
Level Two:	10 to 100
Level Three:	100 to 1000
Level Four:	1000 to 10,000
Level Five:	10,000 to 100,000 and more

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[1] In the creative, rather than legal, sense.

On the higher sub-levels of Level Five, the amount of trials is infinite because there are no potential solutions to be found that can resolve the given inventive task.

Psychologists can precisely define the mechanics of both Level One and Level Two thinking processes because they are not different from the non-creative thinking process —different variants are sorted out while any bad variants are rejected. Each rejected variant further clears the problem and restates it.

Difficulties for traditional psychology appear when uncovering higher-level mechanisms of creativity. Theoretically, the number of variants is large; however, there is no doubt that an inventor does not sort out everything. Somehow, the inventor reduces the total potential number. From 100,000 possible trials, the inventor heuristically selects a block — let's say 100 trials. Here, the selection mechanism plays the determining role while further actions are usually done through the conventional trial process.

Heuristics (and, for the most part, any psychology of creative thinking) was developed with the hope of defining a mechanism for transforming 100,000 variants down to 100 variants. Experiments along this line are as old as Heuristics itself —and just as worthless.

The basic assumption is erroneous. There are no mechanisms to make the transition from a large search field (hundreds of thousands of trials) to a small, but essential, field (a hundred trials). Although the problem may require 100,000 trials, in reality the inventor attempts only 100.

This seeming contradiction can be explained. Psychologists only consider the action of a single person, while problems at higher levels are solved by the sequential efforts of many people.

Imagine a treasure hidden in a field of 100,000 acres. Thousands of people over several generations search the field trying to find the treasure. Each person digs an area of 200 acres. Sometimes these areas overlapped each other. Gradually it becomes apparent where digging has been in vain. Meanwhile, people still continue to dig. Finally, the one thousand and *one* treasure hunter happens by. He already knows the areas where he should not dig because his predecessors cleared them over the previous fifty years. He chooses another section of the field —and finds the treasure. Now the psychologist appears: "Tell me, how did you do it with such a small numbers of attempts?" In reality, it is very simple. All the "bad" areas were dug out by others during half a century of hard work. The new search area was reduced to a small size.

As an example, let's observe the process of inventing a compact variator.

A variator is a continuously variable speed transmission. It is important for industry to have a device that provides continuously adjustable RPM. The search for this type of variator had been in progress since the beginning of this century. Inventor E.I. Pirozkov, under the supervision of Dr. G. G. Baranov, began working on this problem in 1945. Earlier, Pirozkov had invented the hydraulic variator (Author's Certificate #70,842). Here we have an ideal circumstance: an inventor is working on a problem with which he has had previous relevant experience, while under the supervision of a scientist.

Let's see how this work went. Below is an excerpt from the magazine *Inventor and Innovator* from July 1969:

> *"Serious research work was done. A large number of local and foreign literatures were studied. Designs of all variators were studied in detail, with both the strong and weak elements of each variator determined. It was titanic, non-stop hard work. In spite of the success of his previous invention, Pirozkov understood that hydraulic, as well as pneumatic and electric variators, suffer from one significant defect that cannot be resolved. . . .*
>
> *". . . Not many variator experts paid attention to friction type. Many designs were threatened by obvious shortcomings. For instance, "dry" variators are unreliable because one friction surface is slipping over another. Therefore, it is necessary to firmly press the contacting pair together. In this case, forces of 20 to 30 tons act on shafts and bearings and can rapidly destroy them."*

It is interesting to note that it once was believed that the wheels of a locomotive must be made with teeth for better traction; otherwise the train would not move. Biased opinions about friction-type transmission probably derive from that time.

> *". . . Pirozkov recognized this. If he could remove their shortcomings, or at least minimize them, nothing could compete with friction-type variators. This became possible because of a simple yet very smart idea: if forces acting on the satellite gear redistribute so that they form a closed polygon their sum will equal zero. Under this condition, the intermediary body (the satellite gear) will be in equilibrium, whereas pressure on the shaft and bearings will be unloaded. However, there is a problem —in any variator one force is always changing its position. This means that it is necessary to find such a shape for the intermediary body as to allow balance of the satellite. It became clear that the combination of two truncated cones was an acceptable shape of the intermediate body to resolve this problem. . . .*
>
> *"This solution came unexpectedly. Pirozkov was on a business trip, breaking away from his every day routine of teaching and writing reports and presentations. On the train, a rare and delightful thought flashed suddenly inside him. As Einstein said, you do not need to write down a delightful thought. A diagram for a new variator appeared before his eyes. This was 1952. Seven years of hard work had passed since Pirozkov first faced the problem of variators."*

Let's analyze this seven years of work.

There was a wide-open field where thousands of people worked during the last 50 years. The inventor started from an area where he had personal experience — hydraulic variators. His explorations were unsuccessful, *and his search area began drifting throughout the entire available field*. At the same time, information from other areas was collected.

This very important characteristic of the actual inventive process completely dropped away during its psychological modeling. If a psychologist followed Pirozkov, he could record only Pirozkov's personal explorations without considering those of other inventors. Meanwhile, search area "drift" was corrected through information gleaned from other sections of the field. If Pirozkov had started work on this problem 20 or 30 years earlier, he would not have had as much information from the other sections, and his search picture would look quite different.

Today, evaluation of similar situations is done in reverse. If an inventor solved a problem that thousands of his predecessors could not solve, it would be said that he possesses extraordinary inventive ability. People do not consider that solving a problem without predecessors is much more difficult — the degree of uncertainty increases, and therefore the number of trials increases. Although it appears paradoxical, the more people are *unsuccessful* in solving a problem, the easier it is to solve. Each and every unsuccessful trial is additional information allowing for a better understanding of the problem — along with a reduction of the search area.

The turning point in Pirozkov's work began when the inventor restated the problem. Based on his errors, and information about other people's errors, he rejected the direction toward improving the most popular prototypes and paid attention to friction-type transmission. The search area shifted to that farthest away in the field. The transition was made from a field with a hundred thousand trials to a small area with only a hundred trials.

The idea of moving polygonal forces is widely used in the textile industry. However, the same idea can easily be rediscovered if the search area were to be initially limited by friction-type transmissions.

So, an expedient tactic (the heuristic approach we are looking for) should aim towards finding the bewitched "Snow White" and determine how to awaken her and other "Snow Whites" in neighboring kingdoms (industries). We can now see how far removed the picture of real inventive processes is from the processes directed by Heuristics.

◆

Let's make a small retreat.

Surveys show that some inventors do not want to know about any patent information before solving technical problems. Their main reason for this is that the information contained in patents forces one to consider trivial solutions and freezes the imagination.

Let's analyze this reason:

If it is required that we improve something (make an invention on Levels Two and Three), we can always find sections in patents containing information useful to study. In this case, patent information must be used before solving a problem. If it is required that we invent something new in principle (make an invention on Levels Four and Five), conditions for the task widen to such an extent that it is difficult to determine any specific patent information needed for study.

Now, let's look at a specific example:

There already is a method for determining mid-river depth. Measurements are made by a person swimming out to a certain point (or using a boat) and then lowering a pole or dropping a weighted rope. It is now necessary to find a new method of measuring depth —this time from the river's bank. The method must be simple, and the device should be light and compact so both travelers and geologists can use it.

The basic goal —measuring the river's depth from a boat or a raft —is rejected by the conditions of the task. There arises the question: *What area of any patent information can be used?* The prototype for our problem can probably be found in an invention from an area far removed from that in which we are searching. We can study patents about wells, steam boilers, acoustic and hydroelectric constructions, diving apparatus, and such. Maybe we need other classes of patent information —like pontoons or the building of hot water supplies.

In truth, a prototype can be found within any patent's class. This is a typical situation for problems solved within Levels Four and Five. This is why existing systems of patent information analysis do not work during the solving of an inventive problem of the higher levels.

* * *

From ancient times heuristic methods have been considered universally applicable. During studies of creativity, psychologists experimenting with different puzzles and other simple tasks considered the mechanism of creativity to be the same on all levels. One might as well try to develop a knowledge of shipbuilding by experimenting with paper boats.

A heuristic search for a solution in any search area consisting of 100,000 trials cannot be the same as a search in an area of only 100 trials. Completely different psychological mechanisms are required.

Lower level heuristic methods are described in G. Dickson's book *System Design: Inventing, Analysis and Decision Making* (Mir Publishing Company, 1969). This book contains simple rules: "Remember psychological inertia," "Utilize an analogy," "Consider yourself as the object. (Empathy)," and so on. These procedures are good for solving inventive problems of the first and, to some degree, second levels. For higher levels they are useless, and sometimes even harmful. This was confirmed through problems solved in seminars.

Slogans similar to "Remember psychological inertia" are not valuable if a person does not know how to overcome that inertia. Recommendations to use an analogy are in vain when there are too many available analogies. Empathy only confuses the matter if the technical system is too complex.

Heuristics on this level can be taught to all engineers. Realistically, there is no difference between an invention made from 20 trials and one made heuristically in two trials. Heuristics can reveal its full strength only on the higher levels of creativity —where the lower level heuristic methods are powerless. But, higher level heuristic methods do not exist.

This is no accident.

During the process of evolution, the human brain adapted to solve problems that belong, by their complexity, to the first level. Natural evolution has made its contribution. Problems on this level can now be solved with complete confidence —even with excessive confidence. Scientifically developed mechanisms for thinking (including heuristic methods) are good for the second level. However, they are absolutely unusable for work performed on the higher creative levels.

Natural selection helped to develop and secure mechanisms relative to the first levels. If a person was born with heuristic abilities of the higher levels, he did not have any advantages —in fact, just the opposite.

Nature didn't develop higher level heuristic methods because of the lengthy time needed for each cycle. A person simply did not have time to accumulate heuristic experience while developing one or two Fourth Level inventions.

Evolution went its own way, developing dependable systems out of unreliable elements. There is no inventor that has the capacity to produce 100,000 trials.[1] However, inventions that required this number of trials are, nevertheless, made. A field with 100,000 trials can be amply covered with a thousand areas, each containing 100 trials.

Therefore, heuristic methods that seem to play major roles on the higher levels, in reality manifest themselves only slightly during the problem solving process of a handful of lower level inventive problems. The results of

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[1] Edison found solutions of Level Four problems through a large number of trials. However, Edison did not work alone. These trials were performed by a large organization of his employees and associates.

two surveys, as well as a quarter-century of personal observations by inventors (including ones made during seminars), the analysis of survey information and, finally, my personal experience gives me the confidence to state categorically that inventions of the higher levels are made without higher heuristic methods. Instead, people applied the same methods used when solving lower level inventions.

The tragedy of the inventing process is that people use methods for higher level problem solving that are relevant only to the lower levels.

⁂

Quantitatively, problems from different levels differ by the amount of trials and errors necessary in order to find a solution. But why does one problem require 100 trials, and another 1,000 times more? What is the *qualitative* difference between them?

Comparative analysis of some problems allow us to answer this question.

On Level One: A problem, and its means of solution, exists within an area of one *profession* (one specific section of an industry).

On Level Two: A problem, and its means of solution, exists within an area of one *industry* (machine building problems are solved by methods known within the same industry, only residing in a different area of that industry).

On Level Three: A problem, and its means of solution, exists within an area of one *science* (a mechanical problem is solved by mechanical means).

On Level Four: A problem, and its means of solution, exists *outside the boundary of the science* where the problem originated (mechanical problem is solved through chemistry).

On higher sub-levels of Level Five: A problem, and its means of solution, exists outside the boundary of *contemporary science*. (It is now first necessary to make a new discovery and then, based upon this new scientific data, solve the inventive problem).

When a problem appears, an attempt is made to solve it first on Level One, then Two, and so on. An inventor who begins solving a problem on Level Four, from the psychologist's point of view, starts from trial number one. In reality, he starts from trial *N*, where *N* is a large number.

Solving problems of the first level, a person first of all uses their everyday experience. As shown by L. Sekei's experiments,[1] this is exactly the reason why a person cannot, in the beginning, understand a problem. However, the difference between everyday experience and first level methods is not large. Therefore, only several trials are necessary to understand the problem. **"Ideal" tactics for solving on the first level practically coincide with "real-life" tactics.** This coincidence does not exist on Level Four.

When our ancestors encountered a lion, a problem also appeared: "Behind me is a high tree. A little further is a rocky mountain. There is a lake nearby. In what direction should I run?" Here is their line of thought: "It would be easier to get to the lake —but, who knows, maybe the lion is a good swimmer. How about the tree? There is not enough time to climb it. And, from my experience I know that it will require both time and another person to boost me up. All that is left is the mountain . . . let's go!"

Problems of this level of complexity were solved from one generation to another, and continue to be solved today by each of us in *everyday life situations*. Evolution has developed our thinking process mechanisms for this kind of problem.

Fourth level inventive problems are more complex than normal everyday situations. If we return to our lion model, then the complex inventive problem will look like this: "There are 500 beasts. Not all of them are lions. Some of them, sometimes, transform into snakes, some into sparrows, and others into something unrecognizable. Run to the lake? But there are a hundred lakes with many obstacles in every direction. And beside that, a lake's nature can be very complex —sometimes it can get shallow, and sometimes it moves. At the same time, shape-shifting beasts can probably change into alligators —and lakes are no problem for them. Trees. . . . They change their height right in front of your eyes —becoming pygmies or giant baobabs. Besides, there is something flying through the air. Either eagles or starlings. Nobody knows what is behind this hill, or behind other hills —and what is behind this shrub? This is a very difficult situation. However, there's no rush. I can analyze this situation during the next five years."

* * *

Now we can very accurately formulate the difference between problems of the first and fourth levels.

These are the specific features for first level problems, everyday life situations and experimental psychological problems:

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[1] "Knowledge and the Thinking Process," *Psychology of the Thinking Process*, Progress Publishing, Moscow, 1965, page 355.

1. The number of elements in the problem is small.
2. There are no unknown elements (very seldom there are even one or two unknown elements).
3. Simple analysis: Elements that need to be modified can be easily separated from elements that should remain unchanged under the conditions of the problem. It is easy to trace interrelationships between elements.
4. A short time is given to solve the problem.

Fourth level inventive problems are different:

1. They have a large number of elements.
2. They have a significant number of unknown elements.
3. They are difficult to analyze (hard to separate known elements from unknown elements); it is almost impossible to build a complete model that takes into account all the relationships between elements.
4. A long time is given to solve the problem.

❦

During the process of evolution, our brain learns to find approximate solutions to simple problems.

However, it does not develop mechanisms for slow and precise solutions to complex problems.

Even if we knew with precise accuracy everything going on in the head of good inventor, we would not be any closer to the development of tactics relevent to the fourth level. We would find that an inventor solving fourth level problems uses the same tactics as were used to solve a first level problem.

Higher order heuristic methods cannot be discovered — simply because there are none. They can, and must, be *developed*.

Part 1-3

Inventing Methods of Inventing

In 1953, American psychologist A. Osborn tried to improve upon the trial-and-error method. Attempting to solve problems with this method, an inventor first proposes an idea: What if we do *such-and-such* —then repeats this process whether or not it results in an acceptable solution. Some people can generate ideas very well just by the nature of their mind, but they cannot analyze these ideas. And *vice versa*: some people are more adept at critical analysis of ideas than at the generation of ideas. Osborn decided to separate these two processes. One group received a problem and only generated ideas —no matter how outrageous those ideas were. The other group only analyzed the ideas.

Brainstorming, as Osborn called this method, doesn't eliminate chaotic searching. In reality it makes searching even more chaotic. As we've seen, these attempts follow along vectors of inertia for long periods of time. They are not just chaotic —they mostly point in the wrong directions. Therefore, returning to the original chaotic search method is actually an improvement.

The main rules for brainstorming are not complicated:

1. An idea-generating team should be comprised of people from different fields.

2. Ideas should be generated in such a way that anyone can express any idea —including errors, jokes and fantasies —within a one-minute time limit. Ideas can be expressed without providing proof. All ideas are recorded.

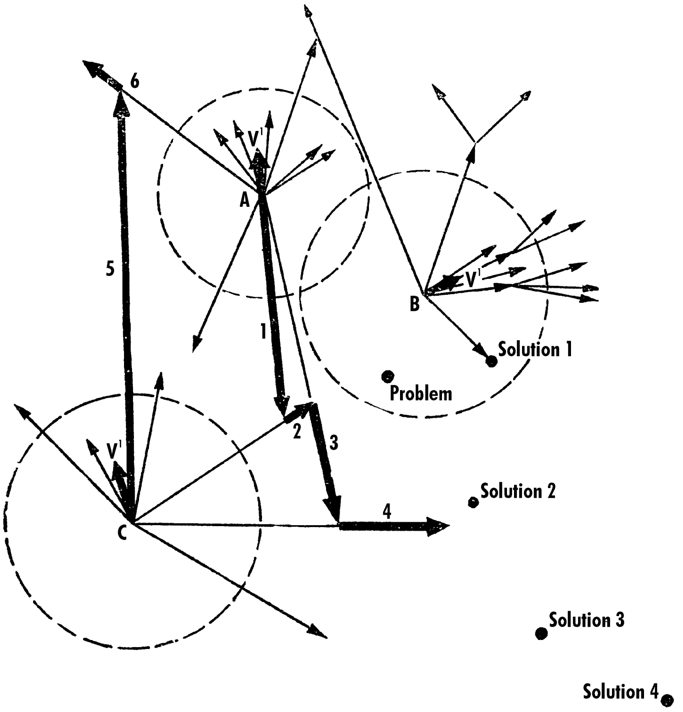
3. No criticism is permitted during the generation of these ideas, not only through words, but also through silence or even in the form of skeptical smiles. Members should maintain a free and friendly relationship during the "storm." It is preferable that ideas proposed by one member should be picked up and developed by others.

4. During analysis all ideas, even those that seem wrong or frivolous, should be attentively analyzed.

Usually, the team generating the ideas consists of six to nine members. The time spent for the brainstorm is twenty minutes.

Figure 3 shows a brainstorming session comprised of three participants (*A*, *B* and *C*). They each have different areas of expertise (shown by three different circles); therefore, their approaches are not locked along the Inertia Vector as is usual. At the same time, the rules for brainstorming stimulate more forthcoming —even fantastic —ideas. Brainstormers escape the narrow boundaries of their expertise to the place exactly where innovative solutions reside.

Figure 3. *American psychologist Osborn improved the trial-and-error method by proposing "brainstorming."*



In the diagram there is an additional important brainstorming mechanism —the interaction and development of ideas. Member *A* of the brainstorming team expresses an idea (*1*). Immediately member *B* makes changes, and a new idea (*2*) appears. Now member *A* sees his original idea differently. This idea is allowed to continue its development (*arrow 3*). A chain of ideas (*1-2-3-4*) forms, leading toward the solution on Level Two. It is also true that this mechanism for a successive (*5-6*) development of ideas sometimes leads in the opposite direction of the solution.

In John Dickson's book *System Design: Inventing, Analysis, and Decision-Making* there are records of several brainstorming sessions. Here is an excerpt from one record showing the solution to the problem of how to separate green tomatoes from ripe ones:

Tom: We can screen them by color. In this case, we probably need to use a color sensor.

Ed: Emitting, or reflecting, characteristics. Green tomatoes should have higher reflecting abilities.

Dave: Hardness. We press on one —gently touch it.

Dick: Electric conductivity.

Tom: Electrical resistance…

Dave: Magnetism.

Dick: Size. Are green tomatoes smaller in size?

Ed: Weight. Ripe tomatoes will be heavier.

Tom: Size and weight are co-dependent.

Dave: Size and weight give you density.

Ed: Specific gravity. Red tomatoes have a lot of water, therefore they have specific gravity closer to that of water.

Dave: Do they float or sink?

Dick: Maybe it's possible to screen by density if they float or not.

Ed: Not necessarily in water. . . . Maybe other types of liquid.[1]

We know of several different types of brainstorming:

Opposite brainstorming. Looking for defects in machines and technological processes that reveal shortcomings. These may lead to the discovery of new inventive tasks.

Individual brainstorming.

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[1] Other examples can be found in an article by V. Gildy and K. Shtarky titled "Ideas are Needed," *Inventor and Innovator*, 1971, issue 5-6.

Coupled brainstorming.

Two-stage brainstorming. Two stages, ½ hour each, with intermissions containing free discussions about the problem.

Sequential brainstorming. The first statement of the problem is brainstormed, then solutions are brainstormed, then the development of each idea into a design is brainstormed and finally "how to manufacture" is brainstormed.

During the past several years, brainstorming concepts have been used to solve problems in various projects, in designing equipment and in several types of practical tests. Its success is explained not because of any advantages in the brainstorming method, but because of inherent shortcomings in the traditional trial-and-error method. If the temperature is -100°, then the transition to -50° feels like a Spring thaw.

The absurdity of brainstorming as a searching process is compensated for by its quantitative factor —problems are attacked by a large team. Brainstorming appears effective from the outside because problems are solved in one day. However, the real gain here is mainly elusive: 50 people spend in one day as much time as one person in fifty days. Considering time spent on preliminary preparation, the brainstorming process always requires several hundred person-days. Any gain here is achieved only through the reduction of inefficient attempts along the direction of the Inertia Vector.

The brainstorming process has produced positive effects, as when used to find new ways of marketing. However, it cannot produce significant results when dealing with more complex problems which cannot be solved on the higher inventive levels. This is the brainstorming process ceiling — solutions of the second level.

There are two ways to improve the brainstorming process. Make it professional (we'll discuss this later) and increase the effectiveness of the process itself. The second direction was studied by the Public Laboratory of Methods of Inventiveness at the Central Committee All-Union Society of Inventors and Innovators using problems for which researchers already knew answers. With this type of structured experiments, experimenters placed themselves above the maze through which the experiment wandered and were clearly able to see whether different steps would lead to an answer or to some other direction.

They found conceptual defects in brainstorming. Brainstorming rejects control of the thought process, and this is its main defect. Brainstorming really helps in overcoming inertia —thought moves from a dead spot, gaining speed but often missing the point where it should stop. Tens of times during the experiment it was found that one member of the process expresses a thought, which should lead in the right direction. Another picks up the thought and develops it. There are several steps left to get to the final stretch. At that moment someone proposes a completely new idea — the chain breaks and the team again finds itself at a starting position.

During brainstorming, any criticism is prohibited. Hidden criticism is, nonetheless, almost inevitably expressed in the form of new ideas that supress development of a previous idea.

We ran brainstorming sessions forbidding hidden criticism. It was forbidden to break the development of any chain of ideas, and it was required that each idea be developed to its logical conclusion:

> "What if we divide the ship into two parts? . . . I would like to suggest we divide it into many parts . . . a ship made out of blocks or small particles . . . out of powder . . . a ship made out of separate molecules . . . a cloud of particles . . . out of separate atoms?"

This structure increases the effectiveness of brainstorming but the time factor also increases —the session continues over several days. This is not just brainstorming; it's brain*blitz*.

During this brainblitz its possible to control the thought process, however it doesn't make much difference —the search, as usual, is done by a simple sorting of variants.

* * *

Some inventors probably had a very tempting thought: would it be possible to obtain for each problem a list of all possible variants? Having such a list, there would be no risk of missing any possibility.

To compile the full list of variants requires a special method. Such a method (or one similar to this method) is the so-called *morphological analysis* developed by the well-known American astronomer F. Zvikki in 1942.

It may seem strange that a methodology for organizing the creative thinking process was developed by an astronomer. Actually, this is quite logical. Astronomy was the first among the sciences to be faced with large dynamic systems —the stars and galaxies —and was the first that felt the necessity for methods to analyze these systems. In the beginning of the twentieth century, Netherlands astronomer Ejnar Hertzsprung and American astrophysicist Henry Norris Russell developed the "spectum-luminance" chart. One axis of the chart depicts star spectrum classes, while the other axis shows their luminance. It was found that each spectrum *class* of stars has a certain luminance. Thus, order is immediately introduced to an infinite number of stars as they organize themselves along this line (the main sequence). Moreover, our understanding of star development also became more orderly —as a star ages, its spectrum changes and the star shifts along the main sequence line.

The Hertzsprung-Russell chart exerted great influence on astronomical thinking (the same as Dmitry Mendeleyev's table on the thought process of chemists). It was improved over the following years, and new lines were found for Giant and Dwarf stars. New charts two- and three-meters in size were soon constructed.

In 1939, Zvikki, analyzing empty areas on the chart, made an outstanding discovery. He theoretically proved the existence of neutron stars. Three years later, when Zvikki was offered work in rocket design, he brought along this method of using multidimensional charts and named it Morphology.

The essence of this method is the building of multidimensional tables (morphological boxes) in which the axes are the main characteristics of a given combination of objects. Suppose we need to find the optimal design for a locomotive backpack for divers. We can begin our search by asking variations of "*What if we do this. . . .*" For example, *"What if we use an electric motor and battery?"* Or, *"What if we use the energy from compressed air with a turbine?"* Or, *"What if we use compressed air —not with a turbine, but with a flipper in the form of a fish tail?"*

Utilizing morphology before sorting our ideas requires the building of a multidimensional table with, in our case, the form of utilizable energies (electrical, mechanical, chemical, etc.) for one axis. The second axis should represent engines of locomotion (electric motors, turbines and rocket engines of varying types). The third axis should be the types of available impelling elements (screw, flipper, rocket). This box covers almost all combinations.

Of course, this box would be more complete with more, and longer, axes. So, the box made by Zvikki for forecasting only one type of rocket engine had eleven axes and 36,864 combinations!

Here, strictly speaking, is one of the major shortcomings of Morphology. During inventive problem solving with only mid-level difficulties it is possible to have hundreds, thousands, and millions of variations in the box.

There are other defects to this method. Absence of certainty that all axes —and all classes along those axes —are considered during the construction of a box. The intuitive search of variants has been replaced with the intuitive search of axes and classes. There is a gain because we are moving from sorting out small (and therefore easily lost) variants to sorting out large elements (axes and the classes along them). There is also a loss. If we miss just one axis we automatically lose a very large group of variants. With axes, as with variants, the most trivial instances jump immediately into our sight —while the most interesting hide behind psychological barriers. Nevertheless, Morphology is a great step forward compared with conventional variant sorting processes.

This method is most effectively used when solving general design problems, like designing new machinery, or searching for new conceptual solutions —for example, the designs for new snowmobiles. We can build a morphology box with the following axes —and classes along these axes:[1]

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1. Engines:

Internal combustion
Gas turbines
Electrical
TurboJet
Sail *(for snowmobiles, this may still have meaning)*

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2. Impelling Elements:

Uni-wheel (driver's compartment inside of wheel)
Conventional wheels
Ribbed wheels
Oval wheels
Square wheels
Cylindrical pneumatics
Caterpillar treads
Snow screws
Ski
Vibro-ski
Air screw
Hover
Walking engine (legs)
Spiral engine
Spring leafs
Impulse frictional engine
Snow Jet engine
Rotary plates

And not less than 15 other types of engines

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3. Body support:

On the engine
Directly on snow

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4. Type of body:

Open
Closed with one cabin
Catamaran
Double cabin
Tandem type

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5. Suspension:

By engine
By special shock absorbers
Without suspension

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[1] For information about different ones see G. Lipman and G. Turgenev, *Snowmobiles*, Knowledge Publishing Company, Moscow, 1967.

6. Control of snowmobile:

Changing position of engine
Changing position of impelling elements
Snow rudder
Air rudder

7. Providing backward motion:

Reverse engine
Reverse impelling element
Without reverse

8. Brakes:

By main engine
By auxiliary engine
Air brakes
Snow brakes

9. Prevention from freezing to ground:

Mechanical
Mechanical, with help from engine
Electrical
Chemical
Thermal
Without prevention

We have covered far from all possible axis and classes. Meanwhile, there are more than one million variants in this box. Morphological methods, we can admit, are therefore useful as an auxiliary method.

* * *

It is possible to make a list of questions, or suggestions, in order to make the sorting of variants more manageable. These are called "Pilot Questions." Many authors submitted different lists early in the 1920's.

In the United States, the most common was the list of questions developed by Osborn. There are nine groups of questions in this list, such as: "*What can be reduced in the technical system?*" Or, "*What can we turn upside-down in the technical system?*" Each group of questions has sub-questions. For example, the question "*What can be reduced?*" includes the sub-question "*Is it possible to make something denser, compressed, thinner —or, can we utilize a method of miniaturization; or a method to shorten, narrow, separate or segment?*"

One of the most useful lists belongs to the English inventor T. Alorti.[1] Here are some items from his list:

- *Can one make a fantasy analogy from biology, economics and other fields?*
- *Can one establish variants, dependencies, possible interrelationships, and logical coincidences?*
- *Can one find opinions from people with no knowledge in this matter?*
- *Can one imagine being inside the mechanism?*

In essence, each question is a trial or series of trials. Making these lists the authors, naturally, are selecting relatively strong questions from their inventive experience. However, these selections are made without studying the internal mechanism of the inventive process. Therefore, these lists point out what to do, but not how to do it. For example: how can we establish variants —or trace possible interactions if there are many variants? Or, how can we make an analogy of imaginatively entering into a mechanism in order that this action will lead to the solution of the problem?

The *Pilot Questions* method helps reduce psychological inertia to some degree —but that's all.

* * *

In trying to improve brainstorming, it's not difficult to see that there are two possibilities:

1. Develop not one method, but a set of different methods.

2. Organize the process in such a way that this set of methods is used by a group of specially trained people who will slowly gain experience of the methodical problem solving process.

Based on this assumption, the American researcher William Gordon developed Synectics, and founded the inventing firm Synectics, Inc. in 1960.

"Synectics," in Greek, means a combination of different elements. The company flyer contains the following definition: "Synectics Groups are groups of people with different occupations that gather together with the purpose of trying to creatively solve problems through unlimited training of the imagination, and by combining elements that are not superimposable."

The foundation of Synectics is based on brainstorming organized in groups. These groups gain experience and methods, allowing them to be much more efficient than accidentally combined or gathered teams. At Synectics, groups usually include people with different expertise. Synectics

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[1] *Inventor and Innovator*, 1970, issue #5.

charges from $20,000 to $200,000 for training such groups. Their customers are General Motors, IBM, General Electric and other large companies.

To begin solving a problem, a Synectic group starts by learning the problem as it is given. Then, the team narrows the problem, transforming it into a structure that they all understand. Then the real problem solving process starts. This process is based upon the transformation of the unfamiliar into the customary, and then back again into the unfamiliar. This means that systematic attempts to see a problem from a new perspective are used to remove psychological inertia. Synectics uses four different types of analogies in order to accomplish this:

1. **Direct Analogy (DA):** The given subject is more or less compared to a similar subject from nature or another area of technology. For example, in order to improve the process of painting furniture, DA may consist of an analysis of how rocks, flowers or birds naturally acquire pigment. Or, how paper is painted. Or, how a color image is produced in a color TV.

2. **Personal Analogy (PA):** Also called empathy. Here the person solving the problem "becomes" the system, imagining its feelings and sensations. Applied to the previous example, one could imagine oneself as a white crow wanting to change color.

3. **Symbolic Analogy (SA):** Generalization and abstract analogy. For example, the property of a wheel's grinding surface is an SA for roughness of the grinding wheel itself.

4. **Imaginary Analogy (FA):** Some imaginary creatures are introduced into the problem. These creatures perform whatever the conditions of the problem require. Or, some magical means (like invisible hats or speeding shoes) may be introduced.

The process of a Synectics meeting should be recorded and analyzed with the goal of improving the solution tactics.

Synectics is the most powerful inventive methodology that exists outside the Soviet Union. However, Synectics has its limitations. Synectics is a set of methods removed from the study of the objective laws of the evolution of technical systems. Second level problems and the lower sub-levels of Level Three problems are the limits for Synectics.

* * *

Increasing the efficiency of solving high-level inventive problems requires heuristic programs that allow the replacing of simple sorting variants with goal-oriented (towards the solution area) movement. In other words, a heuristic algorithm is needed that is capable of making the transition from fourth level problems with 100,000 trials to first level problems with only 10 trials.

This algorithm cannot be developed based upon the experience of a single inventor, or even a group of inventors. In order to develop a working heuristic algorithm the following is required:

1. Define the objective laws of technical system development.
2. Analyze massive amounts of patent information data.
3. Develop a program for the solving process where each step "organically" evolves from the preceding one.
4. Continuously select and improve the program during its practical application.

I began this work in 1946. I don't wish to say that I had in mind, even then, development of a general methodology of inventing. The original goal was much simpler: find principles to help in my personal inventing practice. However, in 1946, inventing became secondary. It was obvious that to "invent methods of inventing" was the most interesting and important problem. General inventions became, for me, "experimental rabbits" used for testing algorithms to solve inventive problems. In the following chapters we will learn in more detail the primary aspects of this inventive methodology, as well as the algorithm for solving inventive problems. At this time, I would like to mention that an algorithmic methodology considers the process of solving inventive problems as a sequential action to define more accurately —and solve —technical contradictions. The thinking process is directed toward an ideal method, or an ideal device. The systematic approach is used in all stages of the solution process. This algorithm also includes specific steps for removing psychological barriers. In addition, it has also developed an informational system consisting of the typical principles used to remove technical contradictions.

To develop a practical and workable methodology for solving inventive problems, each recommendation must be tested with real applications.

The first and fundamental paper on this subject was published in 1956 in *Questions of Psychology*, a magazine very far removed from the field of technology. The article did not attract the attention of inventors. This situation changed only in 1959 when the newspaper *Komsomol Truth* [a publication of the organization for teenage Communist Party members] wrote about the practical results this methodology produced. After that, the basic concepts of the methodology were published in the magazine *Inventors and Innovators*.[1] Discussions continued in its pages throughout the following year.

Most of the participants in these discussions expressed confidence that the methodology would become a strong weapon in the hands of thousands of innovators and technology manufacturers. The Expert Committee on Inventing and Discovery at the Soviet Ministry approved the methodology.

In concluding the discussion results, the publisher wrote:

> *"Today, at a time of strong development of science and technology, when creativity becomes the concern of millions of Soviet people, the problem of discovering the secrets of inventive creativity —developing useful rules and working methods to improve technology —becomes an increasingly vital task."*

From 1961 to 1965, a series of works was published to help inventors use a methodology for solving technological problems, as well as for validating and improving the methodology itself. At the same time there was a continuous study of the experiences gained by inventors. There were two surveys of innovators from more than 180 Soviet towns. Seminars were held in Moscow, Baku, Sverdlovsk, Novosibirsk, Dubna and other cities on the theory and practice of innovation. The number of inventions made with the help of this methodology exceeded 3,000.

In 1968, the Central Committee of VOIR [All-Union Organization of Inventors and Innovators] formed the Department of Methodology for Technical Creativity —and one year later, the Community Laboratory for Methodological Innovation. This laboratory was the combined effort of many enthusiasts. It developed and published programs, textbooks, problem lists, and seminar handouts. The organized training of teachers began. Now the theory and its practical application are taught in both communal and public institutions of creativity, in schools for young inventors and in universities of technical creativity.

A public research institute of technical creativity has been open in Baku since 1971. This institute prepares inventors capable of solving complex technical problems in different areas of technology. The main subject of the institute is the Algorithmic Methodology for Solving Inventive Problems. The ability to use this heuristic algorithm was developed during its practical application —first on practice problems, then on real-life problems.

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[1] G. Altshuller and P. Shapiro, "Expulsion of Six-Winged Seraphims," *Inventor and Innovator*, 1959, issue #10.

Part 1-4
Through Knowledge, not Numbers

The evolution of technology adheres, like any other evolution, to the laws of dialectics. Therefore, a general theory for inventiveness must be based upon the application of dialectic logic to the creative act of technical problem solving. However, logic alone is not enough to develop a working methodology. It is also necessary to consider the specifics of the instrument with which the inventor works. This instrument is unique—it is the human mind. With the correct organization of creative work there is a maximization of the stronger elements of human thought processes like intuition and imagination. However, the weaker sides of the thought process—such as inertia—must also be considered.

Finally, a theory of inventiveness should gather much from experience and practice. An experienced inventor slowly develops his own methods for solving technical problems. As a rule, the number of these methods is limited, and related to a single stage of the creative process. This methodology of inventiveness is then generalized by critically selecting the most valuable principles.

It is understood that, in order to do important and great inventing (inventing that relates by our classification to the higher sub-levels of Level Five), it is necessary that the time be historically right. In addition, conditions must be favorable for creative work. Also, conspicuous human abilities such as persuasion, industriousness, courage and erudition must be present. An inventive methodology is not a self-study course or a prescription for churning-out inventions. Its goal is the scientific organization of the creative process. The importance of this organization is clear from the examples given in the first chapter. However, I would like to give you one more example that often appears in the magazine *Inventor and Innovator*.

> *“I was banging my head over an invention. I was trying to figure out how to automate the deployance of rescue devices into water. Nothing was working out.*
>
> *“I found myself sitting on a train with nothing to read, thinking about my lifesaving devices. A young, attractive woman walked in. ‘Please sit down,’ I said, offering her my seat. She thought for a moment, then thanked me, rejecting my offer by saying—‘I must leave soon.’*

> *"I watched her while she left. Suddenly I noticed the way the train doors closed. How many times had I seen the same thing? Now, for the first time, I was really paying attention: cylinders with pistons. They fit my invention perfectly.*
>
> *"Later, I got my Inventor's Certificate."*

This was told for the purpose of highlighting the traditional moral that "anything can happen." Now, pay close attention to how badly the search for a solution was organized. Rescue devices such as boats must be removed from a ship and lowered into the water. Cylinders with pistons are, in general, a trivial solution lying within the first level. Nevertheless, it took a combination of coincidences (train, stranger, glance at door) to arrive at this simple solution.

Once while reviewing patent descriptions, I stumbled over an invention under the name of "diving boots."[1] I already knew it was inevitable that inventions often arrived after their time, but here was a case incredible in its obviousness.

The Inventors wrote:

> *"There are already known diving boots. As a rule, they are made so that one-size-fits-all. Therefore, they are too large for one diver and too small for another. These new boots eliminate this shortcoming because they have a moving toe with elongated slots. A screw passes through a slot to hold the toe in a certain position relative to the foot of the diver."*

So, during at least 100 years, lead boots for divers were made in one size. For 100 years, diving boots were too small for some people and too large for others. For 100 years, people worked in uncomfortable boots while nobody designed boots with an adjustable toe.

This invention is very simple. It doesn't beg the question: "How can this problem be solved?" A schoolboy is capable of solving it. It is more difficult to understand the reason why this problem was *not* solved 70 –80 years ago.

People can say, after all, that diving boots are trivial things. First of all, they are not so trivial. Second, more important inventions are also developed late —sometimes very late. Lenses and glasses were known 300 years before the telescope was invented. For 300 years nobody thought to take one lens and view it through another lens. Perhaps there was no need for telescopes; but, military leaders from ancient times needed spyglasses. Nevertheless, the first spyglass invention came 300 years later.

Why?

It was generally believed that lenses distort an image. Two consecutively placed lenses must, by "common sense," produce twice as much

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[1] Author's Certificate #132,499. *Inventors and Trademarks Magazine*, 1960, #19.

distortion. This "psychological barrier" prevented the development of the telescope for 300 years. However, it is difficult to name another invention that had a greater and more revolutionary influence on humanity's world outlook than the telescope. Telescopes revealed for humans the distant stars, and transported humanity to the infinite boundaries of the universe. Telescopes have undermined the foundation of religions and the image of our world as a limited space. Utilization of the telescope stimulated a great deal of scientific development. It is difficult to imagine how much further advanced our civilization would be if the telescope had appeared "on time."

The following words appear in one of Einstein's works:

> *"The history of scientific and technological discoveries does not sparkle with much independent thought and creative imagination. Humanity needs some form of outside stimulation in order for a needed idea to ripen into reality. Humanity has to clash with situations head on before an idea is born."*

Unfortunately, contemporary innovation convincingly supports this bitter statement.

Let's look for example at Author's Certificate #162,593 concerning an independent underwater flashlight. Deep-sea divers, in order to prevent an involuntarily rise to the surface, have to fasten heavy lead plates to themselves. A new idea came about to replace these heavy plates with flashlight batteries. It's a very simple and witty idea. When previous flashlights were developed, their every gram was counted in order to reduce additional and unnecessary weight. No one paid any attention to the dead weight inherent in the diving suit itself.

Utilization of passive weight is a principle that has been well known for a long time in the aviation industry. Even in the 1940's, Iliushin [a famous Russian airplane designer/manufacturer] built airplanes with shielding that performed additional structural functions such as ribs, airframes, and so on.

The overwhelming majority of inventions are based on principles that, in one form or another, are already used in solutions for problems residing in other industries.

Let's consider two inventions:

> ***Invention #112,684, 1958.***
> *A device to clean the surface of pylons placed in water. This device is distinguished by having a donut type float placed over the pylon. This float has spring-activated ribbed rollers for cleaning the surface of the pylon during the vertical movement of the float forced by water waves.*
>
> ***Invention #163,892, 1964.***
> *A device to clean ocean seaweed from an intake pipe of a pump. This device is distinguished by having a yoke (collar) with knives over the intake pipe. The cleaning of the pipe is done during the vertical movement of the float on waves."*

These inventions belong to different patent classes. However, they have the same basic idea —a cylindrical construction (pylon or pipe), placed in water, is capable of self-cleaning by a donut-type float that moves along the construction during the rising and falling of waves. However, the second invention was made only six years after the first, and even more years will pass by until somebody uses this idea again relative to another construction —and not necessarily a cylindrical one.

A low-level of inventive organization is clearly seen here. There is a common principle —a common key —for a complete group of inventions. However, after one application, that key is thrown away and the next time the search for a solution must be done all over again by the trial-and-error method.

It could be even worse —the key may be thrown away without ever being used. Once there was a sarcastic editorial note in the magazine *Inventor and Innovator*. It said that inventor R. Petz, from Saint Petersburg, received Author's Certificate #22347 for designing a pneumatic protection device for locomotives during a collision. The inventor had suggested placing an air-inflated shock absorber on the front of a locomotive. The editorial comment ended as follows: "Of course, during the first serious collision, this invention will 'blow-out' both literally and figuratively." So, the invention literally "explodes." On the other hand, in the figurative sense, it has withstood the test of time —the idea of an air shock absorber was discovered by other inventors. The Soviet inventor Morev received Author's Certificate #115,000 for an air-inflated shock absorbing vest for airplane passengers. Soon afterwards, the American inventor Bell received patent #2,931,665 for a similar shock absorber for car drivers. Later, for French railroad tracks, air-inflated shock absorbers were used to prevent cargo from being damaged during transportation. Finally came the announcement of experiments in Hamburg utilizing inflated, rubberized nylon sacks to protect a ship's cargo during rolling ocean conditions.

Analysis of thousands of Author's Certificates and patents demonstrates the existence of several common principles forming the bases for the majority of contemporary inventive ideas.

Here is one example: Straight beams for supporting mining tunnels were replaced with arched beams for better counteraction against pressure developed from the heavy stratum above. Some years later, the same principle was used in the construction of hydroelectric power stations: straight dams were replaced with arching ones. The next step for the mining industry was to make the transition from rigid arching beams to flexible beams with joints. The same thing happened when arching dams were replaced with flexible ones.

Excavator bucket (power shovel) manufacturing is a different industry; however, here the same logic still exists. The shovel bucket's front edge was initially straight and toothed. Even from the outside, it resembled a straight dam. Then, an arched bucket appeared. "It might be presumed," I wrote in the first edition of this book, "that the next step, not yet made, will be the development of a pliable joint type bucket." My forecast was correct. Soon I saw Author's Certificate #284,715: "A bucket for a machine to load ore has a bottom with a cutting edge, sides and back walls. To reduce the shearing force, the cutting edge of the bottom is made of sections, each connected to the bottom with a joint."

Continuous analysis reveals that a common principle can span different industries —a distinct tendency of the transition from linear to curvilinear, from planes to curved surfaces, and from cubes to spherical designs.

There are other common principles, each yielding their own set of inventions. All these are different patentable inventions based upon common principles. Knowledge of these principles, along with the knowledge of how to use them, creates the possibility for increasing the efficiency of creative work. This is one of the main prerequisites for developing a rational system for solving inventive problems.

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When people ask the question, "How do inventions appear?" they often forget that inventive creativity is not static. People in different historical periods had different ways to invent. Therefore, statements relating to the creativity of contemporary inventors cannot be based upon facts associated with inventions made 50 or 100 years ago. However, it is often done this way. Time elapsed since the invention should also be taken into consideration because, when the story of an invention is told, the conclusions drawn from it have power to help solve contemporary technical problems.

N. Sereda wrote in his book *Worker-Inventor*: "It is known that the British inventor Henry Bessemer (1813-1898) was not a metallurgist, and lacked considerable important technical information. However, he did discover, through empirical methods, a means for converting liquid cast iron into steel by blowing compressed air through the molten metal inside a rotating converter. He received a patent for this invention in 1860. Therefore, among inventors there are those people who do not possess necessary theoretical knowledge, and their inventions are a result of inquiring thought and tenacious, tedious labor."[1]

Bessemer, in fact, made his invention by groping his way along. Today, a hundred years later, in the same field of metallurgy, the search for something new using an empirical method is quite irrational. For example, within metallurgy, consider the narrow and specific area of new heat resistant alloy development. Academician P. Kapiza has this to say about it:

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[1] N. Sereda. *Worker-Inventor*. Liesma Publishing, Riga, Latvia 1961, page 26.

> *"The utilization of empirical methods in this research usually involved a labor-intensive process of collecting large amounts of data, along with the complicated process of its systematization and further utilization. There are about 100 elements known to form alloys. Suppose the description of a necessary property of one type of metal or alloy —its strength, conductivity, heat resistance, elasticity, and so on — requires one page. To describe the characteristics of each element would then require 100 pages. To describe alloys composed of two elements would require 10,000 pages. Three-element alloys require a million pages. Therefore, the empirical method of investigation has its own natural limit."*[1]

In fact, there are not enough human lifetimes to randomly sort out all possible variants for solving contemporary technical problems.

"Multicomponent alloys," continues P. Kapiza, "may have been found accidentally; however, most likely they were found by the intuitive nose of a talented scientist —just as an experienced cook knows how to prepare tasty food. If there is such a thing as intuition, then there must be some kind of underlying regularity. The goal of science is to reveal these regularities."

In Bessemer's time, an inventor was forced to reach his goal through the trial-and-error method, relying upon patience and luck because there were no other available methods of creativity. The situation has now changed. An inventive problem, as a rule, can be solved through structured thought processes. The correct *organization* of the creative process now plays the major role —not the number of days, months, or years spent in blind searching.

Giving full credit to the patience possessed by inventors of the past, we must not forget that the contemporary inventor can, and must, work differently. Today, taking a long time searching for an idea or solution is proof of not just an inventor's persistence, but of a poorly organized creative process.

* * *

Creativity is quite compatible with systematic processes, characterized not by sudden illuminations and inspirations, but instead by its resulting accomplishments. If something *new* is created, then the work is *creative*. It does not matter how many trials and errors are made. Problems must be solved through *knowledge*, not through a large number of trials.

No one doubts that, for instance, the creation of a new chemical substance is a creative act. However, an endless number of chemical substances are built from the same "typical parts" —chemical elements. It is possible to try to develop new chemical substances randomly. In the past, alchemists did it exactly this way. It is possible to learn not only

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[1] P. Kapiza. "The Future of Science," *Science and Life*. 1962, # 3, page 22.

about "typical parts" (chemical elements), but also about the laws of their interaction. Contemporary chemistry is concerned about just that. The new substances developed and being developed by contemporary chemists are more complex than sulfuric acid "creatively" discovered by alchemists. However, who can say that a synthetic polymer —for example —is not the result of a creative process?

Creativity is a changing concept. Its meaning is constantly renewed. While one type of activity is excluded from the category of creativity other more complex activities are included. At one time, even simple arithmetic problems were considered representative of the creative process. In the fifteenth century, one scientist agreed to teach a merchant's son how to perform addition. He wrote, in a letter preserved into our time, that he could not teach the multiplication of Roman numerals. He suggested in the letter that the pupil be sent to Italy where, possibly, there were experts in such multiplication.

The essence of a theory for creativity lies in this: *problems today that are considered creative can be solved on a new level of structured mental processes that will not exist until tomorrow.*

Once upon a time, the idea of combining a steam engine with a ship to produce the steamboat —or the joining of a steam engine with a railroad truck to make the locomotive —was considered to be the highest flight of fantasy. The names of authors who imagined these ideas went down in history. But now, don't even try to remember the name of the inventor of atomic-powered vehicles. Simple principles for combining elements —once considered the height of creativity —are now common place. In *Basics of Inventiveness* there is described a problem that put Edison in an awkward position. The essence of the problem follows:

> *Edison personally interviewed everyone who wanted to work in his laboratory. He asked about their plans. He was interested if they had any ideas they would like to develop. Once, a young man told Edison that he had a miraculous idea.*
>
> *"Miraculous?" Edison asked.*
>
> *The young man explained:*
>
> *"I want to invent a universal solvent. You know, a liquid that will dissolve anything."*
>
> *"Universal solvent?" the astonished Edison asked. "Tell me, what kind of vessel will you store it in?"*
>
> *The young man stood in bewildered silence.*

Pioneer Truth Magazine offered this problem to fifth- through seventhgrade school children. The publisher agreed to give me a chance to review the answers. Out of 3,000 "Pioneers groups" taking part in the competition, 2,500 solved the problem that had astonished Edison.

Here are some of their answers:

Store the solvent under freezing conditions (6th grader).

Store the solvent as a solid substance (6th grader).

Make the solvent conductive so it can be stored in an electromagnetic field as plasma (7th grader).

Half a century ago, the idea of storing a universal solvent in a different physical state —in a chemically combined form or an electromagnetic field —would be a masterpiece of inventive creativity. Today, school children confidently handle these principles.

Will inventiveness die out because of this? New and more complex problems always appear —along with newer and more refined principles to solve them.

Suppose that the most "terrible" thing happens: it becomes possible to completely automate the process of solving inventive problems. Immediately, new problems will spring forth —problems on much higher innovative levels.

The world is endless, the universe inexhaustible, and the human brain will never be threatened with unemployment.

Part 1-5

The Ideal Machine

There is a naïve and widespread opinion that new machines, mechanisms, and devices appear from out of nowhere. In the beginning, there is *nothing* —then a great inventor comes along and develops a completely finished *something*. The Goddess Athena, if we can trust the ancient myth, appeared in the same way. A powerful axe stroke split Zeus' skull and an unharmed Athena stepped out in full armament. There she stood, with spear and shield, before the surprised eyes of the Olympian Gods.

Machines, however, do not appear from inside the head of an inventor completely "armed." Instead, they are born weak; slowly gaining strength by absorbing many inventions.

Figure 4 illustrates the two hundred year evolution of the screw propeller. Here, the thoughts of inventors flowed in three directions: windmill "wings," the Archimedean screw, and the paddle wheel. Each prototype develops through the efforts of many inventors from various countries.[1] The three directions (chains) of innovation slowly converged, finally making possible the development of contemporary propellers.

Behind any contemporary machine (mechanism, technological process —in fact, any technical system) there are tens, hundreds and thousands of sequential inventions. Even a simple machine such as a pencil has been the subject of 20,000 patents and Authors Certificates!

Each invention pushes a machine's development forward. The machine stays unchanged throughout each pause between advances. These pauses were once long, and caused machines to improve slowly. The time from the first experimental model until the first practical, useable system took decades. For instance, the initial idea for the electric incandescent lamp appeared at the beginning of the nineteenth century, while the first experiments to produce light by heating a wire were not made until 1840. However, the first mass-produced lightbulb appeared only thirty-nine years later.

In our time, machines and instruments mature much faster. For example, the concept of a laser was expressed in 1952. A first device based on this idea was tested two years later —and only five years after that, the production of laser devices began.

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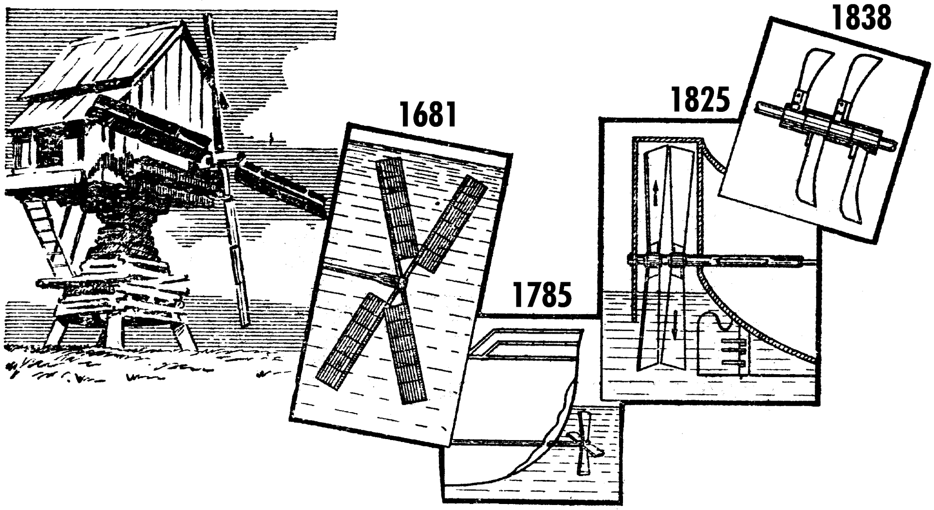
[1] *Inventor and Innovator.* 1964. #6, page 41.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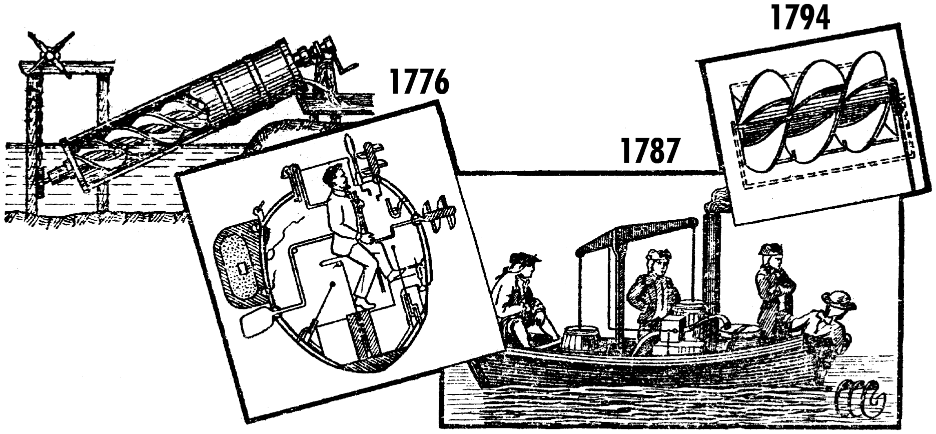
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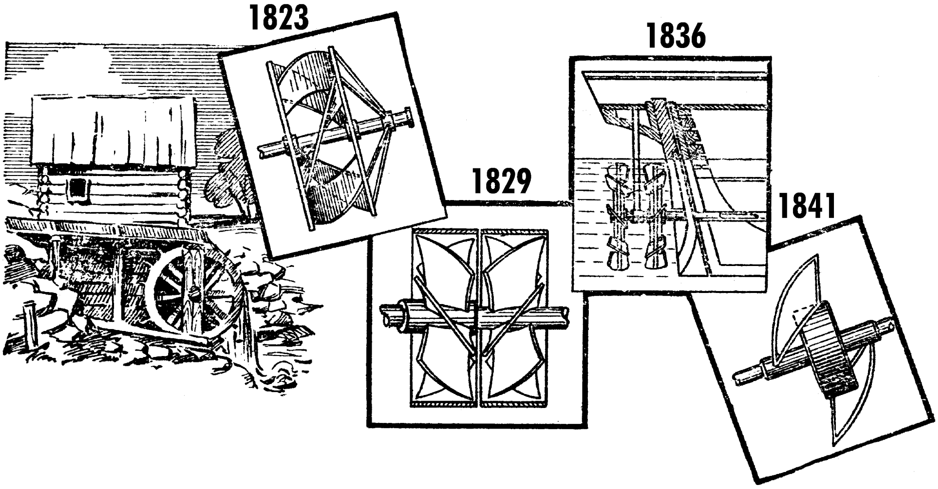
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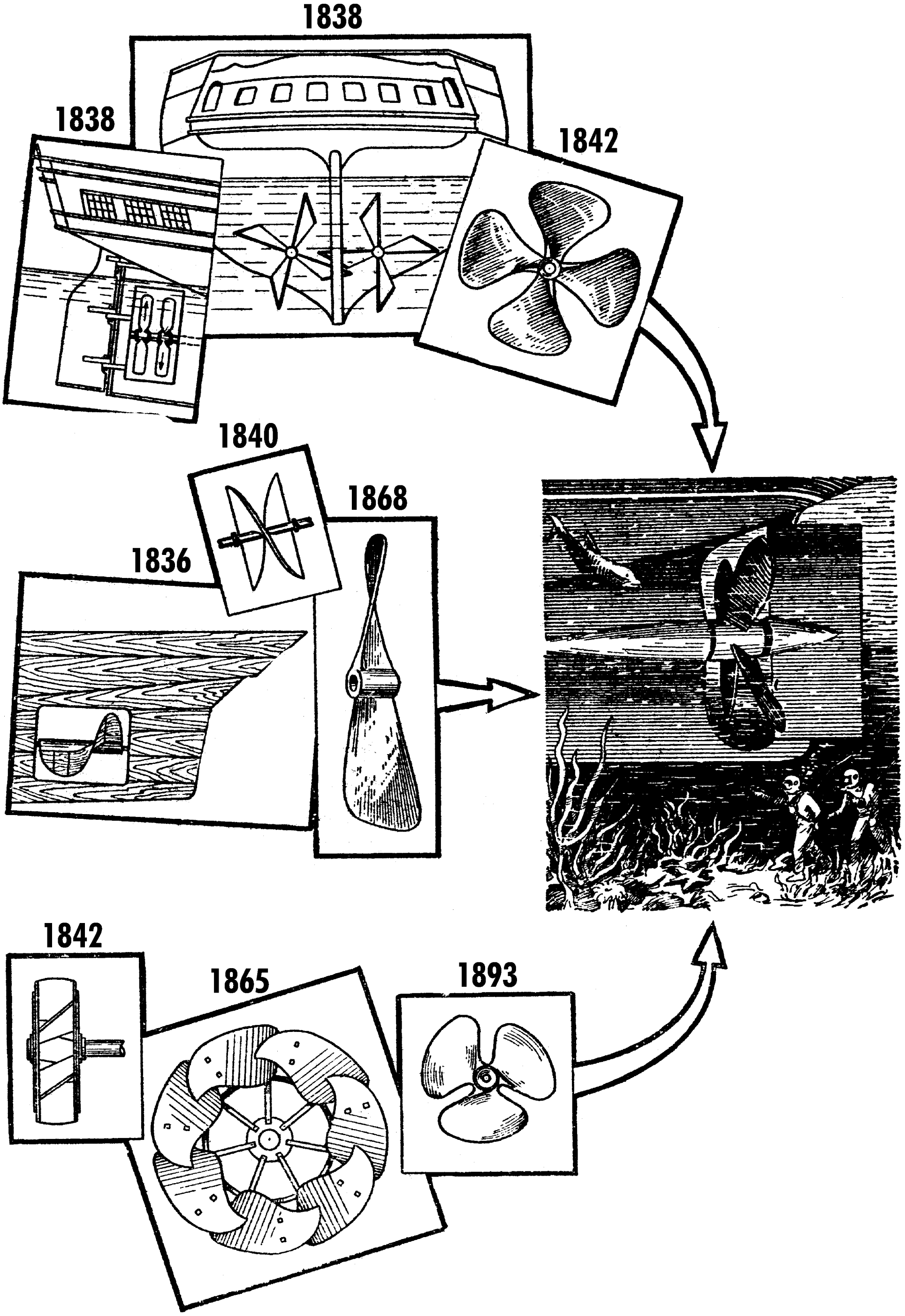

__Figure 4.__
Two hundred year history of propellor development.

Machines constantly evolve, so there is never a shortage of problems for inventors. Yet, as a rule, they solve these new problems only sporadically.

As surveys have shown, there are two types of relationships between inventors and inventive problems. Eight out of ten inventors seem to wait until a problem becomes urgent before starting to work on it. Here, in essence, the problem finds an inventor. Other inventors actively search for unsolved problems. They understand that tomorrow's requirements for a particular machine will increase, so they look for prospective problems to solve today using the most contemporary technical means.

The difference here is essential. Imagine yourself as the person who pushes a small platform truck. It is possible to give the truck a push and, after it comes to a stop, push it again. However, it is also possible to approach this differently: continuously push the truck. Clearly, in the second case the speed will be much greater. The same thing happens in the inventing industry. As long as the manufacturing process runs smoothly and without obstacles, it does not drive inventors to search for improvements. Later, a "bottleneck" suddenly appears – say, a material supply interruption – and only then does an inventor start work on a problem that could have been predicted earlier.

For a long time, every available inventor was used when eliminating bottlenecks in the manufacturing process. Inventors were considered a last resort to be used only in emergencies.

❧

Several decades ago, people were inventing episodically in almost all industries. A person was considered to be an inventor if, over a ten- to fifteen-year period, they produced one or two inventions. In our time, the rate of technical development has so dramatically increased that the need for innovation is constantly growing. Old machines are rapidly replaced by new ones that are modern and faster. Under these conditions it is difficult to consider a person an inventor who creates new things only from time to time, inventing something once every fifteen years. After all, we do not consider a person a singer who sings but once a year.

Experience, and the skills gained during the creative process, are lost if inventive problems appear only with extended time period between them. Inventive skills must be regained all over again every time one starts solving a problem. Continuous creative work, on the contrary, enriches one's arsenal of principles while confering confidence in one's ability.

It is significant that almost all inventors (according to survey data) who actively search for problems make between 15 and 20 inventions during the relatively short working period of five-to-seven years.

Inventing becomes a second profession for workers, technicians and engineers who think creatively.

* * *

There is no shortage of problems needing innovation. All we require is the knowledge to determine what problems *must* be solved, and separate them from those that *can*, or *cannot*, be solved.

Usually, an inventive problem is formulated like this:

"Create a technical system
for whatever purpose."

Sometimes, it is necessary to improve an already existing system rather than create a new one:

"Improve such and such a system
to get such and such a result."

It could happen that a problem is only stated partially:

"Improve something."
(Without stipulating a result).

Here the goal is obvious. For instance, if it is a matter of reducing the weight of hauling machines, the goal is relatively clear. It is very rare when a problem's statement contains only the second half of the original statement: "*Get such and such result*." In this case it is not clear what is the technical system —and what machine, or its part, has to be improved.

When an inventor gets a statement of a problem it is usually already formulated. However, it is very important to avoid mistakes in problem formulation during each stage of the innovation process. Consequently, one should never accept a problem statement fabricated by others. Any correctly stated problem would probably have been solved by the person encountering the problem for the first time.

Can you imagine being a person at the dead end of a maze? You are asked to continue searching for an exit. This is now a meaningless activity. It should be approached differently. First, return to the initial start position. Then proceed in the proper direction. Unfortunately, problems are stated in such a way that they force us, however imperceptibly, back to our "dead end."

To understand why this happens, let's see how the statement of an inventive problem occurs.

Every hour, every minute, manufacturers are setting up different problems. Each day, chief engineers, designers, technologists and workers solve many technical tasks. Most of the time these tasks can be solved conventionally, utilizing known means and principles. Often, problems arise that require some small element of creativity. These are innovations where the creativity resides in finding something already known within a given industry, and adapting it to a specific circumstance. In other words, it requires finding the closest-sized key and adjusting it to fit the lock. An inventive problem, however, requires a solution where a "best-fitting" key does not exist.

It is much easier to make a new key than to adapt an already existing, bad-fitting key (which is frequently completely unusable). Yet, more often than not, an inventor has to start with just such a "bad key." Why does this happen?

The problem appears during the manufacturing process itself. In the beginning, a solution was searched for using conventional and well-known means. This didn't work. Then there was an attempt to solve the problem through a simple innovative approach. The result was the same. Then came attempts to find a solution through inventing by developing something entirely new. If this proved successful —well, at least the problem didn't wind-up on the "unsolved" list.

Suppose, however, that nothing new was developed. This means that the person facing the problem for the first time reached a dead end trying to solve it. So, he asked other inventors to help —and he formulated a problem to show them. There were two options available at that time: state the problem as it was understood at its inception, or formulate the problem that later became an obstacle to the solution. In the majority of cases, the latter was preferred. The intention at the time was benevolent: "We've already gone halfway, why should we have to start all over again?" It's true that half the distance to a solution was covered, and sometimes this distance was not a short one. However, the distance covered led in the wrong direction.

As we saw before, a statement of the problem has two sections: the *goal* (what must be *achieved*) and the *means* (what must be *done, improved, changed*). The goal is always stated correctly. However, the same goal can be achieved differently.

Perhaps this is the most widespread mistake made when stating a problem. To reach a result, an inventor is oriented by the very nature of the problem formulation to create a new *machine* (*process, device, instrument* and so on). From outside, this seems logical. There is machine **A-1** that produces result **R-1**. Now it is necessary to achieve result **R-2**, which therefore requires the development of machine **M-2**. Usually **R-2** should be greater than **R-1**; therefore, it seems obvious that **M-2** be greater than **M-1**.

As far as formal logic goes, this is correct. But the logic of technology development is dialectic logic. For example, to reach double the result it is not necessary to utilize twice the resources.

Some time ago, a design competition was announced for a better concept to mechanize the loading of cargo (sacks) into railroad trucks. During manual loading, workers take one sack from a pallet, carry it to the truck, and place it on another pallet. The transport of cargo from warehouse to railroad truck can easily be mechanized —perhaps by using a conveyor belt. However, portable and compact machines that can stack cargo inside a truck do not yet exist. Forklifts that carry six to eight sacks on a platform have difficulty maneuvering inside a truck and, therefore, cannot provide the necessary productivity. During the competition, this problem was formulated thus: it is required that we improve conveyors and forklifts so that they provide complete automation of cargo loading.

Was the problem stated correctly?

Of course not.

The original attempts to solve this problem, by utilizing already known means (conveyors, forklifts, etc.), led to a dead end. Then the problem was offered in this dead end formulation: *improve the conveyors and forklifts*.

The conditions of the problem have now been narrowed. The original task was to provide a high-productivity process for loading packaged cargo onto a truck; however, we have prohibited this, *a priori*, by replacing the broad task with a narrow one (*make improvements to conveyors and forklifts*). Without exception, this problem must be solved *without* utilizing these machines.

To make a correct statement of the problem, it is necessary to consider the evolutionary tendencies of a given technical system. In particular, the main evolutionary tendency in the loading/unloading processes is for the handling of large blocks of cargo units. This means that a block should consist of 50 to 70 sacks instead of one sack (as is used in conveyor processing) —or, 6 to 10 sacks (as is used with a forklift). This is the correct problem statement.

There is a simple method to check whether a problem is stated correctly. Look at identical problem statements in other industries — specifically, those industries where problems are stated more precisely, or where the scale of operation is greater. For example, in order to refine the problem statement about the transportation of cargo, it is useful to look at the construction industry, where transportation of loads consisting of small units often occurs.

Construction material such as stones and bricks were once loaded and unloaded into a truck by hand. Then the transition was made to using larger blocks and panels, thereby creating more effective conditions for mechanization of the work.

A stack of sacks is similar to a large block. Does it make sense to break this block up, and then, with the help of a machine, deliver its "fragmented" parts into the railroad truck, only to recompile the block? Obviously, such a solution was not imposed by a technical evolution tendency.

Therefore, we can make a conclusion that the original statement of this problem has no future. At the same time, a correct statement of the problem becomes clear. A large block (the size of the block is limited only by the size of the doorway) must be moved into the truck as a single unit, and then take its place on the floor.

As was expected, the best suggestion was the concept that exactly solved this problem. It provided the highest productivity during the loading process —at minimum mechanization cost. Pallets with casters (or air cushions), each carrying 50 sacks, rolled down into the open doors of the truck.

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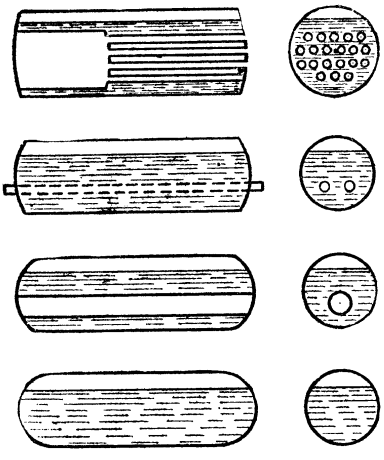

Figure 5. *Evolution of the steam boiler. The boiler-vessel is transformed into a system of pipes producing a greater total heating surface.*

Machines develop along certain logical sequences — not at random. *Figure 5*, for example, shows the development of the steam boiler. Contradictory requirements were set forth in the design of the steam boiler (a boiler must have a spherical, or cylindrical, shape in order to provide the needed strength under high steam pressures; however, these shapes create a minimal heating surface) that therefore lower the production of steam. To satisfy these requirements the cylindrical shape was preserved, but its length was increased. The boiler-vessel slowly transformed into a system of pipes with a large total heating surface.

One of the major directions in technical system evolution is the changing of a system's size. Machines are born in so-called "mid-size." Then their development follows along two opposite directions —machines increase in size while, at the same time, the development of miniature systems takes place. These two tendencies are clearly seen in the excavator's evolution. Increase in size is typical for transportation and processing machines. For control and measuring devices, a reduction in size is more typical.

Each machine strives toward a certain ideal stage, having its own "line of development." In the end, these lines converge at the same point, just as meridians meet at a Pole. The Pole for all lines of technical system (machine) evolution is the "Ideal Machine."

The Ideal Machine is an arbitrary standard system that possesses the following characteristics: weight, volume, and area of the object with which the machine *interacts* (*transports, processes*, and so on). These coincide, or almost coinciding, with the weight, volume, and area of the machine.

This machine is not the goal in itself. It is a means to produce certain work. For example, consider a helicopter made to transport passengers and cargo. At the same time, the helicopter is "obliged" to also carry *itself*. It is clear that a helicopter would be more Ideal if it had less weight (providing that its other characteristics do not deteriorate). The Ideal helicopter will have just a passenger cabin, and will be capable of moving at a speed with which the helicopter can carry itself.

One more characteristic of an Ideal Machine is that all parts of the machine perform useful work with the greatest possible capacity.

Machines exist to produce work. Meanwhile, many machines work only periodically. In addition, we are accustomed to believing that a machine is working even when only one part of the machine is working and others are not. A machine that transports wall panels is idle 40-50 minutes during each delivery. During loading and unloading time, only the truck's body is working, but the engine and chassis are idling. The same truck composed of several removable bodies loses almost no time while loading and unloading: while one body unloads, another transports to its destination, and the third loads the body waiting at the construction site. Only tendencies that bring a machine closer toward its ideal state (Ideality) will progress and remain active for a long time. Take for example the tendency to increase the size of a single technical system (machine). At first glance, it is not clear why a size increase brings the machine further toward Ideality. It is, however, very simple: a larger machine usually has a smaller ratio of weight (or volume, or area) to the weight (or volume, or area) of work performed. A truck carrying three tons of cargo weighs a ton-and-a-half. One third of the truck's power is spent moving its own body. A truck built to carry 15 tons of cargo weighs only five tons. That part which is dead weight is reduced substantially. This is exactly what brings a machine closer toward Ideality. One 140-ton truck can unload gravel in 15 seconds—much faster than it takes 28 five-ton trucks.

It is often believed that an Ideal Machine should look nice. This is a serious mistake. It creates psychological barriers that are difficult for an inventor to overcome. The thought predisposes inventors to search for solutions that lead toward elegant and beautiful machines. In this case, new concepts may be left out of consideration.

Nobody argues that a good machine must be like a graceful swan; however, this only applies to mature machines. "Newborn" machines have the right to be clumsy. It is important that their essence is more advanced than that of already existing machines. If this condition is met, there is no doubt that the new machine will grow into an elegant and beautiful swan, overshadowing any of its siblings.

While solving a problem, an inventor should not think about the future beauty of a machine. He must not be afraid to offer an outwardly ugly, yet inwardly beautiful design.

* * *

If a problem is solved by the trial-and-error method, the search is going to be either along the Inertia Vector or, at best, scattered in all directions. Meanwhile, the inventor can drastically reduce the search sector when approaching a problem. The solution must bring the original system to its ideal state. An inventor will at once find the most promising direction to search when the parameters for an Ideal Machine are determined.

Of course, it is necessary to determine the Ideal Machine for each case. The more precisely an inventor can imagine the Ideal Machine, the less the search direction is left to chance.

An Ideal Machine plays the role of a beacon illuminating the direction in which to proceed. When an inventor looks for the solution without a beacon, his thoughts are scattered under the influence of too many personal motivations. "Each of us," writes American psychologist Edward Thorndyke, "when solving intellectual problems, is besieged, figuratively speaking, from all sides by different tendencies. Each element, as if trying to win its sphere influence over our nervous system, provokes its own associations while not taking into account other elements and their overall states."

Habitual concepts besiege the inventor, blocking any directions that lead to fundamentally new solutions. Under such conditions, as Pavlov noted, thrive common weaknesses of thought —stereotype and preconception.

Structured searches, on the contrary, organize one's thought processes and increase productivity. Thoughts concentrate into one major direction for a particular problem. At the same time, secondary ideas are pushed away, and ideas that relate directly to the problem come closer. As a result, the probability of encountering those ideas sharply increases, creating conditions for the birth of a new invention.

A directed search does not, by any means, exclude intuition. On the contrary, a structured thought process creates that special mental tuning which helpfully promotes intuition.

* * *

The "Ideal Machine" is a fundamental concept of inventive methodology. Many "difficult" problems are difficult only because they have requirements contradictory to the central tendency of technical system evolution: the desire to be like "thin air." Almost all thematic lists of problems are colored with the words: "Develop a device that. . . ." However, very often there is no need to develop a device —the essence of the problem is to provide a required function "without any *thing*," or almost "without any *thing*." An ideal solution is a machine that does not exist —with the same result as if a machine *did* exist.

Let's take as an example a concrete inventive problem published in the magazine *Inventor and Innovator* under the section "Looking for Inventions."

Problem 2

> *"Modern farm water spraying machines have a low capacity. Attempts to achieve a necessary higher spraying productivity by extending their wingspan also increases the amount of metal used.*
>
> *"What can be done? Lighten the wing-frame by using plastic. Reflect upon how the concept of "spraying" can be improved. The simple garden watering spout is the principle used in spraying machines; however, many different concepts can be used: bundles of tubing, multitier showers, pulverizers, turbines —anything, as long as the wing area can produce maximum rain for the largest area."*[1]

A spraying machine is a tractor equipped with a pump and wing-type cantilevers. Spouts are attached to the wings. The twin-cantilever machine DD-100M can deliver 90-100 liters of water per second. Its operating pressure extends 30 meters, and its spraying width is 120 meters. DD-100M moves along irrigating canals that are 120 meters apart.

A spraying machine is cumbersome and consumes a lot of metal. The weight of its wing is proportional to its length raised to the third power. If, for example, the wing-length increases by only one-half, its weight will increase three-and-a-half times. Therefore, wing-size is limited to 100 meters.

There have been many attempts to solve this problem. For example, a spraying pipe was suspended upon dirigibles. Sprinklers were lifted-up by a helicopter whose propeller was supposed to rotate by water pressure pumped from the ground. Other ideas suggested installing a sprinkler-pipe on a tower and rotating it by a turbine engine. It is not difficult to notice that these ideas have something in common —they do not bring the original machine to its ideal state.

It takes only water to water a field. Equipment can merely help deliver the water. Clearly, the simpler and more compact the machine, the closer we get to an ideal sprinkler system. Dirigibles, helicopters and turbine engines only complicate the design. They unquestionably point in a direction away from the ideal system.

A self-propelled machine with air-inflated cantilevers is much better.[2] This design brings the machine closer to ideality. The cantilever's weight is reduced, and can be folded compactly away when the machine is not operating. Unfortunately, as the size of the inflated cantilevers increases, their sail surface also drastically increases, creating problems during even the slightest wind.

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1. *Inventor and Innovator*, 1964, #6, page 4.
2. Authors Certificate #144,335

The ideal sprinkler machine should look like a perforated pipe moving across the field by itself, without a tractor and supporting frame. The pipe should probably be many times longer than the frame of existing machines. During inoperable conditions, the pipe should take up as little space as possible.

We have pretty accurately determined the image of our Ideal Machine. Now try to find a solution. This is a practice problem; therefore, do not offer other methods of irrigation (underground pipelines, portable pipelines and so on). We are talking about a mobile sprinkler system required to move a light, perforated pipe over a 300-meter long field. A simple design is preferable.

Part 1-6
Technical Contradictions

Let's try to solve the sprinkler problem using conventional methods.

It is necessary that the sprinkler wingspan be increased threefold. Building a three hundred meter frame can technically be accomplished. What are its disadvantages? Well, the overall weight will increase. If the wingspan increases threefold, the supporting frame will become twenty-seven times heavier.

There are several important characteristics (such as weight, dimensions, power, and reliability) that pertain to machines, and technical devices in general, which indicate their degree of efficiency. Certain interdependencies exist between these characteristics. For instance, one unit of power requires a certain weight of structure. By improving one characteristic with means already known in a given industry we are paying the price of worsening another characteristic.

Here is a typical example from the aviation industry:

> *"Doubling the area of a vertical stabilizer fin on an airplane decreases the amplitude of the airplane's vibration by 50 percent. However, this in turn increases the airplane's susceptibility to wind gusts by increasing air resistance, and also makes the airplane heavier —adding even more complex problems."* [1]

Taking specific conditions into account, a designer chooses the most favorable combination of characteristics. Yet, while something is always gained, something else is also lost. "When considering a solution," says the well-known airplane designer O. Antonov, "along with its technical requirements —all of which, perhaps, will never be put on paper —select the most important ones. At worst, if something cannot be built, an allowable variant may be acceptable. 'Allowable variant' means some deviation from the given technical condition —a compromise solution, so to speak. Let's assume that, in designing an airplane, you meet the requirements for its cargo capacity and speed but do not comply completely with the requirements for runway length. You begin to consider these three important requirements, perhaps forfeiting runway length requirements slightly —550 meters instead of 500 —in order to retain the other favorable characteristics. This is precisely a compromise solution."[2]

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[1] V. G. Denisov, R. N. Lopatin. *Pilot and Airplane*. M. Oboringiz. 1962, page 17.

[2] *Weekly* #15, 1965, page 10.

Academician A. N. Krilov recounts in his memoirs the following story:

> *In 1924, a scientist [Krilov] was working as part of the Soviet-French Committee observing Russian military ships in Bizerta Harbor. These ships were conveyed to the harbor by Vrangel [a French General]. In the harbor, Russian and French battleships were anchored side-by-side. They were built during almost the same period. The difference in fighting power between the ships was so great that Admiral Bui, chairman of the Committee, could not restrain himself and exclaimed: "Your ships have giant cannons while ours have mere pop-guns! How did you achieve that much difference in battleship armament?"*
>
> *Krilov answered: "Admiral, look at the deck; except for the ship's frame, which carries the main load, everything else acting as a roof is almost rusted out. Pipes, shells, conning towers and so on — everything is worn out. Look at your battleship. Everything on it looks brand new. Of course, our battleship went without maintenance and paint work for six years. However, this isn't the main point. Your battleship is built from regular steel with a calculated tension of 7 kilograms per square millimeter — as if it was a commerce ship that must be in service not less than 24 years. Ours is built completely out of high-strength steel with a calculated tension of 12 kilograms and higher (in some places up to 23 kg/mm^2). Our battleship is built for 10 – 12 years of service because, during that time, it will become so out-of-date that it will no longer have adequate fighting capability. The bulk saved from the body of the ship went to increase the fighting power of its cannons. As you can see, in artillery battle our ship will destroy at least four of yours before your ships can come within the range of their "pop-guns."*
>
> *"It's so simple," Admiral Bui declared.* [1]

The designer's art depends, for the most part, on skills for determining what must be gained and lost through compromise. The essence of inventive creativity is to find a way where compromise will not be needed (or, where it is disproportionately small relative to an achieved result).

Suppose there is a need to develop a portable crane that can be installed inside heavy-transport airplanes to speed up the loading and unloading of cargo. This problem can be solved with existing technology. Based on the general design principles of lifting devices — and using experiences gained from the development of light autocranes — qualified engineers can design the required mechanism.

It's understandable that this will increase the dead ballast of an airplane. While gaining something, the designer simultaneously loses something else. We can often resign ourselves to this because the goal of the designer is to gain a little more while losing a little less.

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[1] A. N. Krilov. *Remembrances and Notes*. Military Publishing, 1949, page 249.

The need for invention arises when a problem contains one additional requirement: gain *without* loss. For example, a lifting device must be sufficiently powerful while, at the same time, not increasing the airplane's weight. It is impossible to solve this problem using conventional methods since even the best portable cranes are heavy. We need a brand new approach: an invention.

Thus, a commonplace problem is transformed into an inventive one when, as in this case, removal of a technical contradiction is a necessary condition for solving the problem.

It is not difficult to develop a new machine if all the technical contradictions are ignored; however, the resulting machine will prove to be incapacitated and impracticable.

Does an invention always require the removal of a technical contradiction?

It's necessary to note here that there are two concepts of "invention"—patent (legal) and technical.

The patent concept frequently changes and is differs in many countries. It endeavors to exactly identify the boundaries within which, at any given moment, legal protection for a new engineering solution will make economic sense. For the technical concept, it is more important to identify the core of the invention —its historically stable essence.

From the engineering perspective, creation of a new invention always manifests as the full or partial overcoming of a technical contradiction.

The formation and overcoming of a contradiction has been one of the main characteristics of technical progress. Analyzing the development of mills, Marx wrote in *Das Kapital*:

> *"An increased size of a working machine and its number of simultaneously operating parts requires a larger engine. . . . Even by the eighteenth century, an attempt was made to set in motion two crusher-wheels and two mill-stones using a single waterwheel. The resulting increased size of the driving gear, however, was in conflict with the inadequate water power."*

This is a vivid example of a technical contradiction: an attempt to improve one characteristic of a machine comes into conflict with another characteristic.

Friedrich Engels, in his article, "The History of the Gun," gives numerous examples of technical contradictions. As a matter of fact, the entire article represents an analysis of the inner contradictions that determined the historical development of the gun. Engels demonstrated, for instance, that from the time of the gun's creation until the invention the breech-loading gun, the main contradiction was as follows. To strengthen a gun's firing characteristics, it is necessary to shorten the barrel (loading was done through the barrel, thus shorter barrels made loading easier). On the contrary, to strengthen a gun's bayonet properties, the barrel should be longer. These contradictory characteristics were combined in the breech-loading gun.[1]

Here are several problems from different industries that contain contradictions. These problems were taken from newspapers, magazines, and books. They were not fabricated by the author.

Mining Industry

For a long time, in order to isolate one area of an underground fire, miners built partitions —special walls made out of bricks, concrete, or wood. Construction of these partitions becomes very complicated if gases are in the shaft. In such a case, the partitions should be hermetic with every crack thoroughly sealed. All of this must be done while under the constant threat of explosion. For safety reasons, miners began to construct two partitions, one after the other. The first was temporary and built in a hurry. It let air pass through while acting as a barricade providing protection for the construction of the second, permanent partition. Thus, the miners gained in safety —but lost in the amount of work they had to perform.

Chemical Technology

When pressure rises, the speed of a chemical synthesis increases, and so, consequently, does the productivity of synthesis containers. However, the energy consumption for compressing a given amount of gas increases at the same time. For structural considerations, it is necessary to limit the apparatus size, and therefore its capacity. Hence, the solubility of a hydrazoic mixture in liquid ammonia increases while losses from the mixture also increase.

Electronics

Contemporary electronics faces a serious dilemma. On one hand, the requirements of the working characteristics of electronic systems constantly rise, while the systems themselves accordingly become more complex. On the other hand, limitations of dimensions, weight, and energy consumption are getting stricter. To the same degree, and perhaps even more importantly, reliability problems caused by this increased system complexity is also rising.

Radio Technology

The antenna of a radio telescope has two main characteristics: reception sensitivity and resolution power. The larger the size of its antenna, the greater the radio telescope's reception —and the further it can look into the depths of the universe. Resolving power is the "sharpness of vision" of a telescope. It shows how well the apparatus can distinguish

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[1] F. Engels. "History of the Gun," *History of Technology*, Issue 5, 1936, page 18.

two different sources of radiation located at a small angular distance from each other. Furthermore, a large "radio eye" has to have access to the greatest possible section of the sky. For this, the antenna must be mobile. However, it's very difficult to move a large antenna while keeping its structure unaltered and correct to within millimeters.

Until this contradiction is resolved, telescope antenna design will progress in two directions: either very large, but immobile, or mobile, yet relatively small.

Engine Manufacturing

The internal combustion engine valves and gas-distribution system consists of several parts in reciprocal motion. If engine RPM is increased, so is mass inertia. To avoid this, attempts are made to decrease the mass of the reciprocally moving parts by placing the valves and gas-distribution mechanism inside a block. However, this narrows and flattens the combustion chamber, increasing the heat transmission surface. Here is the contradiction: an increase of RPM, combined with lower valve positions, leads to an increase in power and economy —but the narrow, flattened combustion chamber removes this gain.

Agricultural Machine Manufacturing

There is a concept known as "pull capacity" that refers to that part of a tractor engine's power actually able to perform useful work. Efficiency of this power for a specific tractor first depends on the traction characteristics of its wheels, or caterpillar tracks, in conjunction with the total weight of the tractor. A powerful but lightweight machine will spin under a large towing load; therefore, only a small part of the tractor engine's power can be used to provide useful work. Heavy tractors have better ground traction, but an essential portion of their engine's energy is being consumed in just moving the tractor across a field. Designers make machines lighter, consequently increasing their capacity. However, during operation, the reverse process begins —the decreased weight worsens its traction characteristics. This, in turn, causes a decrease of "pull capacity." This is why, at work sites, people make tractors heavier —placing cast iron disks on wheels, widening caterpillar tracks and wheels —thus eradicating the designer's achievements.

Automotive Industry

As soon as we increase the power of an engine without applying new designing solutions, the engine's weight and gas consumption also increases. This means that the frame and body of the automobile has to be stronger and heavier. This, in turn, means less space for passengers.

Soft tires provide a quiet ride —an automobile floats along a bumpy road like a boat. However, reduced tire pressure creates more road resistance and reduced speed. It is possible to design an automobile that rides close to the ground and thus provides greater stability; however, it could not ride on rough terrain roads. An engineer finds the Golden Mean, weighing all characteristics towards a compromise solution: which characteristic can be sacrificed so that others may be advanced.[1]

Ship Building Industry

In designing the hull of a yacht, it is necessary to consider three main requirements:

1. Hull shape that exhibits the least resistance.
2. Minimum friction.
3. Maximum stability.

These requirements are contradictory. A long, narrow yacht has low form resistance —hence it is not stable and can not carry enough of the sail's capacity. Increasing the stability of the yacht with more ballast weight increases its submergence and, consequently, its frictional resistance. Increasing its stability by widening the hull also brings increased resistance. The designer's task is to find the Golden Mean —the best possible solution reconciling these contradictory requirements.[2]

Aircraft Industry

The chief designer conceives an idea. Let's say there is a need for an airplane to transport large and heavy cargoes. It is also necessary to provide a fast and convenient loading system. For this purpose, the fuselage has to be roomy and as low to the ground as possible under parking conditions. This means low landing gear easily folded into the fuselage when flying.

Cargo weight determines the weight of the airplane structure, and both affect the power and number of engines. If the engines are turboprops, they must be installed on wings elevated at such a level that the propellers will not touch the ground. It becomes clear that the wings should be attached to the upper part of the fuselage.

This is the first step in the project. A multitude of different requirements gradually defines the "face" of the future airplane. Field airports dictate the necessity for effective take-off and landing characteristics, requiring the utilization of large low-pressure tires and straight, aerodynamically powerful wings. In this case, of course, great speed cannot be achieved.

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1. U. Dolmatovski, *I Need an Automobile*. Molodaia Guardia, 1967, Page 256.
2. C. Marhai. *The theory to sail*. Physical Education and Sport. 1963, Page 43.

However, to retain other important characteristics, the designer searches for some sensible compromise.[1]

◆

In principle, an invention has to possess "substantial novelty." But, what does the word "substantial" mean? The *Manual on Methods of Examination of Applications for Inventions* relates the following: "Such solutions that have new, previously unknown features providing fresh properties to the object of the invention (machine, process, or substance) while generating a positive effect, are characterized by substantial novelty in their solution of technical problems." Such definitions, with insignificant variation, have been applied for decades producing endless arguments about the validity of their application. This definition states that novelty means the presence of new properties. What is considered a new property? There are no exact regulations on that score.

Here it is revealed:

Novelty exists where there is novelty.

In practice, "substantial novelty" inevitably turns into the notion "substantial change" (with comparison to the prototype), and then further into the notion "significant change." If there are many changes, it becomes an invention. If there are few changes, it is not an invention. Furthermore, the notions "many" and "little," when all is said and done, are determined by utterly personal opinion.

However, there exists our objective criterion:

An invention is the removal of technical contradictions.

By using this criterion, an examination of its applications can be made significantly more objective.

Let's look at a specific example.

The magazine *Inventor and Innovator* published an article "What is an Invention?" by the [Russian patent] expert E. Nemirovsky. In this article, the author describes a case from his personal experience.

Two engineers designed a device for loading binders for further processing. "Examining this application," the patent expert writes, "I recalled the same device from one of the German Patents. The only difference was that our inventors installed the sides of the case at a distance less than the length of the binder's cover. . . . I considered this difference insignificant, and prepared the refusal to grant an Author's Certificate."

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[1] I. Shelest, *From Wing to Wing*, Molodaia Guardia, 1969. Pages 479-480.

This is very typical, and is a classical example of the comparison method. The expert is not interested in the reasons why the changes were made, or what results they have brought. Only the principle of formal comparison was used. The expert tries to find a prototype. The change seems to him insignificant: it is not a big deal to change the side lengths. Insignificant change means, in an expert's opinion, a lack of substantial novelty. Then, without blinking an eye, he writes a formal refusal.

However, here the comparison method clearly failed. Nemirovsky continues: "However, the inventors explained that the side supports, described in the German patent, must be very rigid to eliminate the deflection of the binder's ream. On the other hand, if the side supports become too rigid, suction cups cannot lift out the covers from their box. This contradiction made the packaging device malfunction. I admit making a mistake. The inventors received their Author's Certificate." Here, at the end of the article, Nemirovsky wrote the word that ought to have been at the beginning: *contradiction*. It turned out not to matter how significant the new change was, but that the contradiction present was eliminated.

Let's look at one more example.

Engineers L. Ginsburg and J. Persky, from St. Petersburg, submitted an application for an electronic lamp block with a toroidal transformer. "You were able to create a very good device," a patent officer answered, "but it does not have elements of substantial novelty." The application was reconsidered in St. Petersburg's regional office, VOIR [All Union Society for Inventors and Innovators], and the substantial novelty was found. Here is its description:

> *"Design for an electronic block consisting of a high-voltage lamp and a current transformer. It is necessary to insolate the lamp sockets, and other high-voltage points of the lamp, from surrounding objects of different voltage potentials, including the transformer. Up to now, the conventional design was to create a large discharge distance between the lamp's sockets and the body of the transformer. This required installation of a long, high-voltage insulator between the transformer and the high-voltage lamp. However, it's important to reduce, not enlarge, the overall product dimensions when designing such blocks.*
>
> *"So, the engineers L. Ginsburg and J. Persky proposed to slightly increase a window of the toroidal transformer, place the lamp socket inside, and seal the other high-voltage elements in a resistant compound. This witty solution enabled us to get rid of the insulator and outside high-voltage support. The most important element was the following: the overall block dimensions were reduced, and now with such a design concept, an increase in high-voltage does not require an increase in block dimensions."*[1]

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[1] *Inventor and Innovator* Magazine, 1961, Issue #8, page 26.

The dispute with the experts ended as follows: "It was proven that the authors were able to overcome the contradiction described above and solve the problem because, in their design, the transformer plays the role of not only a transformer, but also an insulator of high-voltage points. Utilization of the transformer as the insulator represents the novelty of the design." The inventors were given an Author's Certificate.

When inventors learn to recognize the removal of technical contradictions as inventions, and the experts learn to find in their patent applications the means for removal of such contradictions, then the number of rejected applications will be significantly reduced.

* * *

Sometimes, the technical contradiction within a problem is clearly evident. For example, there are problems that, if solved by conventional methods, would develop unacceptable weight increases. Sometimes the contradiction is imperceptible as though it was dissolved within the problem conditions. However, an inventor always has to remember that a technical contradiction will have to be conquered.

"It's necessary to achieve *such-and-such* a result." This is only half the problem. An inventor must see the second part: "To achieve something without losing *this-and-that*."

Surveys indicate that experienced inventors clearly see the technical contradiction contained in a problem. So, P. Fridman (of St.Petersburg), who has more than twenty Author's Certificates for his inventions, writes:

> *"I study the difficulties and contradictions of existing machines, apparatus, and systems."*

The inventor, Y. Chepele, from Kaunass, precisely characterizes this most important feature of the art of inventing:

> *"It's necessary to find the technical contradictions within a problem, then use methods suggested by experience and knowledge to remove them."*

Considering the results of his 30-year inventing career, the well-known Soviet inventor B. Blinov writes:

> *"I learned from my own experience that you cannot become an inventor if you don't learn to clearly see the contradictions in objects."*[1]

Inventor Y. Chinov had nine Author's Certificates. After Chinov mastered methods of inventing, he received 30 more Author's Certificates for solving a number of problems previously considered unsolvable. One of

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[1] *Mysterious Impulse*, Molodaia Guardia, 1969, page 163.

Chinov's main tools was the analysis of technical contradictions. When Chinov got an assignment to design a high-capacity machine for twisting telephone cables, his first step was to reveal the technical contradiction contained in the problem:

> *"During machine design, it became clear that the tension force of wires hinders any increase of the machine's capacity. This tension force arises because of the wires' friction against the walls of a twisting frame during the wire's movement, leading to an unacceptable stretching of the wires. With an increase of the twisting frame's rotating speed and diameter, the centrifugal force pressing the wires against the frame increases and, consequently, the frictional force between the wires and the frame also increases.*
>
> *"This leads in a vicious cycle. With each increase in the diameter and twisting speed of the frame comes an unacceptable increase in centrifugal force — leading finally to stretched wires. On the other hand, by reducing the diameter of the frame, the twisting speed is increased. However, this leads to an unacceptable reduction of the diameter of the receiving bobbin located inside the frame —consequently reducing the output of cable.*
>
> *"This is an obvious technical contradiction!"*[1]

It is common for the main act of inventing to be the discovery of a technical contradiction. Once discovered, it is not difficult to overcome. However, it may transpire that a clearly seen technical contradiction will scare an inventor away —like the necessity to superimpose that which is not superimposable, which seems to be impossible!

Chinov continues:

> *"It's necessary to find a method for twisting cable by `twisting* en passant*' This means the receiving bobbin must be removed from the twisting frame and attached to a stationary base outside the frame."*

Such a bobbin can be made with an unlimited diameter, and the cable can be of unlimited length —and the twisting speed will also be increased.

The Director of the Design Department of New Technology for the Tashkent Cable Plant warned me that inventors and designers had already invested a lot of effort in this direction. At the end, they came to the conclusion that inventing a "twisting *en passant*" method is as impossible as inventing a perpetual-motion engine. However, I didn't give up the thought that I would be able to manage this problem. I decided to follow the "method for inventing."

Don't be afraid of technical contradictions!

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1. U. Chinov, "When there is a Need to Twist, and it is Impossible to Twist...". Materials for the Seminar on Inventive Methods, Minsk. Published by the Institute for Heat Exchange AN, Belorussia, 1971, page 44-45.

Here is one of the simpler problems. Try to solve it independently. For this, you only need to precisely formulate the technical contradiction.

Problem 3

> *"When looking at a racing car, its wheels immediately strike your eyes. They give the car a fierce appearance. By the way, they also create additional air resistance and reduce maximum speed. Even conventional automobiles have wheels covered with streamlined fenders. So why are racing car wheels not shielded?*
>
> *"At sharp turns, a race driver constantly watches the front wheels. Seeing their position conveys the first information about the direction in which the car is going. Now, let's assume that wheels are shielded with fenders. Turning the steering wheel, the racecar driver has to watch the direction the car takes, and apply control after the car visibly deviates from its course. That's why automobiles for road racing are made without fenders. It's different for those cars intended to race on specially equipped tracks where maneuverability is not needed. There, cars have fenders."*[1]

To solve this problem, it is necessary to precisely determine what is "not superimposable"—and then answer the question: "What needs to be changed, and where, in order to remove that which is `not superimposable?'" This problem relates only to racing cars, and the solution might not be intended for long-time consumer applications.

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[1] *Science and Life*. 1963, #2, page 57.

Part 2

The Dialectic of Invention

Even formal logic primarily represents
a method for discovering new results,
for making a transition from the known to unknown.
Dialectics represents the same thing, only in a much higher sense.

Frederick Engels

Part 2-1:
Step-by-Step

Utilizing the concepts of **Ideal Machine** and **Technical Contradiction** make it possible to substantially control the process of solving inventive problems. The **Ideal Machine** helps to determine the *direction to search,* while the **Technical Contradiction** indicates the *obstacle that must be removed*. However, occasionally a contradiction is ingeniously hidden inside the problem statement. Moreover, an isolated contradiction does not disappear all by itself. It is necessary to find a way to remove it. It is not always possible to cover the distance between a problem statement and its solution in one single jump. This requires rational tactics that allow for a step-by-step progression toward a problem's solution. The Algorithm for Solving Inventive Problems (ARIZ) is offered here as a way to implement these tactics.

In the following sections, we will examine in detail the separate sections of the Algorithm, and we will demonstrate with examples how it works. Meanwhile, we'll provide some general observation on ARIZ.

Generally speaking, the term "algorithm" is vague. In mathematics, an algorithm means a strictly regulated sequence of steps necessary for solving a problem. For example, a mathematical algorithm is an action that must be performed in order to determine the square root of a positive integer. These types of algorithms are characteristically strict: each action step is precisely determined and depends neither upon changing conditions of the problem, nor the personality of the person solving the problem.

In the broader sense, an algorithm is a process having a sequentially structured set of actions. This is why the process for solving inventive problems is called an algorithm.

ARIZ is adaptable —the same problem can be solved with diverse approaches depending upon who is solving the problem, and how the problem is to be solved. ARIZ does not ignore the individual personality of the person using it. On the contrary, ARIZ stimulates the maximum utilization of an inventor's specific characteristic strengths. Therefore, the path from the problem statement to its solution can be executed differently. The inventor acts in accordance with his knowledge, experience and creative ability. The algorithm only saves the inventor from performing wrong steps.

Moreover, different inventors when utilizing TRIZ can reveal different solutions to the same problem. ARIZ has a structure that leads *inventors* toward the most powerful solution for their given problem.

As with any tool, ARIZ produces results dependent largely upon the user's knowledge of the tool. Don't assume that after merely reading the text of the Algorithm it is possible to solve any problem. One cannot participate in karate competitions after only reading a description of the different fighting methods. The same holds true for ARIZ. Battling a problem requires practical skills. We will develop these skills through working with training problems.

* * *

Envision a 25 year work scenario for developing and improving ARIZ. You will notice a long chain of events. The first version of ARIZ is followed by practical tests of this version along with final corrections; then, the second version, with more practical tests and corrections; then the third version —and so on.

Some inventors successfully used ARIZ even as early as ARIZ-59 (the Algorithm as published in 1959). Then ARIZ-61, ARIZ-64, and ARIZ-65 were developed. Experiences from many seminars were taken into consideration in developing these Algorithms. During the course of these seminars, the Algorithm was used to solve many different inventive problems. ARIZ-64, and especially ARIZ-65, were good for solving many inventive problems in practice. Meanwhile, improvements of the Algorithm continued, and ARIZ-68 was finally published in the First Edition of this book (1969).

We are going to illustrate two variants of the Algorithm: ARIZ-61 and ARIZ-71. This will show us the direction which the Algorithm's development has taken —and, consequently, allow us to imagine how it will look in five years.

ARIZ-61 divides the creative process into three stages: analytical, operative (removing a technical contradiction), and synthetic (introduction of additional changes). Each stage is divided into several sequential steps. Thus, the Algorithm seperates a single complex (and, therefore, very difficult) action into several much easier actions. It looks like this:

ARIZ-61
Part One: Analytical stage.

Step One: *State the problem.*

Step Two: *Imagine the Ideal Final Result (IFR).*

Step Three: *Determine what interferes with attaining this result (i.e., find the contradiction).*

Step Four: Determine why it interferes (i.e., find the reason for the contradiction).

Step Five: Determine under what conditions it will not interfere (find conditions during which the contradiction is removed).

Part Two: Operative stage.

Step One: *Explore the possibility of making changes in the object (the given machine, device and/or technological process) itself.*

1. Change size.
2. Change shape.
3. Change material.
4. Change temperature.
5. Change pressure.
6. Change speed.
7. Change color.
8. Change the relative position of parts.
9. Change the working conditions of parts with the purpose of maximizing their work load.

Step Two: *Explore the possibility of dividing an object into independent parts.*

1. Isolate “weak “ part.
2. Isolate “necessary/adequate” part.
3. Separate an object into identical parts.

Step Three: *Explore the possibility of altering the outside environment (of the given object).*

1. Change parameters of the environment.
2. Replace the environment.
3. Separate the environment into several mediums.
4. Utilize characteristics of the environment to perform useful functions.

Step Four: *Explore the possibility of making changes in neighboring (interacting) objects.*

1. Define relationships between independent objects participating in performance of the same function.
2. Eliminate one object by transferring its function to another object.
3. Increase the number of objects that operate simultaneously

on a defined area by utilizing free space in its *opposite* area.

Step Five: *Study prototypes from other industries (propose this question: How was a similar contradiction resolved in another area of technology?).*

Step Six: *Return to the original problem (in case the above steps are not applicable) and widen that problem's conditions —make the transition to a more general problem statement.*

Part Three: Synthetic stage.

Step One: *Change the shape of a given object —a machine with a new function should have a new shape.*

Step Two: *Change other objects that interact with the one under consideration.*

Step Three: *Introduce changes into the means of an object's functionality.*

Step Four: *Explore the implementation of the new-found principle in solving other technical problems.*

* * *

In 1969, the Coal Mining Ministry announced an All-Union Competition to develop a cooling suit for teams rescuing people during underground fires. The problem was extremely difficult and, at first glance, unsolvable.

Let's look at the way this problem is solved with ARIZ-61:

Problem 4

Underground fires are accompanied by the emission of poisonous gas (carbon monoxide); therefore, rescue workers are forced to wear oxygen devices. These devices work in a so-called closed-loop system: oxygen stored under pressure slowly moves into a breathing bag, and then into the mask. Exhaled gas, having a high content of unused oxygen, is then filtered through a special device and flows back into the breathing bag again.

This closed-loop system is more economical then an open-ended one where exhaled gas is discarded outside —as is used, for instance, in scuba diving devices. Even still, the system is not ideal. The oxygen device is quite heavy, weighing over 12 kg, and has the main disadvantage of not being protected from high temperatures. Meanwhile, the air inside burning mines can rapidly reach over 100° C.

While performing heavy physical work, the human body exerts 400 kcal per hour. These calories have no where to go in our problem because the outside temperature is higher than human body temperature. Intensive perspiration doesn't help either because, during an underground fire, air humidity prevents the evaporation of sweat, causing it to stream down the body. In addition to this 400 kcal, there is a powerful flow of heat from outside (at 100° C, this exceedes 300 kcal per hour). Therefore, two hours of work requires the removal of 1,400 kcal!

The main problem in developing a cooling apparatus is that it must be light. A rescue worker can only carry a load of no more than 28 kg, otherwise he cannot work. The oxygen apparatus accounts for 12 kg out of a total 28 kg weight, while tools weigh 7 kg. Nine kilograms are left over. If, for instance, the whole apparatus consists of only a cooling substance (and, of course, the device itself must weigh something), the stored amount of cooling power will not be enough to perform two hours of rescue work. This was all specified in the problem stated for the open proposal competition. Ice, dry ice, Freon™, liquid gases—none of these cooling substances can conform to the strict weight requirements.

Let's take ice, for example. This is a very powerful cooling agent. It requires 80 kcal to melt 1 kg of ice. To heat water from melted ice to 35° C requires an additional 35 kcal. Thus, one kilogram of ice can remove 115 kcal from the body. We need to remove 1400 calories; therefore, we require 12 kg of ice. Considering the weight of the suit and cooling apparatus (all cooling must be distributed and controlled), we will end up with a weight of not less than 15 –20 kg. [For tables detailing the solution process for this problem, see the next two pages.]

Engineer R. Shapiro[1] and I developed two concepts for a cooling and breathing apparatus. Both concepts received the highest marks in competition: First and Second Place. This basic principle for the consolidation of cooling and breathing devices, developed for the first time in the world in the Soviet Union, become the foundation for all contemporary gas heat-protection suits.

"An apparatus for individual gas/heat protective suits," said Author's Certificate #111,144, "is comprised of hermetically sealed coveralls, helmet, connecting ring, breathing sack, and mask. Placed inside the overall suit space is a tank of liquid oxygen. This device is different because it

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[1] Translator's note: One of the first published articles on TRIZ, "On the Psychology of Inventive Creativity," in *Elements of Psychology,* #6, 1956, was co-authored by Altshuller and Shapiro.

Solution Process for Problem 4

STEPS	LOGICAL STAGES	THOUGHT PROCESS
ANALYTICAL STAGE		
1	Imagine the problem in general.	Develop a cooling apparatus.
2	Imagine the Ideal Final Result.	The maximum cooling capacity.
3	What interferes with this?	Heavy weight of the needed cooling substance.
4	Why?	Because the weight of the apparatus is limited. Out of 28 kg of allowable load for a rescue worker, only 9 kg can be used for the cooling apparatus.
5	Under what condition will it not interfere?	If the weight-share for the cooling apparatus is not 9 kg, but 15–20 kg?
Conclusion: The weight of the tools and oxygen apparatus must be reduced.		
OPERATIVE STAGE		
1	Verify changes in the *object itself*, in particular, possibility of its segmentation.	The *object itself* is now the oxygen apparatus and tools. Their weight must be reduced. This is a very difficult path because, as the oxygen apparatus and tools were improved over the years, designers fought for literally every gram. No, here we can do nothing.
2	Verify the possibility of changing an environment.	Outside the mining environment is air. Of course, if this air could be cleaned, it would be possible to remove the oxygen apparatus. However, it is impossible to clean mining air during a fire.
3	Verify the possibility of making changes in neighboring objects.	A neighboring object for the tools and oxygen apparatus is the third component of the rescue worker's load –the cooling apparatus. Can we design an apparatus that will produce oxygen at the same time? For that, we have to use neither ice nor dry ice. We need liquid oxygen (LOX). This may be possible. Though LOX has less cooling power than liquid ammonia, we can carry as much as 15 kg of LOX.
Conclusion: Instead of two devices – one for oxygen and another for cooling – we may only need one that uses liquid oxygen. Heat evaporates the liquid oxygen and provides our cooling action. The liquid oxygen, heated to normal temperature, can now be used for breathing. The entire apparatus weighs 21 kg.		

SYNTHETIC STAGE		
STEPS	**LOGICAL STAGES**	**THOUGHT PROCESS**
1	Develop a new shape.	A new principle of operation is the utilization of liquid oxygen. Now there will be plenty of oxygen. Before, there was little oxygen; therefore, it was necessary to use a closed-loop system to preserve some of it —exhaled oxygen passed through a lime filter was used for re-breathing. Now, we can get rid of this complex and bulky closed-loop cycle. The new apparatus will be simpler and less expensive than each separate apparatus.
2	Changes in other objects.	The only other object is the set of tools. It is doubtful that they can be made to perform additional functions.
3	Make changes in the methodology of its utilization.	Let's think about how this apparatus will differ in its utilization. Oxygen is rapidly evaporating. This means that the weight of the apparatus will also change: out of 21 kg, the oxygen share is 15 kg. Towards the end of work, the apparatus will weigh only 6 kg. Worker fatigue depends upon the average weight. This means that it is possible to overload the apparatus in the beginning —and bring along much more oxygen.
Four	Utilize the found principle to solve other problems.	Where is it possible to use the principle of joining two devices to work as one? I remember a similar problem in welding technology that used portable gasoline canisters and an oxygen apparatus.
	Conclusion: A complex cooling device works with liquid oxygen, an open loop to feed the oxygen, and overloading in the beginning to increase its capacity.	

uses spent gas from the cooling system for breathing, thus eliminating the need for special respirators."

Design of the gas/heat protective suit is shown in Picture 6. Liquid oxygen is placed in knapsack reservoir (1) Evaporating oxygen reaches injector (2), placed on the axis of canal (3). Flowing out of the injector, the oxygen mixes with the warm air from inside the suit and cools it.

The reservoir can hold 15–16 kg of liquid oxygen, providing 2,000–2,200 kcal of heat transfer. The starting weight of the coveralls is 20–22 kg. If the

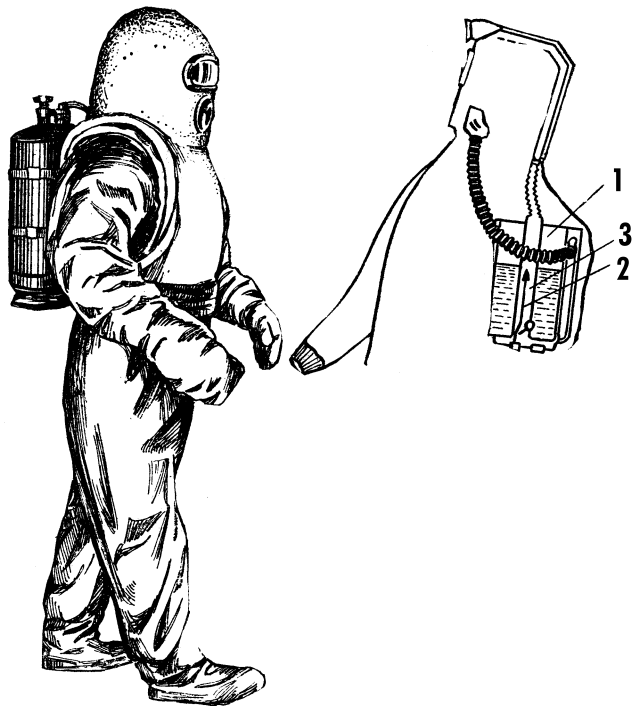

Figure 6.
Gas/heat safety suit for rescuing workers in mines, first developed in the Soviet Union.

starting weight increases to 30–35 kg, the amount of oxygen will be increased one and one-half times. In such a suit, it is not frightening to enter a red-hot kiln.

Now, let's get to know a new variant of the Algorithm.

ARIZ-71

Part One: Choosing the Problem.

Step 1-1: *Determine the final goal of a solution.*

a. What is the *technical* goal (what characteristic of the object must be changed)?

b. What *characteristic* of the object obviously cannot be changed in the process of solving a problem?

c. What is the *economical* goal of the solution? (which expense will be reduced if the problem is solved?).

d. What is the roughly acceptable expense?

e. What is the main technical/economical characteristic that must be improved?

Step 1-2: *Investigate a "bypass approach." Imagine that the problem, in principle, cannot be solved. What other, more general problem, can be solved to reach the required final result?*

Step 1-3: *Determine which problem, the original or the bypass, makes the most sense to solve.*

a. Compare the original problem with a tendency (a direction of evolution) within the *given* industry.

b. Compare the original problem with a tendency (a direction of evolution) within a *leading* industry.

c. Compare the by-pass problem with a tendency (a direction of evolution) in the *given* industry.

d. Compare the by-pass problem with a tendency (a direction of evolution) in a *leading* industry.

e. Compare the original problem with the by-pass one. Choose which to pursue.

Step 1-4: *Determine the required quantitative characteristics.*

Step 1-5: *Introduce time-correction into the quantitative characteristics.*

Step 1-6: *Define the requirements for the specific conditions in which the invention is going to function.*

a. Consider specific conditions for manufacturing the product: in particular, the acceptable degree of complexity.

b. Consider the scale of future applications.

Part Two: Define the Problem more Precisely.

Step 2-1: *Define the problem more precisely utilizing patent information.*

a. How are problems close to the given one solved in other patents?

b. How are similar problems solved in leading industries?

c. How are opposite problems solved?

Step 2-2: *Use Operator STC (Size, Time, Cost).*

a. Imagine changing the *dimensions* of an object from its given value to *zero* ($S \to 0$). Can this problem now be solved? If so, how?

b. Imagine changing the *dimensions* of an object from its given value to *infinity* ($S \to \infty$). Can this problem now be solved? If so, how?

c. Imagine changing the *time of the process* (or the *speed of an object*) from its given value to *zero* ($T \to 0$). Can this problem now be solved? If so, how?

d. Imagine changing the *time of the process* (or the speed of an object) from its given value to *infinity* ($T \to \infty$). Can this problem now be solved? If so, how?

e. Imagine changing the *cost* of an object or process — its acceptable expenses — from its given value to *zero* ($C \to 0$). Can this problem now be solved? If so, how?

f. Imagine changing the *cost* of an object or process — its acceptable expenses — from its given value to *infinity* ($C \to \infty$). Can this problem now be solved? If so, how?

Step 2-3: *Describe the conditions of the problem (without using special terms, and without stating what exactly must be thought out, found, or developed) in two phrases using the following format:*

a. “Given a system consisting of (*describe its elements*).”

Example: ‘There is a *pipeline* with a *valve*.”

b. "Element (*state element*), under conditions (*state conditions*), produces the undesirable effect (*state effect*)."

Example: "*Water* with *particles of iron ore* is *transported through this pipe*. The particles of ore are *wearing the valve*."

Step 2-4: *Enter the elements of Step 2-3a into a table.*

TYPES OF ELEMENTS	ELEMENTS
a. Elements that can be changed, redesigned, or retuned (under the conditions of this problem)	Example from above: *pipeline, valve*.
b. Elements that are difficult to change (under the conditions of this problem)	Example from above: *water,ore particles*.

Step 2-5: *Choose from Step 2-4a the easiest element to change, redesign, or tune.*

Note:

1. If all elements in *Step 2-4a* are equal by degree of possible changes, begin with an immobile element (usually they are easier to change than mobile ones).

2. If there is an element in *Step 2-4a* that is connected with an undesirable effect (usually this is indicated in *Step 2-3b*), choose it only as the last resort.

3. If the system has only the elements in *Step 2-4b*, take as an element the **outside environment.**

   Example: Choose *pipeline* because *valve* is connected to the undesirable effect *wearing*.

Part Three: Analytical stage.

Step 3-1: *Formulate the* ***IFR (Ideal Final Result)*** *using the following format:*

a. Select the element from *Step 2-5*.

b. State its action.

c. State *how* it performs this action (when answering this question, always use the words "by itself").

d. State *when* it performs this action.

e. State under what *conditions* (*limitations, requirements,* etc.) it performs this action.

Example: (a) Pipeline ... (b) changes its cross section ... (c) *by itself* ... (d) when flow control is required ... (e) without wearing.

Step 3-2: *Draw two pictures –(1) "Initial" (the condition before* **IFR***), and (2) "Ideal" (condition upon attaining* **IFR***).*

Note: The pictures may be arbitrary as long as they reflect the essences "Initial" and "Ideal." The "Ideal" picture must reflect the written formulation of the **IFR**.

Test of *Step 3-2:* All elements stated in *Step 2-3a* must be in the picture. If the outside environment is chosen in *Step 2-5*, it must be shown in the "Ideal" section of the picture.

Step 3-3: *In the "Ideal" picture, find the element indicated in* Step 3-1a *and highlight (by a different color, or other means) that part which cannot perform the required function under the required conditions.*

Example: In our problem, the internal surface of the pipeline will be such a part.

Step 3-4: *Why can this element (by itself)* ***not*** *perform the required action?*

Supplementary questions:

1. What do we expect from the highlighted area of the object?

Example: The internal surface of the pipe must, by itself, change its cross-section in order to change the flow.

2. What prevents it from performing this action by itself?

   Example: It is immobile; therefore, it cannot separate itself from the pipe's wall.

3. What is the conflict between "a" and "b" above?

   Example: It must be *immobile* (as an element of the rigid pipe) and *mobile* (as a contractible and releasable element of the controller).

Step 3-5: *Under what conditions can this part provide the required action? (What parameters should this part posses?)*

Note: Do not consider whether or not this is possible to realize at this time. Just name the characteristic and don't be concerned about how it will be accomplished.

Example: On the internal surface of the pipe a layer of some substance appears, bringing the internal surface closer to the axis of the pipe. When required, this layer disappears, and the internal surface moves further from the axis.

Step 3-6: *What must be done so that this element (the internal surface of the pipe) attains the characteristic described in* Step 3-5?

Auxiliary points:

1. On your picture, indicate with arrows the forces that need to be applied to the highlighted part of the object in order to produce the desired characteristic.

2. How can these forces be developed? (Do not consider methods that contradict the conditions in *Step 3-1e*).

   Example: On the internal surface of the pipe, particles of iron ore or water (ice) can be grown. There are no other substances inside the pipe. This will determine our choice.

Step 3-7: *Formulate a concept that can be practically realized. If there are several concepts, number them with the most promising as number one. Write down all such concepts.*

Example: Design a section of the pipe from a non-magnetic material. Then, with the help of an electro-magnetic field, "grow" particles of iron ore on the pipe's internal surface.

Step 3-8: *Provide a schematic for realizing the first concept.*

Auxiliary questions:

1. What is the "aggregate" (composite parts) state of the working element of the new device?

2. How does the device change during one cycle?

3. How does the device change after many cycles?

After creating this concept, it is recommended that you return to *Step 3-7* and consider other concepts.

Part Four: Preliminary Analysis of the Arrived-at Concept.

Step 4-1: *What is getting better, and what is getting worse, during the utilization of the new idea or concept? Write down what is achieved and what is getting more complicated or more expensive.*

Step 4-2: *Is it possible to prevent that which is getting worse by changing the proposed device or method? Make a drawing of the changed device or method.*

Step 4-3: *What is getting worse (more complicated, more expensive) now?*

Step 4-4: *Compare gains and losses.*

a. Which is larger?

b. Why?

If there is greater gain than loss (even in the future), go to *Part Six*, *the Synthesis Stage of ARIZ*. If losses are greater than gains, return to *Step 3-1*. Record, on the same paper as the original analysis, the sequence of the secondary analysis as well as its result. Proceed to *Step 4-5*.

Step 4-5: *If the gain is now greater than any losses, go to Part Six, the Synthesis stage of ARIZ. If the secondary analysis did not produce a new result, return to* Step 2-4 *and check the table. Take from* Step 2-5 *other elements of the system and make a new analysis. Write down the second analysis and its result.*

If there is no satisfactory solution after *Step 4-5*, go to the next part of ARIZ.

Part Five: Operative Stage.

Step 5-1: *From the vertical column of the Contradiction Matrix (see Appendix), choose the characteristic that must be improved.*

Step 5-2:

a. How can we improve this characteristic (from *Step 5-1*) utilizing any known means (if losses are not considered).

b. Which characteristic becomes unacceptable if a known means is used?

Step 5-3: *From the horizontal row of the Contradiction Matrix (see Appendix), choose that characteristic corresponding to* Step 5-2b.

Step 5-4: *In the Matrix, find the principles for removing the technical contradiction (this means, locate the cell at the intersection of the column from* Step 5-1 *and the row from* Step 5-3*).*

Step 5-5: *Investigate how these principles can be used (we will discuss these principles in the following chapters).*

If the problem is now solved, return to *Part 4* of ARIZ, evaluate the new idea, and then go to *Part 6* of ARIZ. If the problem is not solved, perform the following *Part 5* Steps:

Step 5-6: *Investigate the possibility of applying physical phenomena and effects.*

Step 5-7: *Investigate the possibility of changing the action's point-in-time/duration.*

Auxiliary questions:

1. Is it possible to remove a contradiction by "stretching" the time frame of its action?
2. Is it possible to remove a contradiction by "shrinking" the time frame of its action?
3. Is it possible to remove a contradiction by providing an action *before* an object starts to operate?
4. Is it possible to remove a contradiction by providing an action *after* an object finishes its operation?
5. If the process is continuous, investigate the possibility of making a transition to periodic action.
6. If the process is periodic, investigate the possibility of making a transition to continuous action.

Step 5-8: *How are similar problems solved in nature?*

Auxiliary questions:

1. How have non-living parts of nature solved this problem?
2. How did ancient plants or animals solve this problem?

3. How do contemporary organisms solve this problem?

4. What corrections must be made in consideration of specific new technology and materials?

Step 5-9: *Investigate the possibility of making changes to those objects that operate in conjunction with ours.*

Auxiliary questions:

1. What super-system does our system belong to?

2. How can this problem be solved if we change the super-system?

If the problem is still not solved, return to *Step 1-3*. If it is solved, return to *Part 4* of ARIZ —evaluate the found idea — and then proceed to *Part 6* of ARIZ.

Part Six: Synthetic Stage.

Step 6-1: *Determine how the super-system to which our modified system belongs must be changed.*

Step 6-2: *Explore how our modified system may be used differently.*

Step 6-3: *Utilize the newly found technical idea (or an idea opposite to the one found) to solve other technical problems.*

* * *

How is ARIZ-71 different from ARIZ-61?

First, it differs by having two additional Stages that provide for the working-out of problems before analysis begins (and defining the relationship of the inventor to the problem). This makes analysis easier, and provides better results after the analytical stage is completed. The new algorithm has more details, with difficult steps segmented into sub-steps for increased solution reliability.

The Operative stage was also severely modified. Instead of separate principles, a system of Standard Principles and Matrix is offered. The Matrix indicates the most probable principles for removing any detected contradiction.

Thus, the development of the Algorithm has proceeded along two directions:

1. Wider consideration of psychological factors, making the Algorithm more flexible;

2. Improved solution search during all stages of the creative process, making the Algorithm more precise.

Part 2-2:
An Alloy Made of Logic, Intuition, and Skills

While applying the Algorithm, the inventor steadily moves closer to a solution. Some of the steps along the way are almost completely logical. Sometimes logic steps aside —and then the Algorithm helps the inventor move in the correct direction by stimulating intuition. There are steps along the way to a solution where the Algorithm works only through extensive inventive experience.

The first two stages of the creative inventive process are devoted to choosing the problem *and redefining its conditions*. Most of the time, the original statement of the problem, as it comes to the inventor, is imprecise —and occasionally even incorrect. For example, the inventor is told: "We need to find a method to provide *such* and *such* a function." However, it might be better to eliminate the necessity for this function all together. Very often, the bypass concept is more productive than the direct one. During the first stage of the creative process, the inventor determines the final goal of the solution concept, investigates the possible use of a bypass solution, and redefines the conditions for the task (both direct and bypass). The fifth step is very important: the inventor deliberately increases the task's requirements. For example, according to the problem statement, it is necessary to provide control with an accuracy of ± 0.5 microns. It is next recommended that the accuracy by increased to ± 0.1 micron, because during the development and introduction of the invention to the market, those requirements might be increased.

Surveys and direct observation of the inventor's creative process show that, in the majority of cases, the inventor tries to solve the problem without a careful analysis of its conditions. After each unsuccessful attempt, the inventor returns to the problem, clarifies one detail, and immediately makes another trial. This process is repeated many times —and the inventor, without fully understanding the problem's conditions, very often gives up any future attempts at solving the problem.

The Algorithm takes into consideration the actuality of this widespread mistake. While working with the algorithm, the inventor first thoroughly analyzes a problem, and then, step-by-step, removes the non-specific outer layers, highlighting the problem's essence.

Therefore, the first part of the Algorithm presents a chain of logical actions. Here, the role of logic in the creative process can be clearly seen.

The original problem statement can be compared to a large pile of coal: you can try to set fire to the pile as many times as you wish —but there will be no fire. Logic breaks-up the pile —smaller pieces of coal are easy to light. At some stage of the pile's segmentation, even self-ignition of the pile becomes possible.

The second part of the Algorithm resembles a series of logical actions. The inventor continues to work with the specific program. Concrete questions are asked that require concrete answers. Thus, previously developed structures and controlled thinking processes are preserved. However, ARIZ is not a program to be used by a machine. The Algorithm was developed for humans; therefore, it must consider specifics of both the human thinking process and human psychology.

L. Infeld, in his autobiography, discusses a problem offered by P. Kapiza to L. Landau and Infeld:

> *"A metal frying pan is attached to a dog's tail. When the dog runs, the pan hits the road making a noise. Question: At what speed must the dog run to not hear the noise from the pan? Landau and I thought for a long time about the solution. Finally, Kapiza felt compassion towards us and gave us the answer. Of course, it's a very funny one."*[1]

The answer really was unexpected —the speed is equal to zero.

What was the obstacle to solving such a simple problem? The *speed* of the dog was mentioned in the description of the problem, and the word *speed* in our imagination is firmly connected with *movement*. While solving the problem, we subconsciously considered those variants that only include *movement*. Of course, everyone knows that *speed* can be equal to zero. However, this is "not typical," and *inertia* connected with the word *speed* sidetracks our thoughts. If the problem were formulated without the word *speed* (i.e., how must the dog behave so it will not hear the noise?), the solution would be obvious.

Any object (machine, process, or substance) which an inventor imagines is usually described in specific terms. These terms have customary boundaries. Meanwhile, every invention is bound to widen these boundaries. For example, when we imagine dropping cargo with a parachute we clearly visualize the parachute with the dome *up* and the cargo hanging *under* the dome. And suddenly the invention appears. Everything is upside down —the cargo is placed *above* the parachute, descending with the dome below.[2] The conventional term is widened: now we know that parachutes can be both "normal" and "reversed."

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[1] L. Infeld, "Pages of a Physicist's Autobiography," *New World*, 1965, #9

[2] Author's Certificate #66,269. A light emitting device is placed above a parachute. The parachute's dome acts as reflector, beaming the light rays upward.

The original terminology blocks the inventor's imagination. Seminars on inventive methodology show that the successful process for solving a problem is mainly determined by those skills used to "loosen" the system from its original mental images. The second part of the Algorithm represents exactly this "loosening" program.

An analysis of surveys shows that some experienced inventors consciously do not want to study patent information *before* solving a problem. The study of patents, inventors affirm, inhibits "the free thinking process." We cannot ignore this kind of opinion because, during the creative process, individual and personal characteristics play a certain role. In any case, ARIZ anticipates patent information that does not freeze, but rather stimulates, the imagination (*Step 2-1*).

Working through the Algorithm, an inventor does not limit his search only to patents related to his problem. He searches patents on similar, yet more "elaborate," inventions. Let's say that the problem involves the reduction of noise of construction equipment. It makes sense to look at patents related to noise reduction in the aviation industry. It is also wise to search patents for "opposite" inventions (*increase* noise).

The process of "loosening" those original images continues with the help of the Operator STC (*Step 2-2*). Psychological inertia is caused not only by the terminology describing the object, but also by the customary space/time imaging of the object: its **size**, as well as the duration of its **action** (either directly stated in the problem, or implied by itself). It is enough to say "automobile" —and we imagine a machine of a certain size (not less than one meter, not more than 20 meters). It is enough to say "drilling an oil well," and we imagine a process that continues for a certain period of time (months, years).

There is another measurement of an object's mental image — **cost**. It is enough to just say "television," and we immediately imagine a device that costs between a couple of hundred and several thousand dollars.

Operator STC is the sequence of mental experiments helping to overcome these conventional images of an object. When the Operator is applied, the successive changes in the problem are considered. These changes are made in three parameters: size (**S**), time (**T**) and cost (**C**).

Let's look how Operator STC is applied to a simple problem: "Find a method of controlling the cross section size of a pipeline carrying pulp." See Table 1.

Operator STC does not give a precise, unambiguous answer. Its goal is to produce several ideas pointing in the "direction of an answer," helping overcome psychological barriers to analysis of the problem.

Let's look at one more example. Suppose our task is to find a method for detecting leaking joints in refrigerators. (See Table 2).

Imaginary mental experiments with this problem, utilizing Operator STC, can yield different answers depending upon imagination, knowledge, and skill —in other words, upon the individual capabilities of each person. One thing cannot be done: replace the original problem with another one. For instance, any answer to *Step 2-2f* in the second example should not state: "Increase the manufacturing quality of refrigerators" —although it makes more sense to prevent the emergence of leaking joints than to fight them once they exist. The problem chosen in the first part of ARIZ must be worked out. If the chosen problem consists of locating leaking connections, then only this must be solved.

In some problems it is recommended to consider quantitative parameters other than size. For example, in the problem "Find a method for introducing 24 types of powder into a reactor following a specific graph," it is possible to use the word "number" for the different types of powder as a quantitative parameter. Here *Step 2-2a* would be one type of powder, and *Step 2-2b* thousands, or tens of thousands, types of powder.

The next step (*2-3*) is used in order to overcome psychological inertia. Let's take, for example, the problem of finding a method for producing a cubical glass filter with equal capillaries (the dimension of the cube is one meter; the number of capillaries is several tens per cm^2). The condition of the problem dictates (imperceptibly) a certain mental image: *There is a glass cube; it is necessary to make holes in it*. During the process of solving this problem, the cube and (the habitually anticipated) round holes appear in the sketch. In the majority of solutions, the basic mental image is preserved —it is suggested, one way or another, to make the holes in a solid glass (or liquid) block.

Let's now change the problem statement: "Find a way to manufacture a cube of air containing glass longitudinal partitions." Or, "Find a way to manufacture a cube of air containing many thin glass rods or threads." A glass cube with holes is the same as a cube of air with rods, because holes can also be called *air rods*.

By virtue of our psychological inertia, we envision a "glass cube with holes," and not "an air cube made of glass rods," although these are equal definitions. If the problem is worded as in the second statement it can be solved easily and fast (a cube made out of glass threads).

In essence, when we make a transition from "a glass cube with air holes" to "an air cube with glass rods," (by transforming the **usual** into the **unusual**) it means that the process mentioned by W. Gordon, developer of Synectics, is accomplished. However, Synectics does not offer any methods for transforming the **usual** into the **unusual.** It only calls for the performance of such a transformation. In ARIZ, this process is programmed in *Step 2-2* (Operator STC) and *Step 2-3*. By answering the questions in *Step 2-3*, we make a transition from an incorrect statement of the problem to the correct statement without emphasizing one element (glass). **The Systematic approach forces us to see all the elements that are, in the majority of cases, non-habitual.**

Table 1 (Pipe Carrying Pulp)

STEPS	PROCEDURES	CHANGING THE OBJECT OR PROCESS	HOW CHANGED PROBLEM IS SOLVED	PRINCIPLE USED IN THE SOLUTION
2-2a	S → 0	$D_{pipe} < 1$ m.	Control crossection by squeezing its walls (they become thin and flexible).	Deformation of pipe's wall
2-2b	S → ∞	$D_{pipe} > 1000$m	This pipeline is similar to a river. A dam must be built, or we must wait for *natural* control, like freezing, or melting.	The dam (acting as a valve) will wear out. The best thing is to change the aggregate state of the flow.
2-2c	T → 0	To stop the flow within 0.001 sec	This requires fast action (like an electromagnetic field).	Instead of a mechanical, use an electromagnetic working element.
2-2d	T → ∞	To stop the flow within 100 days	Mechanical gate will wear out (as the crossection is reduced, the flow speed increases). Worn out areas need to be restored.	Gate with an increasing number of particles.
2-2e	C → 0	Cost of closing the flow equals zero.	The flow has to close itself.	Self-adjustments.
2-2f	C → ∞	The cost to close the flow is higher then $1,000,000	It is possible to introduce into the flow something very expensive, but easily controlled. Example: molten metal instead of water, controlled with electromagnets.	Controllable additives.

Table 2 (Detecting Leaking Refrigeration Joints)

STEPS	PROCEDURES	CHANGING THE OBJECT OR PROCESS	HOW CHANGED PROBLEM IS SOLVED	PRINCIPLE USED IN THE SOLUTION
2-2a	S → 0	Length of the coil is less then 1 mm.	Quantity of leaking liquid is small. This liquid should be made more detectable. Add something to it.	Micro-additives that make detection easy.
2-2b	S → ∞	Length of the coil is more then 100 km.	Distance detection: locators, radio-detectors, thermo-detectors. Conventional observations.	Location by conventional infrared rays; radio location.
2-2c	T → 0	Time of detection is 0.001 sec.	Mechanical and chemical means of detection are excluded. What is left: electromagnetic and optical means.	Electromagnetic and optical radiation.
2-2d	T → ∞	Time of detection is 10 years.	Seeping through a joint, the liquid will react with coil material. It is easy to detect a leak by the changed outward appearance of the coil.	Coil's material is an indicator of seeping liquid.
2-2e	C → 0	Cost of detection equals zero.	Leaking liquid provides a fast means for detection.	Self-detection, self-indicators.
2-2f	C → ∞	Cost of detection is $1,000,000	Add to the liquid an expensive, but easily detectable, substance.	Indicator additives.

The correct execution of *Step 2-3* significantly simplifies the process of problem solving. While executing this step, it is recommended that you carefully watch for the following:

1. All special terms are removed from the statement of the problem.
2. All elements included in the system are listed correctly.

For example, in the statement, "There is a system consisting of a glass cube and capillaries," two mistakes are made:

1. It is better for the word "capillary" to be replaced with the word "hole," and
2. "Glass cube" – this is still solid, but we are left with the remains of the cube after many holes are made in it. The correct statement is: "There is a system consisting of holes and glass partitions between the holes."

Let's break a system into elements. Choose an element that needs to change in order to solve the problem (*Step 2-4* and *Step 2-5*). The main criterian for selection is the element's degree of variability and controllability. The easier it is to change an element (under the conditions of a given problem), the more reason to choose that element as an object for further analysis. There is a simple, though not universal, empirical rule:

1. **Technical** objects usually belong to *Step 2-4*a.
2. **Natural** objects usually belong to *Step 2-4b*.

Many inventive mistakes, as will be shown later, are explained by a desire to change those elements belonging to *Step 2-4b*.

Completing the first two parts of ARIZ requires spending no more than two hours for a problem of average complexity (not counting the time necessary to analyze any patent material). Not one single step was included in the Algorithm without being repeatedly tested in seminars. In this regard, the only steps included were those that *significantly* made the process of problem solving easier. There are many tips and methods that some times can be very useful; however, these are not compulsory. The Algorithm is designed for human use and, therefore, must be compact: running too long a distance leaves little energy for take off. With ARIZ, just the opposite applies. When each step causes the original statement of the problem to appreciably change, clearly showing that the problem is being "worked out," then confidence appears. This is the basis for inspiration. Two hours of organized thinking allows an inventor to feel the essence of a problem more deeply than weeks, or months, of disorganized mental jumps. Now the inventor can confidently move ahead to reveal the technical contradiction that must be removed.

* * *

American mathematician D. Poia, who studied the psychology of creativity, tells about the following experiment:

> *"A chicken was placed in front of a screen behind which was some food. The chicken could not reach the food until it went around the screen. However, for the chicken this problem became rather difficult. A bustling chicken will run back and forth on her side of the fence, losing a lot of time before reaching her food — or she may never reach it. By the way, after a long and restless run, she may accidentally do it."*

Poia ironically compares the chicken's behavior with a human who is sporadically trying to solve a technical problem:

> *"No, we cannot blame the chicken for absence of wit. It is definitely difficult when there is the necessity to turn away from the target — walk away from it and then continue again toward it without constantly seeing the target in front of you. There is an analogy between the problems the chicken experienced and our own."*[1]

As an illustration, Poia offers this simple task: How can you bring exactly six liters of water from a river using two buckets, one of four liters, the other of nine liters?

It is obvious that pouring water "by guessing" from one bucket to the other is prohibited. The problem has to be solved using the exact measuring capacity of the two buckets.

I offered this problem to students at seminars before we began to study the methodology of searching for a solution. The results never differed from Poia's conclusion. Attempts to solve the problem without our systematical approach looked like this: "What if we do this?" The correct solution appeared after many "what ifs." Meanwhile, the problem can be easily solved. You only have to know the method for approaching problems that require "guess work."

The same thing happens with inventive problems. The thought process of an inventive person possesses a special characteristic: When solving a problem, the person imagines a machine and then mentally changes it. An inventor sort of builds a series of mental models and experiments with them. During this time, an existing machine, or something similar to it, is

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1. D. Poia, *How to Solve a Problem,* pages 156-157.

taken as a basic model. This model has limited possibilities for development, freezing one's imagination. Under these conditions, it is difficult to come to a principally new solution.

If an inventor starts by stating an *Ideal* Final Result, then an *ideal* concept is taken as the basic model. This model is now already simplified and improved. Further mental experiments will not be aggravated by a burden of habitual mental forms. These experiments immediately get the best perspective for their direction: the inventor tries to reach the highest result by the least means possible.

Let's look at the problem of the two buckets. Failures —when the "what if" method is used —are associated with attempts at finding an answer by searching from the beginning forward to the end. Let's try to do it backwards.

It is required that one of the buckets contains six liters. Obviously, this could only be the large bucket. So, an *Ideal* Final Result would be to have a large bucket filled with six liters.

For that, it is necessary to fill the large bucket (with a capacity of nine liters), and then pour out three liters. If the second bucket had a capacity of three —rather than four —liters, the problem would immediately be solved. However, the second bucket has a four-liter capacity. To make it a three-liter bucket requires filling it in advance with one liter. Then it becomes possible to pour three liters out of the large bucket.

Therefore, the original problem is now reduced to another, much easier, one: measure one liter of water with the help of the two existing pails. This creates no difficulty because $9 - (4 + 4) = 1$.

We can fill the large bucket and then pour out four liters twice into the small bucket. After that, one liter of water will be left in the large bucket. We can now dump that one liter into the empty small bucket.

The four-liter bucket now "becomes" a three-liter bucket —exactly what we need. We fill the large bucket once more to its rim, and then pour-off three liters into the small bucket. Six liters of water will now be left in the large bucket. The problem is solved.

By moving step-by-step from the end to the beginning we solved the problem without performing a useless step.

To state the Ideal Final Result correctly means reliably entering onto the correct road to solving a problem.

Some inventors do exactly that. Remarkably, inventors that confer importance to this method mention nothing in their surveys about revealing the technical contradiction belonging to the problem. For example, the inventor U. Emelianov, of Moscow, writes, "After the statement of a problem is made, I try to imagine an ideal final goal, and then I think about how I can reach it. I do not recall any special methods of accomplishing that." Therefore, "before" and "after" determining the Ideal Final Result, the work is done spontaneously —only one method is consciously utilized. This, of course, is not accidental. Good skills in applying that one method compensate for the "idling" effect of others.

Some procedures of this part of the Algorithm are used separately by inventors. More often, an inventor applies two or three well-mastered procedures. The most methodical inventors exploit five -to- seven procedures. The methodology of inventing, even after only one glance, increases one's creative arsenal by including *dozens* of procedures for creating an altogether rational system for solving inventive problems.

* * *

The third part of the Algorithm starts with the definition of the Ideal Final Result. It seems not difficult to answer the question, "What is it desirable to obtain in the ideal case?" However, the practice of teaching inventiveness shows that it is extremely difficult to divert oneself from the limitations and restrictions imposed by real conditions, and be able to imagine an actual ideal result. If, for instance, we are talking about a device to paint the internal surface of a pipe, the ideal result is usually drawn in the form of some compact automatic brush moving inside the pipe. Here we can see the mental attachment to an already known device for painting outside surfaces. The ideal result, in this case, must be formulated differently: "Paint comes **by-itself** into a tube, **and by-itself** evenly covers the tube's internal surface." Later, it will become clear that the paint cannot perform everything we want it to do "by-itself." Then we will support, by structure or technical procedure, some part of the ideal concept, while trying to side-step Ideality as little as possible.

A correct definition of the Ideal Final Result is extremely important for all creative processes. Therefore, in seminars on methodology, during the solving of practice problems, the question is stated in the following formulation:

> *"Imagine that you have in your hands a magic wand. What kind of result (for the solution to this problem) will happen if this magic wand can be used?"*

It is impossible to ask the magic wand to build a "painting device." The wand is the "device." The answer is usually correct: "Let the paint get into the pipe by itself." Gradually, the necessity to remind students about the magic wand disappears, and the formulation of the Ideal Final Result from the Algorithm remains.

There are two rules for helping to precisely determine the Ideal Final Result.

Rule One: It is not recommend to guess beforehand whether it is possible to reach an Ideal Final Result or not.

Let's recall the problem about a crane for cargo airplanes. The ideal result for this problem would be the following:

> *A crane appears during the loading process, and disappears when the plane is in the air. At another airport, the crane appears again when unloading cargo.*

At first glance, this is completely impossible to achieve. However, each invention, as we said, is a road through the "impossible." In this problem, "impossible" signifies only "impossible by existing means." The inventor must find a new concept, and then the impossible becomes possible.

A crane installed in an airplane, of course, cannot disappear. But during the flight, the metal frame of the crane can be part of the fuselage structure. The crane, while in the air, becomes part of the airplane design. It will function as a useful load, and then disappear when its a dead load. The crane's weight is compensated for by a reduction of fuselage weight.

Rule Two: Do not think about how, and by what means, an Ideal Final Result will be achieved.

Recall how D. D. Maksutov reached the idea for the meniscus telescope. The inventor must somehow cover the reflector's opening to protect its mirror from pollution and damage. Maksutov started by determining the Ideal Final Result: In his mind, he closed the opening with optical glass. At that moment, he did not think about how this could specifically be accomplished. This is significant. To develop a classroom telescope means developing an inexpensive telescope. Optical glass prevented him from pursuing this direction because it is too expensive.

It requires an heroic effort of thought to turn one's back to a problem. Yet only in this way is it possible to find a direction toward design cost reduction.

When solving different problems, the best method for determining the Ideal Final Result is to simply turn the question contained within the problem statement into an affirmative statement. Let's take the magnetic assembly of bearings. The question, as stated in the problem, was: "How can rollers be held to a shank's track?" An Ideal Final Result can be formulated thus: "The rollers are, by themselves, stuck to their places." (Or, "The outside environment holds the rollers in place ...") Notice that the statement of the Ideal Final Result is not effected by thoughts as to whether the rollers will stick "by themselves" or not —or how this could be done.

Imagine two movie frames. In the first frame, there must be shown the conditions creating a problem. In this case, the shank with its rollers falling down must be sketched in the frame. In the second frame is the Ideal Final Result. The rollers stick to the shank "by themselves."

It is easy to get accustomed to a "two-frame" image. At the same time, it releases us from many mistakes while determining the Ideal Final Result.

Cinema has trained us to overcome the impossible because eerything is possible on screen. This is explicit to the movie making process. Therefore, it makes sense to use every movie making skill one possesses to make a first correct step in the Analytical Stage.

Solution to Problem 1

In the first frame, the toroidal ring must be shown without a wire. In the second frame — the same ring, but with the wire winding.

At this time, it is not important how this winding appears. What is important is how the finished product looks. Here, every detail must be clearly imagined, and then this conceptual image must be simplified.

The ring with the windings can be shown, in general, in the second frame. This is not bad; however, it can be better: Show a magnified image of part of this ring in crossection (Figure 7). The goal we need to achieve is seen clearer. Here, the third frame asks to be drawn. Let's simplify the image and combine the layers of insulation. Now, the fourth frame: remove the **lower common layer** of insulation (because ferrite itself possesses an insulating property). Now, the fifth frame: remove the **upper common layer** of insulation. Because it is common, it is easy to add later.

We obtain a toroid with a spiral metal layer. The problem now is fundamentally simplified: To produce a metal spiral layer is much easier than to wind an insulated wire.

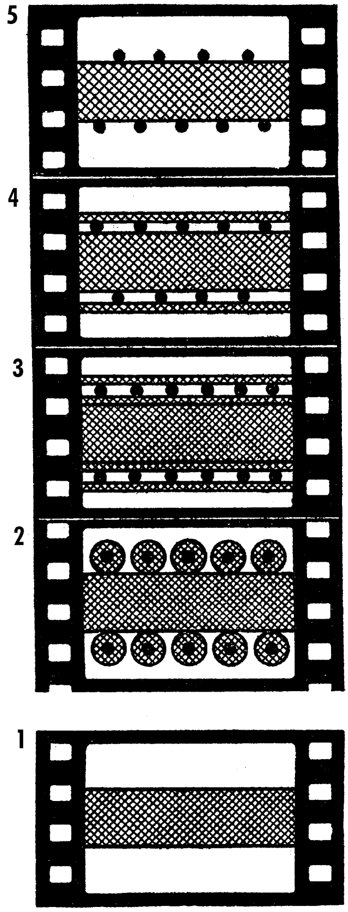

Figure 7. *You have to clearly imagine every part and then simplify the model.*

* * *

Of course, it takes skill to move from frame to frame. But even that is not necessary: *Step 3-2* considers only two frames: "was" and "will be" (the IFR). Further on (*Step 3-3*), in the frame "will be," that part of the object not performing the required action is highlighted. This, to a degree, replaces the other frames.

By taking *Step 3-1* and *Step 3-2*, inventors boldly create what they desire. *Step 3-3* forces them to ask the question, "why is the desirable impossible to achieve?"

It becomes clear that, while trying to achieve what is "desirable" by using known methods, an obstacle in the form of a result appears — additional weight, complex control, increase machine cost, reduction of machine capacity, or an unacceptable reduction of reliability. This is the technical contradiction belonging to the problem.

Each obstacle is stipulated by specific causes. *Step 3-4* defines these causes.

Reasons for an obstacle lie almost always in front of our eyes —and they are not difficult to find. These reasons are seldom unclear. However, it is not necessary to start looking right a way. The point is this: to provide an effective process for solving a problem it is not necessary to learn in detail the physical essence of the problem's cause. Suppose a technical contradiction is stipulated by insufficient material strength, and it is understood that study of this material can provide new information that will allow for the removal of the obstacle. This is a scientific path, not an inventive one. A discovery will be made this way, but not an invention.

Research work requires special equipment and substantial time. It is more beneficial to choose the inventive path, where there are still resources. So, when determining the immediate reasons for technical contradictions, one must limit oneself to providing general formulations.

Let's recall the magnetic assembly problem. The ideal result is for the rollers to stick "by themselves" in place. The obstacle is that the rollers cannot stick "by themselves," they fall down. The reason for this is clear: Rollers are made of metal, the shank is made of metal, and metal to metal cannot stick by itself. This does not require any more detail to determine the reason for the obstacle. When this reason is found, the next step can be made to determine under what conditions the obstacle will disappear.

Here, in the magnetic assembly problem, the obstacle disappears when metal sticks to metal "without anything." With the problem transformed in this way, it is difficult *not* to think about a magnetic field.

Let's look at another problem: the racing car.

Solution to Problem 3

Step 2-3: There is a system comprised of a wheel and fender. The position of the wheel cannot be observed through the fender.

Step 2-4:

a. The fender.

b. The wheel. (The wheel has many requirements, and any change to it may conflict with a requirement. There is only one requirement for the fender —preserve its specific shape. This means that,under the conditions of this problem, the fender is easy to change).

Step 2-5. The fender.

Step 3-1. The fender, by itself, allows observation of the wheel without worsening its aerodynamic characteristics.

This problem is simple, no higher than Second Level. However, at this time we are interested in the process of solving the problem —which is much easier to do using simple tasks.

In *Step 2-3*, the solution demands *by-itself*, and *Step 3-1* leads to the solution with a high degree of accuracy. The fender, by-itself, allows the passing of light rays; therefore, all variations utilizing mirrors, fiber-optics, and so on are eliminated. *Without worsening the fender's aerodynamics* means that the shape and the position of the fender cannot be changed, and holes in the fender cannot be made as well. There's one thing left, and that is to make the fender transparent. This allows us to superimpose that which is not superimposable: the car's aerodynamics is improved while, at the same time, the driver has the ability, as was the case before, to observe the front wheel.

When the solution is found, it seems obvious. Really, this solution could have appeared in the early 1940's. Mental inertia probably played a role here. At the time the problem appeared, material was not available to manufacture transparent fenders, and conventional glass is no good because it's too brittle. At that time, it was customary to believe that wheels could only be covered with metal fenders —and metal, as we all know, is not transparent. Time passed, and the conditions changed. New transparent plastic was developed; however, mental inertia lingered on —and the problem was still unsolved. One contributing factor was that the problem related only to racing cars, and was therefore not in the sight of conventional automobile engineers. It is unlikely that a conventional automobile would have transparent fenders (they soon become dirty and loose their transparency, so the solution could not be applied here). In general, to make a machine, or a portion of it, transparent is one of the most powerful principles for solving inventive problems.

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ARIZ Step 2-3. *Describe the conditions of the problem in two phrases using the following format: a) "Given a system consisting of (state condition); b) Element (state element), under conditions (state conditions), produces the undesirable effect (state effect).*

ARIZ Step 2-4: *Enter the elements of Step 2-3a into a table of:* a) Elements that can be changed, redesigned, or retuned (under the conditions of this problem), b) Elements that are difficult to change (under the conditions of this problem).

ARIZ Step 2-5: *Choose from Step 2-4a the easiest element to change, redesign, or tune.*
Note: 1) If all elements in Step 2-4a are equal by degree of possible changes, begin with an immobile element (usually they are easier to change than mobile ones), 2) If there is an element in Step 2-4a that is connected with an undesirable effect (usually this is indicated in Step 2-3b), choose it only as the last resort, 3) If the system has only the elements in Step 2-4b, take as an element the ***outside environment.***

ARIZ Step 3-1: *Formulate the* ***IFR (Ideal Final Result)*** *using the following format: a) Select an element from Step 2-5, b) State its action, c) State how it performs this action (when answering this question,* ***always*** *use the words "****by itself****"), d) State when it performs this action, e) State under what conditions (limitations, requirements, etc.) it performs this action.*

The diagram in Figure 8 shows how ARIZ works. Utilizing the IFR as a beacon, an inventor immediately comes to the area of strongest solutions. Then follows a step-by-step analysis of the technical contradiction contained in the problem. The clear understanding of the technical contradiction and its internal mechanics allows, in some instances, the idea for the solution to emerge at this stage. However, as a rule, an idea in its infant stage is very raw. It must be extracted, corrected and reinforced with advantages. Then, as much as possible, its shortcomings must be removed. This is done in the fourth part of ARIZ.

Sometimes, the shortcomings of the idea are too serious, its advantages doubtful, and the second analysis produces nothing new. It is then suggested to go to the fifth part of ARIZ.

There are an endless number of inventive problems; however, the technical contradictions contained in them often repeat. If **typical contradictions** exist, then **typical principles** for removing those contradictions must also exist. Indeed, statistical investigation of inventions reveals forty effective principles for resolving technical contradictions. Many inventions are based upon their utilization —either separately, or in combination. This does not, of course, belittle the role of creativity; as a matter of fact, the whole universe is combined out of only a few hundred elements.

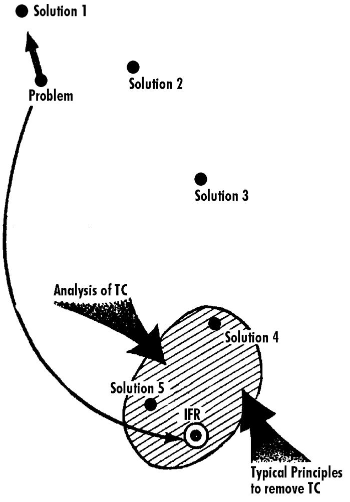

Figure 8.
In accordance with ARIZ, the process of problem solving begins with the stating of the Ideal Final Result (IFR). This helps to immediately reach the area of most powerful solutions. Further search becomes easy by defining the Technical Contradiction (TC) and utilizing the typical principles for its removal.

Let's make a table. In the vertical column we will write those characteristics that we would desire to change (*improve, increase, reduce* and so on); along the horizontal row we place those characteristics that, if the desired change were to be made with known, conventional methods, would become unacceptable.

This Contradiction Matrix is shown in Appendix I. It was produced as the result of an analysis of 40,000 inventions. The fifth part of ARIZ begins with the utilization of this table. Suppose that we want solve the racing car problem mentioned earlier. Can we reduce, through conventional means, the energy loss created by the imperfect aerodynamics of the wheels? Yes, we can: hide the wheels under fenders. But then the driver could not observe the wheel's position. Therefore, we have this contradiction: "loss of energy *versus* conditions of observation"—or, "conditions of observation *versus* loss of energy."

Let's look at the Matrix. "Loss of energy" is in the list of characteristics —line 22; however, there is no characteristic called "Conditions of observation." Let's take column 33 instead: "Convenience of use." In the intersection of line and column we have a cell containing the numbers 35, 32 and 1. These numbers represent the recommended principles. Some of them can be keys for solving the problem.

We will analyze these principles in detail later. At this time, I can only say that among these three principles suggested by the table there is one (#32b) that suggests changing the translucency of an object. If we take the contradictions "Convenience of use *versus* loss of energy" or "Loss of energy *versus* loss of information," then the suggestion "Make an object transparent" is revealed among the suggested principles.

Part 2-3:
The Inventor's Instruments

Let's examine in detail the Contradiction Matrix, as well as the principles contained within it.

Developing this type of table is laborious work. Unfortunately, it cannot be done by merely analyzing successive inventions, selecting repeat solutions, and then placing them into the table. Author's Certificates and patents are quite often issued for trivial solutions. Consequently, a table based upon these patents will, as a rule, suggest "weak" solutions —even if a large number of the analyzed inventions contain "strong" solutions. Some principles —even if originally powerful five, ten, and twenty years ago —may now be insufficient for solving new problems.

Because of this it was necessary, in the course of constructing the table, for each cell to denote the most powerful and promising principles belonging to that leading industry where the specific type of contradiction was resolved. For instance, for contradictions of "weight *vs.* time-of-action," "weight *vs.* speed," "weight *vs.* strength," "weight *vs.* reliability," and so forth, the most appropriate principles can be found in inventions from the aviation industry. Contradictions associated with a requirement to increase accuracy are most effectively removed by principles inherent in inventions of devices made for experimentation.

A table constructed from principles used by leading industries in new technologies will help find powerful solutions for commonplace inventive problems. A table useful for solving leading technological problems must additionally contain the newest principles just emerging from recent inventions. These principles are not found in those "successful" inventions honored with an Author's Certificate —they are instead discovered in those applications rejected as "unrealizable" or "impracticable."

The table for ARIZ-65 was built from the analysis of 5,000 inventions relating to 43 Patent Classes. The table for ARIZ-71 contains even more detail. This completely new table was produced after analyzing over 40,000 inventions. Not every cell of the table is filled; nevertheless, it embraces about 1,500 typical technical contradictions, showing for each type the probable principles for solving a problem.

It is necessary to emphasize that each principle recommended in the table is formulated in general terms. They are like factory-made clothing, and need to be tailored to fit individual problem specifics. For example, if the table recommends Principle 1 (Segmentation), this means only that the solution is somehow connected with *division* of the object. The table by no means releases an inventor from the necessity to *think*, it only directs ones' thought toward more promising directions.

Are these typical principles compatible with the creative character of the inventing process? Yes —in fact, contemporary inventors occasionally use these typical principles unsuspectingly.

Attempts to compose a list of principles were made in the beginning of the 20th century. However, these lists were incomplete because they were made through accidental observations and from diverse data sources. To compose a proper list, and periodically renew it, requires systematically investigating patent information, and analyzing tens-of-thousands of inventions throughout the majority of the Patent Classes. Today, this work is done on a regular basis, and each modification of ARIZ provides an additional, more precise list of principles.

In the inventor's imaginary "creativity factory," the principles play the role of a toolset. Learning to use it properly requires certain skills. In a simple case, the inventor searches through the list of principles for an analogous "clue." This method is very slow, and not very effective. A different thing occurs when a problem is solved through ARIZ: the Matrix reveals the most effective solution for the given problem. When an inventor begins learning ARIZ, he analyzes principles sequentially; later, he uses the Matrix. However, in all cases it is recommended that the principles be understood, along with the way in which they can be applied.

The list of typical principles is a special kind of desk manual. The inventor must consider this list a foundation that must be replenished through new technical and patent publications.

* * *

Let's look at the typical principles for solving technical contradictions, along with some examples .

1. Segmentation

a. Divide an object into independent parts.
b. Make an object sectional (for easy assembly and disassembly).
c. Increase the degree of an object's segmentation.

Example 1: *USA Patent #2859791.* A tire that consists of 12 independent sections.[1]

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[1] Here, as well as in other examples, I tend to provide illustrations for maximum visualization. Let the reader be not confused by "small" and "funny" ideas that support some principles. What's most important is their essence.

Segmentation of the tire was performed in order to increase its *reliability*. However, this is not the only reason to utilize this powerful principle. Segmentation is the leading tendency in the evolution of contemporary technology.

Example 2: *Author's Certificate #168,195.* An excavator's bucket has a semi-circle shaped cutting edge. This excavator is original because its cutting edge is made of removable sections allowing for faster and easier repair.

Example 3: *Author's Certificate #184,219.* A method for the continuous blasting of mine rocks by explosives. This method is original because it uses micro-explosions for the continuous blasting of the top rock layer, thereby allowing the continuous production of smaller rocks.

2. Extraction (Extracting, Retrieving, Removing)
a. Extract the "disturbing" part or property from an object
b. Extract only the necessary part or property from an object.

Example 1: *Author's Certificate #153,533.* A device providing protection from x-rays. This device is original because of its protective shield —a vertical bar corresponding to our spine — made of material that prevents the passage of x-rays. This provides protection from ionized radiation to the head, shoulder area, spine, spinal chord, and sex organs of the patient.

The idea behind this invention is clear. It separates out the most harmful part of the radiation by blocking it. The patent application wasn't made until 1962 —even though this simple and greatly needed invention could have been made much earlier.

We are used to viewing objects as sets of traditional elements assembled together. For instance, a helicopter *has* a fuel tank. In reality, a helicopter must *carry* fuel. However, when a helicopter is assigned short trips, the fuel can be left on the ground. The electric helicopter has an electrical motor instead of a gas engine.

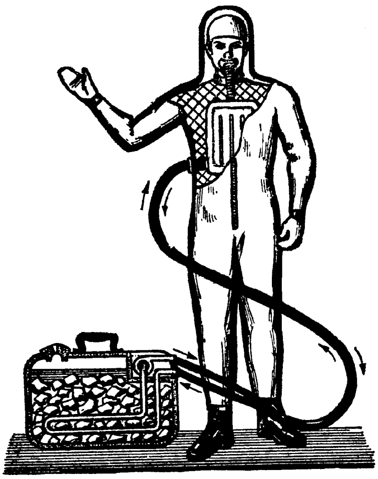

Figure 9. *Extraction Principle: Rescue workers carried backpacks containing cooling devices; now these devices are placed in a separate container.*

Example 2: *Author's Certificate # 257,301.* In Figure 9, a container is shown separate from a man.

Example 3: The collision of birds and airplanes can result in airplane crashes, and consequent casualties. There are many U.S. patents for methods to scare birds away from airport areas — mechanical scarecrows, chemical diffusion, etc. The best was the loud playing of tape recordings of frightened birds. Here, the bird's voices were separated from the birds. This solution is quite unusual, but perfectly supports the principle of Extraction.

3. Local Quality

a. Transition from homogeneous to heterogeneous structure of an object or outside environment (action).
b. Different parts of an object should carry out different functions.
c. Each part of an object should be placed in conditions that are most favorable for its operation.

Example 1: *Author's Certificate #256,708.* A method to suppress dust in coal mines. This method is different because it suppresses dust by simultaneously using fine and course water sprays. A fine mist cone is surrounded by a film of course spray. This method prevents the spreading of fog through mines by moving it out of the dust formation area through a ventilated airflow.

Example 2: *Author's Certificate #280,328*. Method for drying rice grains. This is different because the rice grains are screened by size, and dried separately, thereby reducing the formation of cracks in the grains.

The Principle of Local Quality is clearly seen throughout many examples of the evolution of machine development. Machines are segmented into numerous elements, and these elements are placed in the most favorable conditions for performing their work.

Originally, the steam engine contained a cylinder that performed the functions of a steam boiler and a condenser at the same time. The cycle of the engine was as follows: Water was poured into the cylinder and heated by a coal fire. When the water boiled, steam lifted the piston. Then the fire was removed and the cylinder cooled with chilled water sprinkled on its outside wall. As the steam condensed, atmospheric pressure pushed the piston back down.

Inventors later separated the steam boiler from the cylinder —producing a substantial reduction in fuel consumption. However, steam that had previously been outside condensed inside the cylinder producing large thermal losses. A next step had to be performed: separate the condenser from the cylinder. This idea was developed and implemented by James Watt.

This is how he did it, in his words:

> *"After I analyzed this question, I came to the conclusion that, to have a perfect steam engine, it is necessary for a cylinder to be as hot as the steam going into it. However, to produce a vacuum, steam must be condensed to a temperature no higher than 30° C.*
>
> *"I went for a walk near Glasgow one noontime. It was a beautiful day. I had walked past an old laundry complex while thinking about my machine. I almost reached Gerd's house when a thought struck my mind: steam is expandible and tends to fill a vacuum. If we connect the cylinder to a reservoir containing a vacuum, then the steam will rush into it and the cylinder will not need to be cooled. I had not yet arrived at Gerd's house, yet everything was completed in my mind!"*

4. Asymmetry

a. Replace symmetrical form(s) with asymmetrical form(s).
b. If an object is already asymmetrical, increase its degree of asymmetry.

Machines are born symmetrical. This is their traditional form. Therefore, many problems containing difficulties with relationships to symmetrical objects are easily solved by merely breaking this symmetry.

Example 1: A vise with asymmetrical jaws is able to hold long parts vertically.

Example 2: Automobile headlights need to work under two different operating conditions. One condition calls for the projection of a long distance light beam, another requires projection of a short distance beam without blinding oncoming drivers. Their requirements are different, yet for many years installation of these lights was the same. The idea to have an asymmetrical light installation is recent. Two sets of beams are now installed on a car —low beams and high beams —having different adjustments.

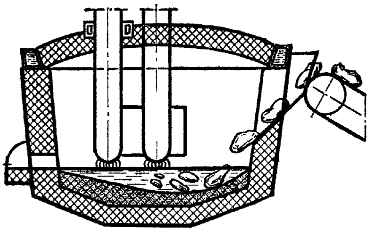

Figure 10.
Asymmetry Principle:
Electrodes of an electric arc furnace are asymmetrically placed creating free space next to the loading window. This permits the continuous loading of ore.

Example 3: *USA Patent #3,435,875.* The outer section of an asymmetrical tire is made from stronger material to withstand impact when colliding with curbs.

Example 4: *Author's Certificate #242,325.* An electrical arc furnace for cast iron smelting that has a side-loading window. This furnace is different because it has an asymmetrically concave fettling hole that widens towards its loading window. This concept provides for a continuous smelting process (Figure 10).

5. Consolidation

a. Consolidate in space homogeneous objects or objects destined for contiguous operations.
b. Consolidate in time homogeneous or contiguous operations.

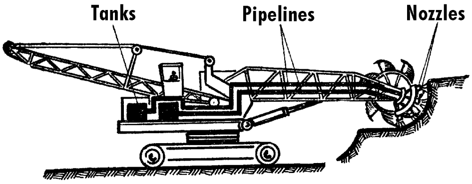

Figure 11.
Consolidation Principle:
It was necessary to interrupt the work of the excavator to thaw the frozen ground; now, heat nozzles are installed on the rotor.

Example 1: *Author's Certificate #235,547.* The working element of a rotor excavator is comprised of a rotor and a crane arm. This excavator is original because it has a device for heating frozen ground (for example, nozzles placed on both sides of the rotor's edges). This allows for a reduction in cutting force.

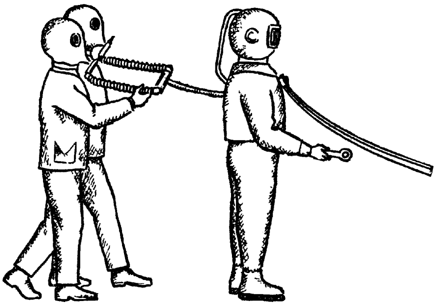

Figure 12.
One more application of the Consolidation Principle.

Example 2: *Author's Certificate #134,155.* An underwater rescue device for bringing people who are trapped in an air bubble of a sunken ship to the surface with the help of helmets. This device is different because it has two-or-three helmets, with hoses and fittings for connecting to valves mounted on the diving suits allowing for the regulation of air supplied to helmets. This invention improves the efficiency of rescue work (Figure 12).

6. Universality

a. An object can perform several different functions; therefore, other elements can be removed.

Example 1: In Japan, the possibility of building an oil tanker that contained a refinery was considered. The idea for the project was to refine crude oil during transportation to its destination.

Example 2: *Author's Certificate #160,100.* A method for the hydrotransportation of materials like tobacco leaves to drying machines. This method is different because the water is heated to around

80°-85° C, allowing for the cleaning of the tobacco leaves while simultaneously preserving their color.

Example 3: *Author's Certificate #264,466.* A computer memory element is made on a thin cylindrical film, and then placed on a dielectric sub-strata. This invention is different because the film functions as a data bus for recording and retrieving information, thereby simplifying the memory element.

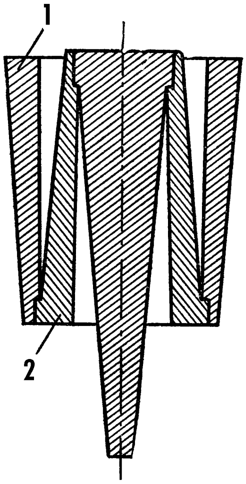

Figure 13. "Matrioshka" Principle: A compact ultrasonic concentrator. Both 1 and 2 are hollow cones.

7. **Nesting** (Matrioshka)
   a. One object is placed inside another. That object is placed inside a third one, and so on....
   b. An object passes through a cavity in another object.

Example 1: *Author's Certificate #186,781.* An ultrasonic wave concentrator is comprised of inter-connected half-wavelength sections. This invention is different because it contains half-wavelength sections made from hollow cones nested one inside the other like "Matrioshka" [the traditional Russian dolls of progressively smaller size, each placed inside the next larger one]. This allows for a reduction of the concentrator lengths while improving stability (Figure 13).

Example 2: *Author's Certificate #110,596.* A method for storage and transportation of different grade oil in a single vessel. This method is different because it places sections of high-viscosity oil inside sections of low viscosity oil. This allows for a reduction in thermal loss of the high viscosity oil.

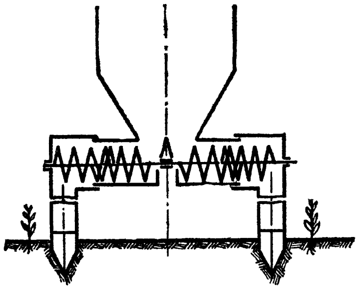

Figure 14. One more "matrioshka:" the width of a dosage thread is adjusted by screwing one section into another.

Example 3: *Author's Certificate #272,705.* A device to fertilize a field is comprised of a bucket with screw-feeder dosage conveyors on each side. This invention is different because each conveyor is made of two screw sections capable of turning both in and out. This provides control over its working width for spreading fertilizer (Figure 14).

8. **Counterweight**
   a. Compensate for the weight of an object by combining it with another object that provides a lifting force.
   b. Compensate for the weight of an object with aerodynamic or hydrodynamic forces influenced by the outside environment.

Example 1: *Author's Certificate #187,700.* A method for lowering and retrieving blasting devices into and out of a well. This method is original because gravity performs the lowering of the devices, while retrieval is done by a rocket engine placed inside the device. This allows for cost reduction and simplification of blasting work.

A serious problem arose during the development of super-powerful turbo generators: how to reduce the pressure produced by the rotor on its bearing. A solution was found by installing a powerful electromagnet over the generator, compensating for some of the pressure.

Sometimes it is required that we solve an "opposite" task; i.e., compensate for a lack of weight. A technical contradiction appeared when engineers designed an electric mining train. To increase engine thrust (the train's pull), its weight must also be increased. This leads to an increase in the dead weight of the train, and subsequently reduces its useful capacity. A team of engineers from Leningrad Mining College developed, and successfully implemented, a simple device that removed this technical contradiction. This concept increased the capacity of mining trains by one and a half times when engineers installed powerful electromagnets inside the front drive-wheels. The strong magnetic field produced by the electromagnet clutches the wheels to the rails, increasing friction (the effective thrust force). So, the train's dead weight is reduced while its tonnage capacity is increased.

9. Prior Counteraction

a. Pre-load countertension to an object to compensate for excessive and undesirable stress.

Example 1: *Author's Certificate #84,355.* The red hot metal stock for a turbine disk is placed on a spinning table. When the stock cools, it contracts (compresses). However, centrifugal force (while the stock is still elastic) "stamps" the stock, pre-stressing it. When the part finally cools, it contains compression forces.

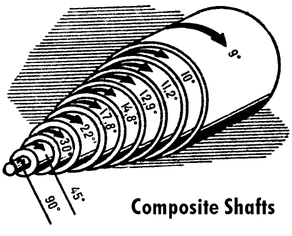

Figure 15. *Prior Counter-action Principle: The pipes of the composite shaft are twisted in the opposite direction from the shaft rotation.*

All pre-stressed concrete production technology is based on the same principle. To improve the tensile characteristics of concrete beams, their armatures are stretched throughout the solidification process, providing compression forces. This is a very rare case —the construction industry uses more advanced methodology than the machine manufacturing industry. At this time, the concept of pre-stressing is seldom used in machines; and yet, the utilization of this method could produce tremendous results.

For example, how can we make a shaft stronger without increasing its diameter? The solution to this problem is shown in Figure 15. The shaft is made out of several steel tubes placed one inside the other, initially twisted at an angle calculated to be opposite that of the deformations it will acquire during its work conditions. At first, the torque removes any advanced deformation, and only then will the deformation of the shaft begin in its "normal" direction. This shaft weighs half that of a conventional solid shaft.

10. Prior Action

a. Perform required changes to an object completely or partially in advance.
b. Place objects in advance so that they can go into action immediately from the most convenient location.

Example 1: *Author's Certificate #61,056.* When the peduncle of many kinds of fruit trees are planted in the ground they cannot set root because of a shortage of nutrients in their stalks. The author of this invention suggested storing nutrients in stalks before planting by soaking them in tubs filled with liquid nutrients.

Example 2: *Author's Certificate #162,919*. A method for removing a plaster cast by using a wire handsaw. This method is different because it consists of a blade inserted into a plastic tube that is then placed inside the plaster cast while the cast is being applied. Because of this, the cast is cut from the inside out, without harming the patient's skin. This method prevents trauma, and makes removal of the cast easy.

A similar concept utilizing this principle was used to paint wood. Before a tree is cut, it is watered with a colored pigment that slowly penetrates the wood cells throughout the whole tree.

11. Cushion in Advance

a. Compensate for the relatively low reliability of an object with emergency measures prepared in advance.

Example 1: *Author's Certificate # 264,626*. A method for reducing the toxic action of chemical compositions by using additives. This method is original because the additives are mixed together with a basic toxic composition during production. This reduces the poisonous effect of the chemical substances, as well as their products, in the human body.

Example 2: *Author's Certificate # 297,361*. A method to prevent forest fires from spreading by planting barrier strips made of plants. This method is different because it introduces chemicals, or biologically assimilated fertilizers that slow combustion, into the soil. This promotes the development of fire resistance properties in plants.

Example 3: *USA Patent #2,879,821.* A rigid metal disk is placed inside a tire allowing it to continue to drive after air pressure is lost.

The *Cushion in Advance Principle* can be used not just to increase a system's reliability. Here is a specific example. Books often disappear from American libraries. The inventor Emanuel Trikilis suggested hiding a small metal plate inside each book's cover. Before the book is registered and handed-out to a reader, it is placed on a demagnetizing device by the librarian. If a person tries to remove a book without registration, the plate triggers an alarm hidden in the door's jamb.

An emergency rescue station in the Swiss Alps uses a similar method for the fast detection of people hidden by avalanches. Now, every skier carries a small magnet. If a skier is buried under the snow, they can be easily detected by a rescue team, even under ten feet of snow.

12. Equipotentiality

a. Change the condition of the work in such a way that it will not require lifting or lowering an object.

Example1: *Author's Certificate #264,679.* A roller-conveyor is installed in an area where molds must be transported. The conveyor height is the same as the mold presses.

Example 3: *Author's Certificate #110,661.* A container is not loaded directly into a truck. Instead, it is lifted slightly by a hydraulic cylinder and placed on a supporting platform. This concept allows loading much taller containers onto trucks without using a crane.

13. Do It in Reverse

a. Instead of the direct action dictated by a problem, implement an opposite action (i.e., cooling instead of heating).
b. Make the movable part of an object, or outside environment, stationary —or a stationary part moveable.
c. Turn an object upside-down.

Example 1: *Author's Certificate #184649.* A method for cleaning metal parts in an abrasive environment. This method is different because it introduces a vibration to the parts instead of the container.

Example 2: *Author's Certificate # 109942.* This invention solves the problem of casting large, thin-walled parts. The problem: pouring metal into a cast form (the "rain" method) must be done from a level not higher than 15 centimeters above the cast – otherwise the metal burns and saturates with gas. If a form is two-to-three meters high, the first portion of poured metal will solidify and not have time to rise to the form's top.

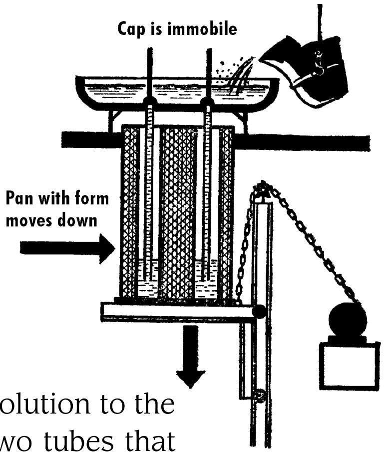

Figure 16. The Do it in Reverse Principle: in contrast with conventional methods of casting, the form moves, and the level of the pouring metal remains constant.

The inventor has here provided a simple and exquisite solution to the problem. In his process, molten metal is poured through two tubes that reach almost to the bottom of the form. The casting form moves down during the filling process; therefore, each portion of the molten metal solidifies in the area where it is supposed to be (Figure 16).

During the conventional casting process, the metal must move inside the form. In this new method, the form moves while the metal stays stationary. Everything here is upside down. It allows us to "superimpose that which is not superimposable"—a smooth filling-up of the form, and bottom-up solidification of the metal, as in the "rain" method.

14. Spheroidality

a. Replace linear parts with curved parts, flat surfaces with spherical surfaces, and cube shapes with ball shapes.
b. Use rollers, balls, spirals.
c. Replace linear motion with rotational motion, utilize centrifugal force.

Examples 1: *German Patent #1,085,073.* A device to weld pipes into a grid using electrodes in the shape of balls.

Example 2: *Author's Certificate #262,045.* A mining machine has rock-breaking electrodes as a working element. These electrodes are free-turning conical rollers mounted on insulating shafts. This allows for increased efficiency in the pulverizing of hard rocks.

Example 3: *Author's Certificate # 260,874.* A method to separate the metal cord from the rubber in worn-out tires which includes soaking the tires in hydrocarbon, processing them with high-pressure water jets, and mechanically separating the thread by cutting. This method is different because each tire is processed at a rotation speed that weakens the bond between its rubber particles. This allows for increased productivity.

15. Dynamicity

a. Characteristics of an object, or outside environment, must be altered to provide optimal performance at each stage of an operation.
b. If an object is immobile, make it mobile. Make it interchangeable.
c. Divide an object into elements capable of changing their position relative to each other.

Examples 1: *Author's Certificate #317,390.* Rubber swimming flippers. These flippers are different because they have longitudinal cavities filled with non-compressed, inert liquid whose static pressure can, if necessary, be adjusted on the beach or underwater. This allows control over the flipper's rigidity for different types of swimming (whether for distance or speed).

Example 2: *Author's Certificate # 161,247.* A ship having a cylindrical hull. This vessel differs because its hull is made of two halves that can be opened by a hinged connector. This provides a reduction of the vessel's full-load immersion.

Example 3: *USSR Patent # 174,748.* A vehicle with a two-section frame connected by a hinge. Sections of the frame are capable of changing their relative position through the use of hydraulic cylinders. This design increases the vehicle's ability to traverse rocky terrain.

Example 4: *Author's Certificate # 162,580.* A method for manufacturing hollow cables having channals made by tubes twisted together with wires. The tubes are pre-filled with a substance that is later removed after the cable is manufactured. This method is different because it uses wax as the tube's filler. After each cable is manufactured, the wax is melted and poured out of the tubes. This allows for simplification of cable production technology.

16. Partial or Excessive Action

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

Example 1: *Author's Certificate #181,897*. A method to control hail based on crystallizing hail from rain clouds through the use of a reagent (i.e., argent iodine). This method is original because it produces crystallization only those with clouds with coarse droplets. This produces a significant reduction of reagent consumption while simplifying its means of delivery.

Example 2: *Author's Certificate #262,333.* A metal-powder batching system is comprised of a silo and dosage apparatus. This system is different because it has an internal funnel and a channel with an electromagnetic pump to feed excessive powder into the silo (Figure 17). This provides a uniform flow of powder to the dosage apparatus.

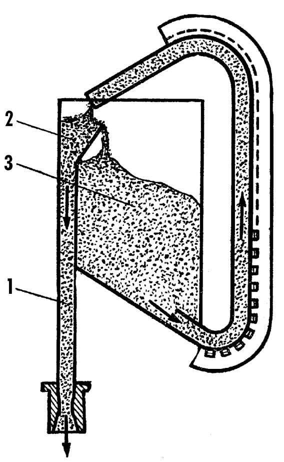

Figure 17. *Partial or Excessive Action Principle: To provide an even feeding of powder through pipe 1, the powder (including excess) is loaded into funnel 2; the extra powder overflows into silo 3, guarantying a constant level in the funnel.*

17. Transition Into a New Dimension.

a. Transition one-dimensional movement, or placement, of objects into two-dimensional; two-dimensional to three-dimensional, etc.
b. Utilize multi-level composition of objects.
c. Incline an object or place it on its side.
d. Utilize the opposite side of a given surface.
e. Project optical lines onto neighboring areas, or onto the reverse side of an object.

Example 1: *Author's Certificate #150,938.* A semi-conducting diode in which a predetermined electron-hole transition, and predetermined resistor contact, are used. This contact does not have an increasable perimeter of its semi-conducting plate. A transition from a flat contact to a three-dimensional one allows for an increase in the area of the semi-conducting plate without changing the size of the diode; therefore, increasing the electron-hole flow power output.

Prominent Soviet inventor D. Kiselev, in his book *The Designer's Quest* explains how he worked on the improvement of chisels for drilling oil wells:

> *"In drill chisels, ball-bearings have a certain load capacity. By increasing the numbers of balls, it is possible to improve their working conditions and prevent wear. This was the exact direction of my thoughts: a different pattern of ball placement. However, the chisel's small dimension became an obstacle to its positioning amidst the required amount of balls and rollers. Suddenly, I saw the solution: I can place the required number of balls closely together in two rows, the same way as people sleep on two-tiered berths while traveling in trains. I now laugh at how simple the solution was that I had looked for the last couple of months."*

Example 2: *Author's Certificate #180,555.* A method of mechanization for exchanging mining lorries. This invention is different because it exchanges a loaded lorry with an empty one. This is done by rotating the empty lorry 90° and lifting it over the loaded one. This method eliminates the presence of a side-track system.

Example 3: *Author's Certificate #259,449.* A magnetized-graphite defect detector. This device is different because it has a double-sided magnetic tape in the form of a Meobius Strip. This allows for an increased life expectancy of the tape.

Example 4: *Author's Certificate #244,783*. A greenhouse for growing vegetables year-round. This invention is different by having a rotating concave mirror placed on the northern side of the house. This allows for improvement of the plant's sunlight conditions.

18. Vibration

a. Utilize oscillation.
b. If an oscillation exists, increase its frequency to ultrasonic.
c. Use the frequency of resonance.
d. Replace mechanical vibrations, with piezo-vibrations.
e. Use ultrasonic vibrations in conjunction with an electromagnetic field.

Examples 1: *Author's Certificate #220,380.* A method for vibration-arc welding of parts inside of flux by using an electrode vibrating at low frequency. A new feature of this invention is a high, ultrasonic frequency (20 kHz, for example) imposed over the low frequency electrode vibration. This provides an increase in the quality of deposited metal.

Example 2: *Author's Certificate # 307,896*. A method for the sawdustless ripping of wooden logs with a cutting tool that changes its geometrical dimensions. This method differs by having the tool pulsate with a frequency close to the internal frequency of the wood. This allows a reduction of force needed for the cutting tool to penetrate the wood.

Example 3: *USA Patent #3,239,283*. Friction resistance significantly reduces the sensitivity of delicate measuring devices, impeding the free movement of needles, pendulums, and other moving parts upon their bearings. To avoid this, bearings are forced to vibrate —and consequently, some parts of the device oscillate relative to each other. An electrical motor is used as a source of vibration, complicating the device, and increasing its weight. American inventors John Bross and William Laubendorfen developed a bearing with a piezo-electric inner ring, all sides of which are covered by conductive foil. When AC current runs through the foil, it produces a vibration.

Example 4: *Author's Certificate # 244,272.* A method to precipitate dust with the application of a magnetic field. This method differs through the simultaneous treatment of air with both acoustic and magnetic fields.

19. Periodic Action

a. Replace a continuous action with a periodic one (impulse).
b. If the action is already periodic, change its frequency.
c. Use pauses between impulses to provide additional action.

Examples 1: *Author's Certificate #267,772.* There is a known method for observing an arc welding process through the application of an additional light source. However, while the observation of solid and liquid substances in the welding arc is improved, the observation of the plasma gas portion of the arc worsens (an obvious technical contradiction). The submitted concept differs through the brightness of the additional light. It periodically changes from zero to a value exceeding the brightness of the welding arc. This allows for the combined observation of the arc itself as well as the melting process of the electrode and the transferring metal.

Example 2: *Author's Certificate # 302,622.* A thermocouple test method consists of heating the coupling and then testing for the presence of an electromotive force (EMF). This new method is different because the thermocouple is heated with a periodic impulse current while testing for the presence of EMF between the impulse intervals. This allows for a reduction of testing time.

20. Continuity of Useful Action

a. Carry out an action without a break. All parts of the object should constantly operate at full capacity.
b. Remove idle and intermediate motion.
c. Replace "back-and-forth" motion with a rotating one.

Example 1: *Author's Certificate # 126,440.* A method of drilling multiple wells using two sets of pipes. When two or three wells are simultaneously drilled, a multi-barrel rotor is used. These barrels work independently of each other. In addition, two sets of drill pipes are alternately lifted and lowered into the well to allow the changing of worn-out chisels. The process of chisel replacement is automatically combined with the drilling of alternating wells.

Example 2: *Author's Certificate #268,926.* A method for transporting raw sugar in tankers. This concept is different because it utilizes an oil tanker that, once unloaded of oil or other liquid cargo, is cleaned by a special means of washing, and then loaded with raw sugar. This allows for the elimination of idle run-time, and provides a reduction of transportation cost.

21. Rushing Through

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

Example 1: *Author's Certificate #241,484.* A method for the high speed heating of metal stock in a gas stream. This method differs through the introduction of a gas flow of not less than 200 meters-per-second. This provides a constant stream over the entire length of its contact with the stock. This produces increased productivity while reducing decarbonization.

Example 2: *Author's Certificate #112,889.* During the unloading of a log carrier, it is tilted by a special ship. To unload all cargo into the water, the carrier must be tilted at an angle which is too high and unsafe. This new method offers a smaller tilting angle through the use of a jerking action. An impulse is developed that allows the logs to unload at a reduced angle.

Example 3: *Patent of Federal Republic of Germany #1,134,821.* A device to slice thin-walled, large diameter plastic pipes. Specifically, this device has a knife cutting through the pipe so rapidly that the pipe has no time for deformation.

22. Convert Harm into Benefit

a. Utilize harmful factors –especially environmental –to obtain a positive effect.
b. Remove one harmful factor by combining it with another harmful factor.
c. Increase the degree of harmful action to such an extent that it ceases to be harmful.

Example 1: Soviet Academician P. Vologdin, in his article "The Road of the Scientist" (*Leningrad Almanac*, 1953, #5), wrote that early in the 1920's he set a goal to utilize high-frequency current to heat metal. Experiments showed that the metal heated only on its surface. It was difficult to force a high-frequency current inside the metal. Experiments were cancelled. Later, Vologdin was sorry that he had not once used this negative effect —industries could have had a method for high-frequency steel treating long before it was actually introduced.

Example 2: There was a much different destiny for another great invention —the electric-spark process for manufacturing metal parts. B.P. Lazarenko and I.N. Lazarenko were working over the problem of the electric erosion of metals. Electric current "eats up" metal in the area where relay contacts touch each other. Nothing can be done about this. Hard, and super-hard, alloys were tested without positive results. Researchers placed contacts in different liquid mediums, but the destruction was even more intense. One day the inventors realized that this negative effect could be used as an advantage, and their research work turned in a different direction. In April 3, 1943 they received an author's certificate for the electric-spark method for manufacturing metal parts.

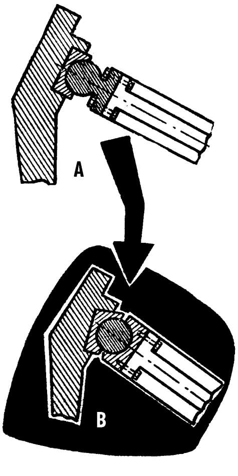

Figure 18. *Principle of "Converting Harm into Benefit."*

Example 3: *Author's Certificate #142,511.* Figure 18-a shows a movable joint between two parts of a jawbreaker. Mobility here is achieved by having *spherical* cast-iron head. The neck for this head is its weakest design point. Usually it is here where a break occurs. Of course, we can make some improvements to reduce the chances of a break. What if we "break" the head off before hand? Then it becomes a cylindrical bushing that is difficult to break. (Figure 18-b.)

Example 4: *Author's Certificate #152,492.* To protect underground electric lines from damage by ground freezing it is proposed that narrow expansion ditches be dug-out on each side of the cable. (Figure 19.)

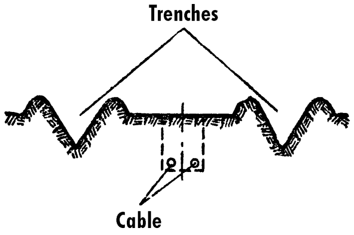

Figure 19. *Man made "clefts" - trenches that prevent a cable line from being cracked by frost clefts.*

This is a simple principle: let's accept something that seems unacceptable —just let it happen. However, here the inventor's thought process often hits a psychological barrier.

23. Feedback

a. Introduce feedback.
b. If feedback already exists, change it.

Example 1: *Author's Certificate #283,997*. Wind inside a water-cooling tower creates circulation zones. These zones reduce the depth of the water's cooling action. To increase the cooling efficiency in different sections of the tower, temperature sensors are installed that automatically signal and control the amount of water running through the tower.

Example 2: *Author's Certificate #167,229*. A method to automatically start a conveyor. This method is different in that it measures the power consumed by a conveyor's main electric motor during its work period, which corresponds to the weight carried by the conveyor. This is recorded at the time the conveyor is shut down. Then a signal, inversely proportional to the weight of the material on the conveyor, is sent to the start-up motor at the time the conveyor restarts.

24. Mediator

a. Use an intermediary object to transfer or carry out an action.
b. Temporarily connect the original object to one that is easily removed.

Example 1: *Author's Certificate #177,436*. A method to supply electric current to a liquid metal. This method differs in that it supplies current to metal through cooling electrodes placed into an intermediate liquid metal whose melting temperature is lower, but whose density at its boiling point is higher, than that of the main metal. This allows for the reduction of electric losses.

Example 2: *Author's Certificate #178,005*. A method to cover a protective surface with a volatile inhibitor of atmospheric corrosion. This method is different because it blows hot air, saturated with this inhibitor, through parts that have a complicated internal shape. This allows these parts to receive an even coverage of their internal surfaces.

25. Self-service

a. An object must service itself while performing supplementary and repair operations.
b. Make use of waste material and energy.

Example 1: *Author's Certificate #261,207.* A shot (pellet) firing apparatus whose body is covered inside with tiles made out of wear-resistant material. This apparatus differs by having magnetic tiles capable of holding a protective coating of the metal shots (pellets) against their surfaces. Therefore, a constantly replenishing protective layer of metal shots is formed on the walls of the shot firing apparatus.

Example 2: *Author's Certificate #307,584*. A method of building an irrigation system out of prefabricated elements. This method differs in that the ends of the canal's first constructed segment are sealed with temporary partitions. This canal segment is then filled with water, allowing the transportation of the next canal section. Each flooded segment facilitates the transport of subsequent prefabricated canal sections, simplifying construction of the total irrigation canal system.

Example 3: *Author's Certificate #108,625*. A method for cooling semiconductor diodes. This method differs in that it consists of a semiconductor thermo-element whose operating current passes directly through the diode. This enables improved thermo-exchange conditions.

26. Copying

a. A simplified and inexpensive copy should be used in place of a fragile original or an object that is inconvenient to operate.
b. If a visible optical copy is used, replace it with infrared or ultraviolet copies.
c. Replace an object (or system of objects) with their optical image. The image can then be reduced or enlarged.

Example 1: *Author's Certificate #86,560.* A visual learning aid for geological surveying is comprised of a drawing representing geological areas projected onto a flat panel. This invention differs by using this image and a tachometer to measure the distance between specific points on the picture where miniature surveying rods are placed. This enables the performing of geological surveys directly off the mapped image.

Sometimes it is necessary for measurement or control to superimpose two objects that physically are not superimposable. In these cases, it makes sense to use a visual copy. This is how, for example, the problem of three-dimensional measurements taken with x-ray film was solved. Conventional x-ray film is not capable of determining the distance from the bodies' surface to a source of illness. Stereo photos make an image three-dimensional; however, even in this case, measurements must be done by eye —there is no ruler inside the body. This therefore requires that we "superimpose that which is not superimposable"–the body of a person under x-ray radiation, and a scaled ruler.

A.I. Aksenov, an inventor from Novosibirsk, solved this problem by utilizing a method of optical superimposition (blending). Aksenov's method superimposes an x-ray image with the stereo image of a screened cube. Looking through these stereoscopic, superimposed images, a doctor can see inside the patient's body while the cube plays the role of three-dimensional scale.

In many cases it is generally better to not manipulate the actual objects, but rather their optical copies. For example, the Canadian Kruter Pulp Company uses a special camera to measure logs loaded and transported on railroad cars. By a company report, the photographic measurement of the ends of logs is 50- 60 times faster than hand measurements. Deviations do not exceed two percent.

One more interesting example:

> **Example 2:** *Author's Certificate # 180,829*. A new method for measuring the internal surface area of spherical parts. A low-reflection liquid is poured into the part, and its level is incrementally changed while color photographic pictures are taken and superimposed onto a single frame of film. After developing and enlarging the film, the concentric rings on the film image are compared with rings on the design drawings. By comparing the photographic lines with those on the drawings, any differences can be measured with high accuracy.

27. Dispose

a. Replace an expensive object with a cheap one, compromising other properties (i.e., longevity).

> **Example 1:** Hygiene rules required that syringes and needles be sterilized for not less than 45 minutes. Meanwhile, in many cases it is necessary to make an injection as soon as possible. At All Union Research Institute Medical Instruments, a new disposable syringe was developed. It was made of a thin plastic tube with its needle protected by a cap on one end. The tube is filled with medicine and sealed at the factory. This syringe can be ready in just a couple of seconds – it only requires removing the cap. During injection, medicine is squeezed from the tube, and the syringe thrown away.

There are many patents of this kind: disposable thermometers, garbage bags, toothbrushes, etc.

28. Replacement of Mechanical System

a. Replace a mechanical system with an optical, acoustic, thermal or olfactory system.

b. Use an electric, magnetic, or electromagnetic field to interact with an object.

c. Replace fields that are:
   - Stationary with mobile.
   - Fixed with ones changing over time.
   - Random with structured ones.

d. Use fields in conjunction with ferromagnetic particles.

Example 1: *Author's Certificate #163,559.* A method to detect any wear of rock drilling tools; i.e., chisels. This method differs by having as a wear indicator an ampoule containing a strong, odoriferous chemical substance (like *ethyl mercaptan*) built into the body of the chisel. This creates a simplified detecting process.

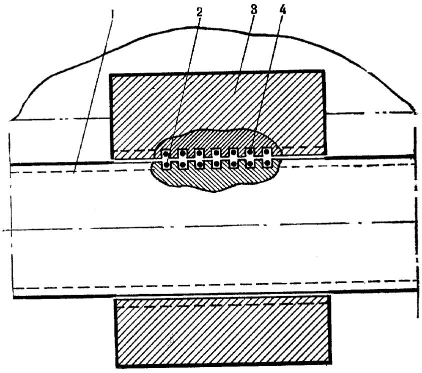

Figure 20. *In this screw coupling, the nut moves without friction, thanks to the interaction of electromagnetic fields.*

Example 2: *Author's Certificate #154,459.* A non-wearing screw coupling (Figure 20). This screw coupling consists of a screw (1), with a coil (2) placed in the thread, and a nut (3) having a coil (4). The screw and nut are positioned with a gap. Nut (3) is rigidly connected to a movable part of the machine or apparatus. When an electric current passes through coils (2) and (4), a magnetic field develops around each coil. A short-circuiting of these fields takes place through the nut and screw. The magnetic field reaches its maximum level when both the coils of the nut and screw are superimposed. When the screw turns, a magnetic field arcs between the screw-coil and the nut. As a result, a force is developed that tries to restore the original positional relationship between the coils. This force provides a forward movement of the nut attached to the movable part of the machine.

The presence of the gap between the nut and the screw prolongs the longevity of this coupling, making it effectively non-wearing.

Example 3: "A factory was doing precision miniature work, polishing the walls of a hole 0.5 mm in diameter. To accomplish this work, a miniature polishing tool only 0.2 mm in diameter was made. The surface of this tool was covered with diamond powder, and a pneumatic turbine rotated it at 1,000 revolutions-per-second.

In addition, the diamond tool moved around the perimeter of the hole 150 times per minute. A worker had no way to see with their naked eye inside the polishing area, and so could not detect the moment when the tool touched the part. The polishing process was either prolonged, or finished too early. In either case the part had to be rejected.

> *"It was decided to design a special automated machine —but instead, an inventive process lead to a simple solution: the part was isolated from the machine, the positive terminal of a battery was connected to the part, and its negative terminal to the machine. An amplifier and speaker were plugged into this circuit. Now, as soon as the tool touches the part, the speaker 'shouts.' This machine produces sounds that mark the time the polishing process occurs, as well as how well it is performed, merely through pitch."*[1]

Example 4: *Author's Certificate #261,372.* A method for conducting a catalytic process in systems using a movable catalyzer. This method is different because it utilizes a moveable magnetic field along with a catalyzer with ferromagnetic characteristics. This allows for a widening of the application area in which the process is conducted.

Example 5: *Author's Certificate #144,500.* A method for thermal exchange intensification inside tubular elements of surface heat exchangers. This method is different because it introduces ferromagnetic particles into a heat-carrier flow. These particles are mixed with the flow by a rotating magnetic field at the inner walls of the tubular elements, allowing for the destruction and turbulization of the boundary layer. This method increases thermal exchange efficiency.

Example 6: *French Patent #1,499,276.* After objects are processed in a tumbler or vibrating-drums for cleaning, they require separation from abrasive granules. If the objects are large, this is not so difficult to do. If they are ferromagnetic, it is possible to use a magnetic separator to remove them. However, if the parts have no magnetic property, and they are the same size as the abrasive granules, what can be done? In accordance with this invention, the problem is solved by providing magnetic characteristics to the abrasive material. This can be done by compressing, or baking together, a mixture of abrasive granules and magnetic particles;

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[1] *Technology —Youth* Magazine, 1965, #6, page 6.

or, also by impregnating magnetic particles into pores of the abrasive granules.

29. Pneumatic or Hydraulic Constructions

a. Replace solid parts of an object with a gas or liquid. These parts can now use air or water for inflation, or use pneumatic or hydrostatic cushions.

Example 1: *Author's Certificate #243,809.* The purpose of this invention is to increase the draft and dissipation height of exhaust gases (Figure 21). This is achieved by having the body of a chimney made out of a hollow conical spiral (1), with nozzles (2). The spiral is connected to hollow supports (3), whose lower ends are connected to a compressor (4). When the compressor is turned on, air is pumped into supports and vented out by way of the spiral's nozzles, creating an "air wall."

Example 2: *Author's Certificate #312,630.* A method for painting large objects by using a spray mist, and then removing the solvent and clouds of paint through a ventilation system. This method is different because it creates an ascending air curtain around the object that is higher than the object itself. The upper portion of the curtain is swirled by a ventilation vacuum system. This method allows for the reduction of the work area space around the painted object.

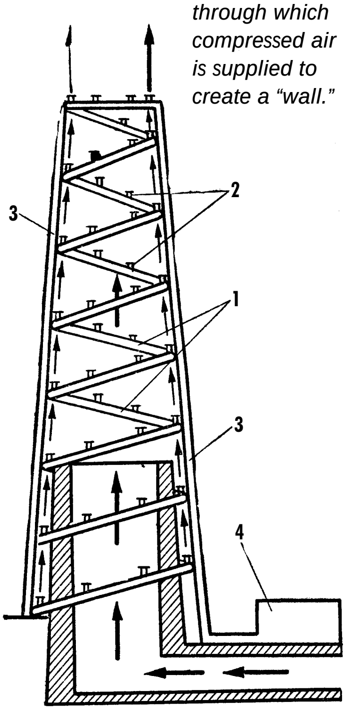

Figure 21. *Instead of a massive chimney, we have an elegant construction: A hollow spiral with nozzles, through which compressed air is supplied to create a "wall."*

This invention removes the same technical contradiction as the previous example; therefore, the solutions are essentially the same: a pneumatic, rather thanrigid metal, wall.

Example 3: *Author's Certificate #264,675.* The support structure and base for a spherical tank. This support structure differs from others by having a base made in the shape of a vessel which is filled with a liquid. The base of the vessel has a concave elastic cover shaped from the pressure produced by the spherical body of the tank.

Example 4: *Author's Certificate #243,177.* Here is the twin of the previous invention A device to transmit pressure from the base of a pile-driver to its foundation. This invention is different because it has a foundation formed as a flat, closed vessel filled with liquid. This allows for even pressure distribution.

It will be interesting to see how many more Author's Certificates will be issued utilizing this same principle. If "A" has to press evenly on "B," place a liquid pillow between "A" and "B."

30. Flexible Membranes or Thin Films

a. Replace customary constructions with flexible membranes or thin film.
b. Isolate an object from its outside environment with flexible membranes or thin films.

Example 1: To reduce the amount of moisture lost through tree leaves, American researchers sprayed the leafs with polyethylene "rain." A very thin plastic film forms on the leaves. The plant, covered with a plastic cloak, grows normally because polyethylene lets oxygen and carbon dioxide pass much better than it does water vapor.

Example 2: *Author's Certificate #312,826*. An extraction method in a liquid-liquid system where one liquid layer passes through a gas membrane on the surface of another liquid layer. This concept allows for the intensification of mass transfer.

31. Porous Material

a. Make an object porous, or use supplementary porous elements (inserts, covers, etc.).
b. If an object is already porous, fill pores in advance with some substance.

Machines have always been built of solid, impermeable materials. Mental inertia causes people to attempt solving usually easily solved problems (when using porous materials) by introducing special devices and systems that preserve all the impermeable construction elements. Meanwhile, permeability is a characteristic belonging to highly organized machines, like all living organisms –from single cells to human beings.

The internal movement of substances is an important function of many machines. "Rough" machines provide this function with the help of pipes, pumps, and so on; "fine" machines do it by utilization permeable membranes and molecular forces.

Example 1: *Author's Certificate #262,092.* A method to protect the internal surfaces of vessel walls from the deposition of hard and viscous particles of products present in the vessel. This method is different because it consists of a pressurized liquid, producing no deposits, passing into a vessel through its walls which are made of a porous material. The pressure of this liquid is greater than the pressure inside the vessel. This method provides increased protection efficiency along with a reduction of any consumed energy.

Example 2: *Author's Certificate #283,264.* A method that utilizes fire resistant materials for the introduction of additives into a liquid metal. This method is different because it suggests using a porous, fire resistance material, saturated with additives before being placed into the liquid metal. This allows for an improvement of the additive introduction process.

Example 3: *Author's Certificate #187,135.* An evaporating cooling system for electric motors. This system differs by having its active parts, and other elements, made out of porous metal. For example, a porous powdered steel, impregnated with a cooling agent that evaporates during the machine's work period, and therefore provides a short term, intensive, and uniform cooling action. This eliminates the need to supply lines of cooling agent to the machine.

32. Changing the Color

a. Change the color of an object or its environment.
b. Change the degree of translucency of an object or its environment.
c. Use color additives to observe an object or process, which is difficult to see.
d. If such additives are already used, employ luminescent traces or trace atoms.

Example 1: Water curtains are used in forge and foundry shops, metallurgy plants, or wherever it is necessary to protect workers from heat. They provide excellent protection from invisible thermal (infrared) rays. However, intense light from the molten steel is free to pass through the thin liquid film. To protect workers from this light, an employee of the Polish Institute of Labor Protection proposed a colored-water curtain. Being transparent, it still completely blocks thermal rays while, to the required degree, weakening the intensity of the visual radiation.[1]

Example 2. *Author's Certificate #165,645.* A dye is added to a photographic fixing solution. The dye is reversible and, while being

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[1] *Inventor and Innovator*, 1970, #5, Page 16.

absorbed by the photo layer, does not color the base paper or celluloid. This dye must be removed from the celluloid layer by further rinsing. The speed of this rinsing is equal to, or a little less than, that of rinsing out the sodium thiosulfate. Discoloration of the photo layer represents a complete rinse of the sodium chloride from the layer that causes fixing of the photo material.

33. Homogeneity

a. Objects interacting with the main object should be made out of the same material (or material with similar properties) as the main object.

Example 1: Patent of German Federal Republic #957,599. A foundry trough for treating molten metal by sound, or ultrasound, with the help of a sound emitter placed inside the molten metal. This treating process is original because that part of the emitter that contacts the molten metal is made of the same metal, or one of its alloys, as that of the processed metal. The contact part is partially melted by the molten metal, while the other parts of the sound emitter are cooled and remain solid.

Example 2: *Author's Certificate #234,800.* A method for lubricating cooled bronze bearings. This method is different because the lubricant material is made from the same material as the bearing's sleeve. This allows for improved lubrication at higher temperatures.

Example 3: *Author's Certificate #180,340.* A method for cleaning gas by removing dust containing melted particles. This method is different because the incoming gas is bubbled through a medium made from a molten fusion of these particles. This allows for an increased efficiency of the filtering process.

Example 4: *Author's Certificate #259, 298.* A method for welding metals where the welded edges, positioned with a gap between them filled with an agent, are then pre-heated. The agent's volatile composition includes material of the metals to be welded. This allows for an improvement of the welding process.

34. Rejecting and Regenerating Parts

a. After completing its function, or becoming useless, an element of an object is rejected (discarded, dissolved, evaporated, etc.) or modified during its work process.
b. Used-up parts of an object should be restored during its work.

Example 1: *Patent USA #3,174,550.* During an emergency landing, airplane fuel is turned into a foam that has special chemical substances making the fuel noncombustible.

Example 2: *Patent USA #3,160,950.* To prevent damage to sensitive devices during the initial firing of a rocket, the devices are wrapped in a foam that evaporates in space after having performed its shock-absorbing duty.

It is not difficult to see that this concept is the next step in the evolution of the dynamization principle —an object changes during its action; although, this change is more drastic. An airplane that alters its wing geometry during flight is an example of the Principle of Dynamization. A rocket that rejects its used-up stages is an example of the Principle of Rejecting. These two principles are innovation "twins."

Example 3: *Author's Certificate #222,322.* A method for manufacturing micro-springs. This method is different because it has a mandrel made of an elastic material that is removed later by dipping it, together with the spring, into a substance that dissolves the elastic material. This allows for increased production capacity.

Example 4: *Author's Certificate #235,979.* A method for manufacturing ball-separators made of rubber. This method is different because it forms a core made of a dried mixture of fine chalk and water. After vulcanization, the hard core is destroyed by a liquid injected inside the ball. This forms a hollow ball of the required size.

Example 5: Author's Certificate #159,783. A method for manufacturing a hollow extrusion. This method is different because it rolls a welded steel sandwich filled with fire resistance material like magnesite powder around a filler that is later removed. This allows for the manufacturing of extrusion profiles of different sizes and shapes.

We can show hundreds of similar examples. It is difficult to imagine how much time inventors have lost searching for an idea —beginning at ground "zero" every time. However, this example contains one typical principle: make object *A* on a mandrel *B* which can later be removed through dissolving, evaporating, melting, chemical reaction, etc.

The Principle of Rejection is the opposite of the Principle of Regeneration.

Example 6: *Author's Certificate #182,492.* A wear compensation method for electrode-tools during an electric erosion process for the manufacturing of conductive materials. This method is different because it continuously spits a layer of metal on the electrode's working surface during the production process. This extends the life of the electrode.

Example 7: *Author's Certificate #212,672.* The internal wall of a pipeline wears out rapidly during the hydro-transport of an acid substance mixed with an abrasive material. The installation of a protective lining is very complex and laborious, and leads to an increased diameter of the pipe. This new concept provides for the formation of a protective layer on the pipe's internal surface. To accomplish this, lime mortar is periodically introduced into the hydro-mix. Therefore, the internal surface of the pipe is always protected, yet its cross-section is insignificantly reduced because the lining is constantly worn by an abrasive acid mix.

35. Transformation of Properties

a. Change the physical state of the system.
b. Change the concentration or density.
c. Change the degree of flexibility.
d. Change the temperature or volume.

Example 1: *Author's Certificate #265,068.* A method for providing a mass-exchange process within a system of gas and viscous liquid. This method is different because it gasifies the viscous liquid before placing it into the apparatus. This provides for an intensification of the mass transfer process.

Example 2: *Author's Certificate #222,781.* A measuring device for free-flowing material (like mineral fertilizers and poison chemicals) consisting of a screw enclosed in a housing with a discharge window. This device is different because its screw surface is made of an elastic material with spiral springs installed on its internal and external sides. This allows for control of the screw's pitch. (Figure 22).

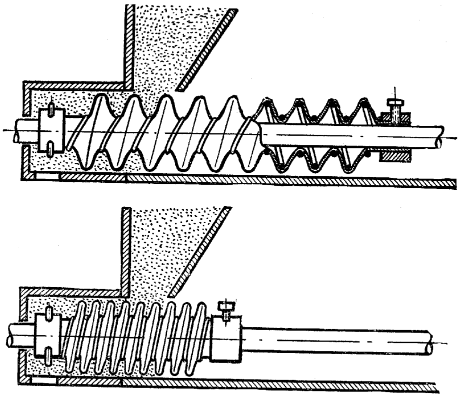

Figure 22. *In the dosage apparatus for free flowing materials, the screw is made out of elastic material with a spiral spring allowing adjustment of the pitch of the screw.*

36. Phase Transition

a. Using the phenomena of phase change (i.e., a change in volume, the liberation or absorption of heat, etc.).

Example 1: *Author's Certificate #190,855.* A method for expanding ribbed pipes. Their ends are capped and filled with pressurized water. This method is different because it freezes the water inside the pipe. This allows for a cost reduction while speeding-up the manufacturing process.

The question can arise of how *Principle 36* differs from *Principle 35a* (*Transformation of Properties*), or *Principle 15* (*Dynamization*). *Principle 35a* suggests the use of an object of physical state *B,* rather than physical state *A*. It is exactly by using the special characteristics of state *B* that the required result is achieved. However, the essence of *Principle 15* lies in the utilization of characteristics belonging either to state *A* or state *B*.

When solving a problem using *Principle 36*, we utilize phenomena related to the process of transition from *A* to *B*, or *visa versa*. If, for instance, we fill a pipe with ice instead of water, nothing will happen to the pipe. The required effect is achieved through the increased volume of frozen water.

Example 2: *Author's Certificate #225,851.* A method for cooling different objects with a liquid coolant circulated through an enclosed loop. This method is different because part of the coolant is transformed into its solid state, cooling the object with a mixture of solid and liquid coolants. This allows for the reduction of both coolant and energy consumption.

"Phase transition" has a wider meaning than "change the physical state of the system." Changing the crystalline structure of a substance is phase transition. For instance, tin (Sn) can exist in the form of white tin (density 7.31) and gray tin (density 5.75). A phase transition at 18^0 C produces an intensive increase in volume —much higher than when water freezes; therefore, its forces can be much bigger.

Polymorphism (crystallization that can take different forms) is characteristic of many substances. A phenomenon that follows after crystallization, it can be utilized when solving a variety of inventive problems. For instance, in *USA Patent #3,156,974*, the polymorphous transformation of bismuth (Bi) and cerium (Ce) are utilized.[1]

37. Thermal Expansion

a. Use expansion or contraction of material by changing its temperature.
b. Use various materials with different coefficients of thermal expansion.

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[1] *Inventor and Innovator*, 1966, #4, page 25.

Example 1: *Author's Certificate #309,758.* A method for drawing pipes on a movable mandrel at low temperatures. This method is different because it inserts a preheated mandrel (i.e., 50-100^0 C) into a cooled pipe before drawing it. Removal of the mandrel after the pipe's deformation is performed when the temperatures of the pipe and mandrel are equalized. This creates a gap between the pipe and mandrel after drawing, and provides for the retrieval of the mandrel from the pipe without having to roll the pipe.

Example 2: *Author's Certificate #312,642.* The stock used for heat compression of a multi-layer component composed of concentric bushings is made from differing materials. This concept is original because each bushing is made out of material with a thermal coefficient of linear expansion higher than the previous one. This allows for the production of multi-layer parts having pre-stressed layers.

This principle shows the transition from macro-level "rough" movements to micro-level "fine" movements. Large forces and pressures can be created with the help of thermal expansion. Such thermal expansion allows the precise control of an object's movement.

Example 3: *Author's Certificate #242,127.* A device to provide micro movements of an object (like a device-holder for seeding a crystal). This device is different because it has two rods —one electrically heated, the other electrically cooled —alternating the movement of an object in a required direction using a pre-set program.

38. Accelerated Oxidation

Make transition from one level of oxidation to the next higher level:

1. Ambient air to oxygenated.
2. Oxygenated to pure oxygen.
3. Pure oxygen to ionized oxygen.
4. Ionized oxygen to ozoned oxygen.
5. Ozoned oxygen to ozone.
6. Ozone to singlet oxygen.

The main goal of this principle is to intensify processes. We can mention several examples here:

1. A method the caking and baking of a dispersion material which intensifies the process by blowing enriched oxygen through the material.

2. A method for cutting stainless steel with plasma performed with pure oxygen as the cutting gas.

3. A process intensifing the agglomeration of iron ore by ionizing an oxidant and fuel gas before it's introduced into the charged layers.

39. Inert Environment

a. Replace a normal environment with an inert one.
b. Introduce a neutral substance or additives into an object.
c. Carry out a process in a vacuum.

This principle is the opposite of the previous principle.

40. Composite Materials

a. Replace homogeneous materials with composite ones.

Example 1: *USA Patent #3, 553,820.* Light and strong parts with a high melting point and an aluminum base are strengthened by a large number of tantalum (Ta) covered carbon fibers. They have a high Coefficient of Elasticity, and are used in the construction of airplanes and ships.

Example 2: *Author's Certificate #147,225.* A writing method where fine magnetic particles are added to ink. The new ink is different because it is controllable by magnetic fields.

Composite materials acquire characteristics that do not belong to their individual components. For instance, a porous material, as mentioned in *Principle #31*, represents the composite of a hard substance and air. Neither the hard substance nor the air separately possess those properties of the porous, composite material.

Composite materials are "invented" by, and widely used in, nature. Wood represents a combination of cellulose and lignin. Cellulose fibers have a high breaking strength, but are easily bent. Lignin holds the fiber together, providing rigidity to the wood.

A combination of easily fusible material (like wood's aggregate) with the fiber of a high-melting material (like steel) make very interesting composites that are easy to melt, but possess high strength when hard. Slowly, the mutual diffusion of particles of solder and fiber occur. As a result, a high-melting temperature alloy is produced.

Another composite material —a suspension of silicon particles in oil — is capable of hardening when placed in an electric field.[1]

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[1] For more details on composite materials, see *Contemporary Materials,* Mir, 1970, pages 116–132.

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In the article *Ordinary Edisons,* by E. Dolota and I. Kliamkin[1] there is a quotation from an actor, Lepko, of the Moscow Theater of Satire. "Stock-phrases," he said, "are not obstacles to creativity. On the contrary, they are tools of the artist." The point here is the quantity of stock-phrases. A weak actor has three or four sets, and everybody says that he repeats himself in every play. A strong, and talented, actor possesses fifty, or even a hundred sets of stock-phrases.

Knowledge of the typical standard principles —the "stock-phrases" of inventiveness —dramatically increases one's creative efficiency.

Let's take a specific problem as an example. It is necessary that, while firing a pellet gun, the esxpelled pellets form a narrow cone without spreading-out widely. The conventional way to increase pellet clustering is to increase the length of the gun's barrel. Here, a technical contradiction appears: improving the shape of the divergence cone (making it smaller), worsens the barrel length factor (it gets longer). What can we do?

If it is difficult to make an immediate guess, first remove the terms "barrel" and "pellets:" some particles are moving inside a pipe . As long as the pipe walls are directing the pellot's movement, everything is okay. However, it is impossible to make a long enough pipe. How, in this case, can we control the direction of the pellets?

The technical contradiction in this problem is the same as in the construction of the high-stack chimney. Therefore, it is possible to use the same principle (#*29*) used in Author's Certificate #243,809: a pneumatic construction instead of a rigid one. Let the particles move inside "walls of gas." This is exactly how this problem was solved in Japanese Patent #44-20,959. Gas release holes were made in a short barrel. An enclosure is placed over the barrel in such a way that both their ends coincide. When fired, gas exhaust passes through the gap formed between the barrel and the enclosure, and is expelled in the form of a containing ring surrounding the pellet cluster.

One more problem: How can we manufacture (by drawing)nichrome tubes with a wall thickness of 0.01 mm, and a tolerance of 0.003 mm? For the inventor who has no knowledge of the Principles, this is a Third Level problem. If one learns the Principles, then this becomes an easy problem no more difficult than Level One. *Principle #34:* Manufacture an object *A* on mandrel *B,* which will later be removed by dissolution, evaporation, melting, or a chemical reaction. Here is Author's Certificate #182,661: "A method for manufacturing thin-walled nichrome tubes. This method is different because it draws the tube by using an aluminum rod that is later removed by corroding it with alkali."

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[1] *Young Communist,* 1972, #1, pages 52-58.

The contemporary inventor has to fully know the standard principles for removing technical contradictions. Without this, a scientific organization of the creative process is impossible.

Part 2-4
How the Algorithm Works

We will continue our study of ARIZ-71 in the following chapters; meanwhile, let's examine the Algorithm in action through concrete problems.

Problem 5

An icebreaker cracks a passage through ice by utilizing the common wedge principle. Therefore, the speed it travels, and the thickness of ice it is capable of crushing, depends upon the icebreaker's energetic capability. The direction of "icebreaker" evolution is towards increased engine power. A contemporary ocean liner has a displacement ratio of one-half horsepower-per-ton. Icebreakers have a ratio six times higher. About 70 percent of the icebreaker's length is taken-up by engines, fuel compartments, and related service systems. Icebreakers are literally filled with an "engine system," and cooling it is a complicated task.

> *"Periodic malfunction of cooling systems during heavy icing conditions can be seen everywhere, and an effective solution for this problem has not been found yet. For instance, it is known from the experiences of American icebreakers that, in some cases, it is not the thickness of ice, but the interruption in the supply of outside cooling water, that limits the forward movement of the ship."*[1]

The engine compartments have hypertrophied so that the ship has no space left for a fairly substantially-sized cargo. Therefore, a caravan of three-or-four transport vessels usually follow behind an icebreaker.

> *"The beginning date and duration time of Arctic and frozen port navigation depends upon icing conditions. Indeed, the principle of icebreaker action, whether with a steam engine installed —as a hundred years ago —or the finest nuclear reactor, has almost never changed. The ship takes a running jump, climbs up on the ice field that bars its way, and breaks the ice with its weight. Then it takes another running jump, and plunges several meters forward again. Engines scream, and ice scrapes the ship's body. A caravan of conventional vessels waits in the distance for the icebreaker to make a path. However, the ice grows thicker and thicker —one meter, two meters, two-and-a-half meters . . . . Now the icebreaker is strangled. The ship pushes*

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1. B. S. Iudovin, *The Power Systems of Icebreakers,* "Shipbuilding," 1967, page 182.

> *from side to side. Its nose starts to swing, trying to free itself from its ice captivity. Pumps pumping hundreds of tons of water from its bow tanks into its stern tanks, from left to right. The icebreaker swings from bow to stern, from side to side, chiseling away blocks of ice. The road behind the icebreaker is now too harsh for conventional vessels. With great difficulty they dodge floating blocks of ice that are capable of breaking their hulls. Harbor areas, including those in front of the berths —and sometimes even the whole port, become a total mess from the broken ice. Everyday, icebreakers add to it, and as a result, the accumulated ice blocks freeze together creating an ice field two- or three-times thicker than the original. Now, even an icebreaker has no power to overcome the barrier.*

This happens often in the ports of Arhangelsk and Leningrad. A Captain's dream is an icebreaker capable of going through ice of any thickness, and even more importantly, leave a clear channel behind, not an icy mess."[1]

There are different methods to make moving through ice easy. For a long time, explosive materials were used to break ice. The shortcomings of this method are high —consumption of explosives, low productivity, and extreme danger.

Another method is to use a vibrating device installed on small-river icebreakers:

> *"Multi-ton disks are fastened to shafts of special machines dead-bolted to the ship's front deck. As soon as this machine starts to work, the icebreaker begins to shake and swing (especially at its bow). Not only is merely being on the ship difficult, looking at the ship is frightening. It seems that this vibrating device will rip the bow off. The ship shakes like it has a high fever. At last, the ice cannot withstand these beatings, and gives up."*[2]

The application of explosives, or vibrations, provides no significant positive effects.

We need to find a method that will guarantee forward movements through ice that is three meters thick. Our method must be economical, and can be implemented by existing technology.

We won't clarify this problem right now. Instead, let's introduce some limitations:

1. Under the conditions of this problem, the transportation of cargo through waterways cannot be replaced by other means (i.e., air and railroad transportation is rejected).

2. It is prohibited to replace the ship with a submarine. Submarines have deep immersion in their surface position. A submarine tanker

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1. E. Muslin. "Cannons and Ice," *Knowledge = Power,* 1968, #5.
2. Z. Kanevski. "Ice plowing," *Knowledge = Power,* 1969, #8.

was built in England with 18 meters of immersion. It must be loaded and unloaded in the open ocean. This problem has to be solved in relation to a ship having between 5-20 thousand tons of displacement.The ship should be capable of developing 18 –20 knots in the open sea.

Solution to Problem #5.

ARIZ Part 1: Choosing the Problem

Step 1-1: *Determine the final goal of a solution.*

a. What is the technical goal (which characteristic of the object must be changed)?

It is required that we increase the *speed* of a caravan of ships and an icebreaker through iced waterways.

b. What characteristic of the object obviously cannot be changed in the process of solving the problem?

It is impossible to increase the *engine's power* —any such possibilities have been exhausted.

d. What is an acceptable expense?

Expenses must be lower than when the best icebreakers are used.

e. What is the main technical/economical characteristic that must be improved?

The goal is to reduce the cost of transporting one ton/km of cargo.

Step 1-2: *Investigate a "bypass approach." Imagine that the problem, in principle, cannot be solved. What other, more general, problem can be solved to reach the same required final result?*

The by-pass direction is to "get rid of the icebreaker." The icebreaker is a machine to make a channel through ice. If transport vessels learn how to move through ice without a channel, the icebreaker will not be necessary.

Step 1-3: *Determine which problem, the original or the by-pass, makes the most sense to solve.*

Should this be done by the icebreaker, or performed independently of it?

a. Compare the original problem with a tendency (a direction of evolution) within the given industry.

b. Compare the original problem with a tendency (a direction of evolution) within a leading industry.

There is a clear tendency to "do it independently" in a water transport (from a towed barge to a self-propelled barge).

c. Compare the by-pass problem with a tendency (a direction of evolution) in the given industry.

d. Compare the by-pass problem with a tendency (a direction of evolution) in a leading industry.

A tendency toward "done by itself" can also be seen in agricultural machine building (use separate, self-propelled machines instead of trailers). The same thing happened in the aviation industry, which is why not many trailered passenger gliderplanes materialized.

e. Compare the original problem with the by-pass one. Choose which to pursue.

Bypassing the problem seems more complex—in a sense, even unreal, or wild. (We want a transport vessel to move through the ice faster than an icebreaker). However, analysis indicates a preference towards the by-pass solution. Let's choose this one.

Step 1-4: *Determine the required quantitative characteristics.*

Let's set the speed through the ice equal to six knots (three times faster than existing icebreakers), and the ice thickness to equal three meters.

Step 1-5: *Introduce time correction into the quantitative characteristics.*

Correction of time: the speed equals eight knots, the ice thickness equals 3.5 meters (practically, this is the maximum limit).

Step 1-6: *Define the requirements for the specific conditions in which the invention will function.*

The thing we need to invent should be reliable in polar conditions. Therefore, we require that there be as few moving elements and protruding parts as possible because they freeze together and are broken by the ice.

Part 2: Define the Problem more Precisely.

Step 2-1: *Define the problem more precisely utilizing patent information.*

a. How are problems close to the given one solved in other patents?

Analysis of patent information immediately reveals a very interesting fact: there are no inventions related to our by-pass direction. For hundreds of years, the evolution of icebreakers followed the framework of their original design. Even the most original recent inventions do not expand beyond this system.

Inventors from the Leningrad Scientific Research Institute of the Arctic and Antarctic offered to break ice with a set of disk blades or impulse hydro-guns.[1]

American Patent #3,130,701 proposed placing the ship's bow under the ice and breaking the ice up from underneath. Lowering the bow is accomplished by pumping water into special tanks, and then pumping the water out while simultaneously adding air into inflating sacks positioned under the bottom of the icebreaker to raise it up again.

In the German Federal Republic, patent #1,175,103 suggested installing dozens of "horns aimed forward, bent under the ice, made of steel with chisel-like plates" in the front of the ship.

Recent suggestions propose "a working element made as a cutter, placed along both sides of the ship and adjusted in height; mount a boom on the back of the ship's hull having on its end a plate to remove the broken ice." This is not a ship; this is a special machine for building a channel through ice.

Many Authors' Certificates and patents have been issued on different devices for removing crushed ice from under the icebreaker, thereby cleaning the channel. It was once even suggested to make a special ice-cleaning vessel equipped with a device for pushing the crushed ice back under the ice field. This system of "icebreaker/caravan" is far removed from an ideal machine—the icebreaker "carries itself," but there is another vessel added just to clean the channel. This surely brings the basic system further away from an ideal machine.

Patent analysis, therefore, confirmed that the straight road leads to a dead-end of excessive specialization. We made the correct decision by choosing the by-pass direction.

b. How are similar problems solved in leading industries?

We can try to solve a related problem of moving through a solid medium. The mining industry, in this case, is the choice nearest to our situation (boring mines, removing coal and ore, and so on). Solid ice is like rock in a mine. Let's see how other machines move through a solid, rocky medium.

In the field of mining, engineers have used hydro-monitors and water guns for some time. Experiments were made using different electromechanical methods to break off coal, ore and rock. Heating by high-frequency current, the electrohydraulic effect, and so on, was implemented. Unfortunately, it is impossible to apply any of these methods to our problem because of the volume of ice needed to be crushed per unit of time in order to provide the ship's required speed.

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[1] *Scientific-Technology Society of the USSR*, 1968, #11, pages 24 and 25.

c. How are opposite problems solved?

The opposite problem is to strengthen the ice instead of breaking it. The solution to that is to "armor" the ice. This solution obviously cannot be accepted; however, to use this solution "with an opposite sign" means to add something into the ice that will *reduce* its strength. This method is also not acceptable —it would require too much substance-disintegration.

Step 2-2: *Use Operator STC (Size, Time, Cost).*

To apply Operator STC, we will consider the ship as an object whose main dimension is *width* (a change in length makes no difference).

a. Imagine changing the dimensions of an object from its given value to zero (S → 0). Can this problem now be solved? If so, how?

The width of the ship tends toward zero. Suppose it equals one millimeter. The ship becomes a blade?

b. Imagine changing the dimensions of an object from its given value to infinity (S → ∞). Can this problem now be solved? If so, how?

Let us now increase the width: 10 m, 100 m, 1000 m, 10,000 m . . . . It is increasingly more difficult to move this giant through the ice. Can we turn it on a side?

c. Imagine changing the time of the process (or the speed of an object) from its given value to zero (T → 0). Can this problem now be solved? If so, how?

The speed of the ship decreases toward zero. In this case, we can slowly melt the ice —and fuel consumption will also decline toward zero.

d. Imagine changing the time of the process (or the speed of an object) from its given value to infinity (T → ∞). Can this problem now be solved? If so, how?

Increase the speed to 50 knots, 100 knots . . . . The ship has to move as fast as a ship with underwater wings. Any method to break the ice is not applicable: it will require too much power. This demands that we think of something that can go through ice without consuming energy. How?

e. Imagine changing the cost of an object or process —its acceptable expenses — from its given value to zero (C → 0). Can this problem now be solved? If so, how?

Let's assume that our expenses are trying to drop to zero. Again, we reach the same conclusion: we will not be able to destroy the ice (for that, we always have to pay).

f. Imagine changing the cost of an object or process — its acceptable expenses — from its given value to infinity (C → ∞). Can this problem now be solved? If so, how?

If our expenses are unlimited, the problem is easily solved: use lasers to cut a road through the ice.

Step 2-3: *Describe the conditions of the problem (without using special terms, and without stating what exactly must be thought out, found, or developed) in two phrases using the following format:*

a. "Given a system consisting of (describe its elements)."

b. "Element (state element), under conditions (state conditions), produces the undesirable effect (state effect)."

Let's state the problem in two sentences — removing such terms as *icebreaker*, *ice-cutter*, *ice-crasher* (they bind us *a priori* to a technology of destruction):

There is a given system composed of *ship* and *ice.*

The ship cannot move through the ice at high speed. (By the way, it is possible to also remove the term *ship*, although it is general enough not to limit our imagination).

Step 2-4: *Enter the elements of Step 2-3a into a table:*

TYPES OF ELEMENTS	ELEMENTS
a. Elements that can be changed, redesigned, or retuned (under the conditions of this problem).	Ship
b. Elements that are difficult to change (under the conditions of this problem)	Ice

A ship is a technical object, and can be transformed as we wish. Ice is a natural object, so it is difficult to change. Therefore, the ship must relate to "a," and the ice to "b."

Step 2-5: *Choose from Step 2-4a the easiest element to change, redesign, or tune.*

The object for our further analysis will be the *ship*.

This conclusion is unexpected: traditional attempts to solve this problem involved breaking the ice — the ice was *broken, cut, blasted,* and so on. The ship seems to stay untouched. We are used to seeing it in a certain *form*, while the ice seemed easy to change. In reality, everything is reversed. To melt one cubic meter of ice (it does not matter how we do it: by a super modern laser, or a simple fire) still requires 80,000 kcal of heat before any loss consideration. One way or another, it requires a large amount of energy to crush one cubic meter of ice. It is much easier to crush the ship. After all, the ship can be built easily breakable —it is entirely up to us.

We came to a wild conclusion. Perhaps someone once came close to this idea but was stopped by a psychological barrier.

Part 3: Analytical stage

Step 3-1: *Formulate the **IFR (Ideal Final Result)** using the following format.*

a. Select the element from Step 2-5.

b. State its action.

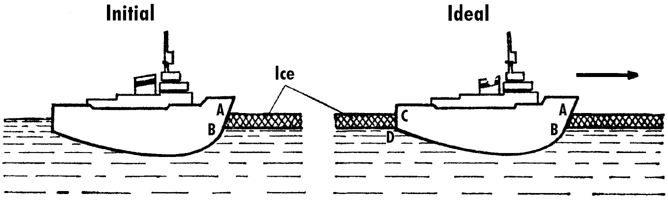
c. State how it performs this action (when answering this question, always use the words "by itself").

d. State when it performs this action.

e. State under what conditions (limitations, requirements, etc.) it performs this action.

Let's formulate the Ideal Final Result (IFR). The ship, by-itself, moves through the ice at high speed with a normal consumption of energy (as if it were in clear water).

Figure 23. *For Problem 5, Step 3-2: "Initial," the ship has reached the ice and stopped; "Ideal," the same ship somehow moves through the ice.*



Step 3-2: *Draw two pictures —(1) "Initial" (the condition before IFR), and (2) "Ideal" (condition upon attaining IFR).*

Step 3-3: *In the "Ideal" picture, find the element indicated in* Step 3-1a *and highlight (by a different color, or other means) that part which cannot perform the required function under the required conditions.*

Section AB of the front part of the ship cannot perform the required action because it leans against the ice. We can answer this a little differently: that part of the hull between AB and CD cannot perform the required action.

Step 3-4: *Why can this element (by itself)* ***not*** *perform the required action?*

a. What do we expect from the highlighted area of the object?

We want this part of the ship not to press against the ice.

b. What prevents it from performing this action by itself?

It is rigid, hard and solid —this is why it is pressing against the ice.

c. What is the conflict between "a" and "b" above?

This part should be there to preserve the integrity of the hull, and it should not be there to press against the ice.

Step 3-5: *Under what conditions can this part provide the required action? (What parameters should this part possess?)*

Since this part is necessary, it will be preserved; however, since it interferes with the ice, it must be reduced to a minimum.

Step 3-6: *What must be done so that this element attains the characteristic described in* Step 3-5*?*

The thickness of the ice and the width of the ship define the size of this area. We cannot reduce the thickness of the ice. However, we can reduce the width of the ship. It is not necessary to have the ship completely flat (*Figure 24a*). We shall consider that part of the ship which interacts with the ice. Let this part become flat (*Figure 24b*).

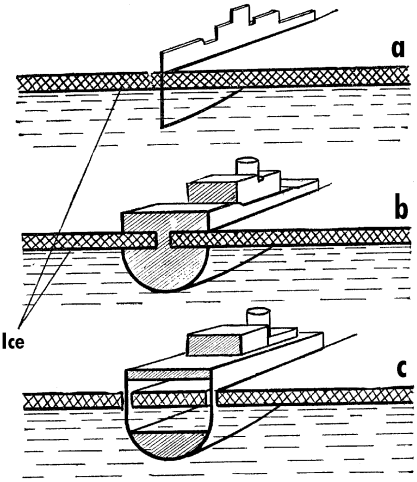


Figure 24. *The smaller the strip of ice broken, the less energy is consumed.*

Step 3-7: *Formulate a concept that can be practically realized. If there are several concepts, number them with the most promising as number one. Write down all such concepts.*

This is an unstable shape. To make the ship flat and stable requires two planes connecting the upper and lower parts of the hull.

Step 3-8: *Provide a schematic for realizing the first concept.*

See *Figure 24c*.

Part 4: Preliminary Analysis of the Chosen Concept.

Step 4-1: *What is getting better, and what is getting worse, during the utilization of the new idea or concept? Write down what is achieved and what is getting more complicated or more expensive.*

The total width of the knife-thin walls is 20–25 times less than the usual width of the ship. Therefore, it is possible to expect a significant reduction in energy consumption during its motion through the ice. The design of the ship, in general, is now simplified because of the drastic reduction in power needed for the engines. It is more difficult to resolve the secondary problems – for instance, movement between the upper and lower parts during navigation in icy conditions.

Step 4-2: Is *it possible to prevent that which is getting worse by changing the proposed device or method? Make a drawing of the changed device or method.*

This type of problem can be removed if the lower section is used only as cargo space.

Step 4-3: *What is getting worse (more complicated, more expensive) now?*

There are no shortcomings in our idea as long as the ship can be navigated easily in clear water. It is interesting to note that, during recent years, a tendancy has been discovered within the conventional shipbuilding industry to lift ships above the waves while lowering the engine sections beneath the surface.

Step 4-4: *Compare gains and losses.*

a. *Which is larger?*
b. *Why?*

The contemporary icebreaker has completely exhausted the resources of its development: it is impossible to install more powerful engines in place of those already in use. This new concept, proposing to break as little ice as possible, has nothing but advantages. At the same time, we cannot ignore some of the mental issues contained in making this concept transition: psychological inertia, and attachment by "experts" to the conventional concept of "break as much ice as you can" (with the hull, disk cutters, water jets, etc.).

Part 5: Operative Stage.

Although we found the solution concept, let's turn to the Contradiction Matrix as a means of control.

Step 5-1: *From the vertical column of the Contradiction Matrix (see Appendix 1), choose the characteristic that must be improved.*

It is required that we increase the ship's **speed** (Matrix line 9), or **capacity/productivity** (Matrix line 39), if the ship is considered as the *machine* transporting the cargo.

Step 5-2:

a. *How can we improve this characteristic (from* Step 5-1*) utilizing any known means (if losses are not considered)?*
b. *Which characteristic is worsening if a known means is used?*

A known way to increase the speed (productivity) of navigating through icy water is to increase the **power** of the engine.

Step 5-3: *From the horizontal row of the Contradiction Matrix (see Appendix), choose that characteristic corresponding to* Step 5-2b*.*

Let's choose column 21.

Step 5-4: *In the Matrix, find the principles for removing the technical contradiction (this means, locate the cell at the intersection of the column from* Step 5-1 *and the row from* Step 5-3*).*

The first contradiction is **9—21** (Principles 19, 35, 38 and 2). The next contradiction is **39—21** (Principles 35, 20 and 10).

Step 5-5: *Investigate how these principles can be used.*

Principle 35a —change the physical state of the system in correspondence with the newfound concept.

We could immediately, without analysis, turn to the Matrix. However, in this case the answer will be unexpected: "Make the ship liquid or gaseous." After Step 3-3, even if we do not have a solution concept, we know to which part of the object the suggested Matrix principle must be applied. There is no need to make the *ship* liquid or gaseous; it is enough to change the physical state of that *part* of the ship that is on the same plane as the ice.

Part 6: Synthetic Stage.

Step 6-1: *Determine how the super-system to which our modified system belongs must be changed.*

Originally, the ship was part of the system "icebreaker and transport ships following it." If this is the case, our transport ship navigates the icy water by itself, and there is no need for an icebreaker. This can be stated differently: The icebreaker itself, released from the need for engines to provide extra power, can transport the cargo.

Step 6-2. *Explore how our modified system may be used differently.*

Because the process of breaking the ice is done by narrow blades it becomes possible to utilize other methods of ice breaking that were previously not economical (for example, use electromechanical methods).

Step 6-3: *Utilize this newly found technical idea (or an idea opposite to the one found) to solve other technical problems.*

This is the essence of our newfound idea: Propel the ship on narrow blades instead of using the bow for ice breaking. This idea can probably also be adapted to earth excavation work.

Part 2-5:
Several Exercise Problems

We solved the icebreaker problem by applying the *by-pass* concept. During the first stage of its solution, the original goal was changed. Let's now take the sprinkler irrigation system problem and analyze a case where the original goal does not change.

To prevent the temptation to use the by-pass concept, we'll begin with *Step 2-3*, replacing prior steps with some brief patent information.

Solution to Problem #2

The main tendency in the evolution of self-propelled irrigating sprinkler systems is to increase the length of their wings.[1] In order to reduce the wing's cantilever load, support is provided by wheeled carriages. This is how, for example, it was done in FRG Patent #1,068,940 (*Figure 25a*). In British patent #778,716, the wings were made as separate frames attached by a joint (*Figure 25b*) —the Principle of Segmentation. Unfortunately, supports do not eliminate the necessity to make wings rigid —and, therefore, heavy. It is no accident that ARE Patent #2,698 considers *self-propelled* supports; therefore, closing the loop —and complicating the design.

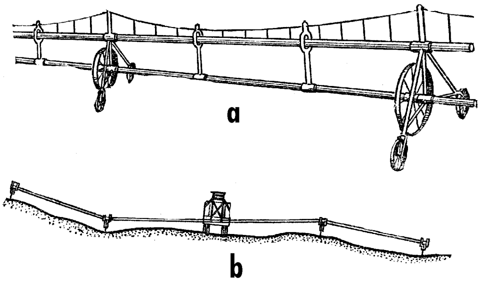


Figure 25.
The main trend in the evolution of self-propelled agricultural water irrigation systems is toward increased wing length: A machine in accordance with FRG Patent #1,068,940 (a); In British patent #778,716 the wings are made out of sections with flexible joints (b).

Let's try to find the better solution.

Step 2-3: *Describe the conditions of the problem (without using special terms, and without stating what exactly must be thought out, found, or developed) in two phrases using the following format:*

---

[1] For more details see A. Karmishin, *Sprinkler Irrigation Apparatus*, M. Publishing CCRIFI, 1965.

There is a system comprised of a carriage, wings, and wing-mounted water sprinklers. Increasing the wing-length makes the system too heavy.

Step 2-4: *Enter the elements of Step 2-3a into a table.*

In principle, all the elements may be changed: carriage, wings, and sprinklers. However, if we are going to solve the central problem (increase the wing length), the carriage and sprinklers must stay unchanged. Therefore:

TYPES OF ELEMENTS	ELEMENTS
a. Elements that can be changed, redesigned, or retuned (under the conditions of this problem).	Wings
b. Elements that are difficult to change (under the conditions of this problem)	Carriage and sprinklers

Step 2-5: *Choose from* Step 2-4a *the easiest element to change, redesign, or tune.*

Wings.

Step 3-1: *Formulate the* ***IFR (Ideal Final Result)****.*

When irrigation starts, the wings must be suspended above the field by themselves (wing span is between 200- and 300-meters).

Step 3-2: *Draw two pictures –(1) "Initial" (the condition before IFR), and (2) "Ideal" (condition upon attaining IFR).*

See *Figure 26.*

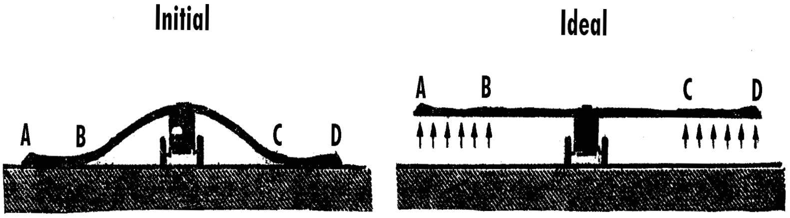


Figure 26. *The wings support themselves with the aid of the jet force of the water shooting through the nozzles.*

Step 3-3: *In the "Ideal" picture, find the element indicated in Step 3-1 and highlight that part which cannot perform the required function under the required conditions.*

"Extra" wing sections *AB* and *CD* can't perform the required action.

Step 3-4: *Why can this element (by itself)* ***not*** *perform the required action?*

a. What do we expect from the highlighted area of the object?

We would like to see sections *AB* and *CD* suspended over the field by themselves.

b. *What prevents it from performing this action by itself?*
Their weight is an obstacle.

c. *What is the conflict between "a" and "b" above?*
Sections *AB* and *CD* must weigh something (this is part of the construction) –and at the same time, they should not weigh anything.

Step 3-5: *Under what conditions can this part provide the required action? (What parameters should this part possess?)*

Sections *AB* and *CD* can be suspended in the air if we provide a maximum reduction of their weight (the same as in the icebreaker problem, where we reduced the width of the vessel interacting with the ice) or counter balance the wings somewhat.

Step 3-6: *What must be done so that this element (the internal surface of the pipe) attains the characteristic described in* Step 3-5*?*

Reduction of the wing's weight can be done through an implementation of an inflated wing construction. This idea was analyzed in the description of the problem's conditions. What's left? To balance the wings. A force must be applied to sections *AB* and *CD* of the wings that must be equal to their weight and applied in the opposite direction. It can be aerodynamic forces (because we have wings), hydrodynamic forces, etc.

Step 3-7: *Formulate a concept that can be practically realized. If there are several concepts, number them with the most promising as number one. Write down all such concepts.*

The aerodynamic forces in our case are relatively small. It makes more sense to use the hydrodynamic force produced by the sprinkler nozzles water jets to keep the wings suspended. Fifty pounds of water pressure at the end of the wings will be sufficient to provide the necessary support. Calculations reveal that a lightweight hydro-construction can both support and propel itself. Even so, if the hydro-jet forces are inadequate, at least it is better to partially reduce the weight of the wings. We can except that the wings be dropped down during idle system conditions; but, during irrigation, these forces will raise the wing-ends.

* * *

The Algorithm does not release the inventor from the necessity to think. The same problem can be solved on different levels depending on the inventor's individuality.

Let's look at the following example.

Problem #6

In the past, during mining work, ten explosive blasts were usually made in two minutes. An operator had enough time to hand-close the electric detonator contacts. When new methods of mining work were introduced, it became necessary to close 40 contacts sequentially during a 0.6-second interval. At the same time, intervals between each blast vary. For instance, blast #2 must follow at a 0.01 second interval after blast #1; blast #3 at 0.02 seconds after blast #2, and so on. During the next sequence, blast #2 must occur 0.03 seconds after blast #1, and so on. The sequencing chart describing the closing of the contacts must be implemented with a preferred accuracy of ± 0.001 second.

It is necessary to develop a simple, reliable, and accurate method to close these contacts.

Solution to Problem #6

Step 2-3: *Describe the conditions of the problem (without using special terms, and without stating what exactly must be thought out, found, or developed) in two phrases using the following format:*

a. "Given a system consisting of (describe its elements)."

The system consists of 40 pairs of terminals and 40 contacts, or one sliding contact (slider).

b. "Element (state element), under conditions (state conditions), produces the undesirable effect (state effect)."

It is difficult to close the terminals precisely following the sequencing chart. (Electronic detonators are not part of our system. We have to close the terminals, and it does not matter where the signal goes after that).

Step 2-4: *Enter the elements of* Step 2-3a *into a table.*

TYPES OF ELEMENTS	ELEMENTS
a. Elements that can be changed, redesigned, or retuned (under the conditions of this problem).	The slider
b. Elements that are difficult to change (under the conditions of this problem)	Terminals

(In our problem, the terminals are the ends of wires that we need to close. We cannot change the wires. Besides, we need something to conduct the current. But the slider is another matter. It can be changed as much as we wish. If both elements (terminals and slider) are "b," then the outside environment is an object. In *Step 3-3*, part of this object will be selected: the space between the terminals. Further solutions coincide with the case when the slider is chosen.

Step 2-5: *Choose from* Step 2-4a *the easiest element to change, redesign, or tune.*
The slider.

Step 3-1: *Formulate the* ***IFR (Ideal Final Result)****.*
The slider *by itself* closes the terminals following the timing chart exactly.

Step 3-2: *Draw two pictures –(1) "Initial" (the condition before* ***IFR****), and (2) "Ideal" (condition upon attaining* ***IFR****).*
Look at *Figure 27*.

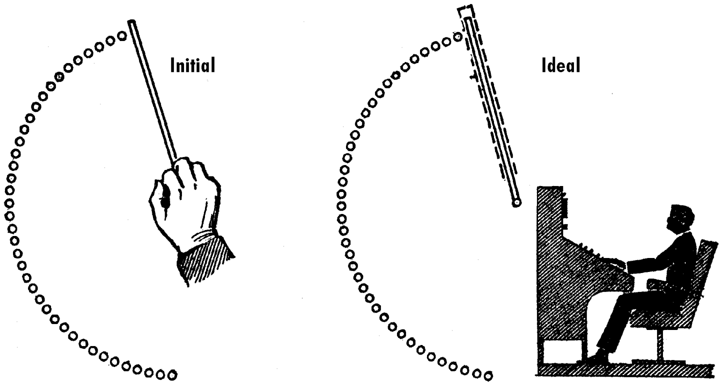


Figure 27. *The contact must move by-itself, without human help.*

Step 3-3: *In the "Ideal" picture, find the element indicated in Step 3-1 and highlight that part which cannot perform the required function under the required conditions.*
The movable part of the slider cannot perform the required action.

Step 3-4: *Why can this element (by itself)* ***not*** *perform the required action?*

a. What do we expect from the highlighted area of the object?
We need the slider to move by itself in accordance with the graph.

b. What prevents it from performing this action by itself?
The slider cannot move independant of a force.

Step 3-5: *Under what conditions can this part provide the required action? (What parameters should this part possess?)*
The slider will move by itself if it possesses the needed force.

Step 3-6: *What must be done so that this element (the internal surface of the pipe) attains the characteristic described in* Step 3-5?

> If such a force appears by itself, it means that natural forces must be present (i.e., gravity).

Step 3-7: *Formulate a concept that can be practically realized. If there are several concepts, number them with the most promising as number one. Write down all such concepts.*

> The simplest case of motion under natural force is *falling.* So, the slider should move under the force of gravity. This can provide the necessary movement in accordance with the sequencing chart.

Step 3-8: *Provide a schematic for realizing the first concept.*

> A vacuum is created inside the tube. The weight falls closing the terminals. If there are many terminals in the tube, it becomes easy to comply with any graph.

Let's compare this solution with Author's Certificate #189,597: A device to set required time intervals. This device is different because it has a rod with a weight that closes terminal contacts connected to electronic detonators during its fall. This allows for increased accuracy in setting the time intervals between blasts.

We call such answers to exercise problems that have been awarded Author's Certificates or Patents, and reflect today's levels of creative thought in a given area of industry, **control answers**.

The purpose of studying ARIZ is not to learn how to find the control answer. To solve an inventive exercise problem during one's initial learning of ARIZ means reaching an answer that is not *too* distant from the control answer. Similar, or even better, answers are attainable near the end of one's study.

Problem #6 can be solved purely through designing an electric circuit system utilizing time delay relays. However, in this case it would be impossible to combine optimum simplicity with the required accuracy. The control answer relates to the second Level of the innovation. It would be possible to reach the same answer without ARIZ by sorting through several dozen variants.

Let's now complicate this problem somewhat. It will give us the chance to utilize ARIZ at its full power.

Problem #7

Let's use the answer we obtained in *Step 3-8*, *Problem #6* as a model: *there is a glass tube with a vacuum.* A steel ball closes the terminals as it falls down tube. The shortcoming of this model is the absence of freefall. The ball, in reality, slows down somewhat as it touches each terminal.

What can we do?

If we take 40 seperate tubes of different lengths, we can get rid of the friction (each terminal will be at the bottom of each tube). However, the device now becomes very complicated. If we replace the terminals with micro-coils, and the ball with a magnet, the friction between the magnet and the magnetic lines will still exist —besides, the system becomes more complex by the introduction of an amplifier. Introduce optical contacts? This is also bad because we complicate the system again.

The device has to remain simple, but its accuracy in comparison with its prototype must be increased.

This is an exercise problem, therefore it cannot be changed: the original conditions (terminals and falling contact) must be preserved.

Solution to Problem #7

Step 2-3: *Describe the conditions of the problem (without using special terms, and without stating what exactly must be thought out, found, or developed) in two phrases using the following format:*

a. "Given a system consisting of (describe its elements)."

There is a system comprised of a vacuum tube, terminals and contacts.

b. "Element (state element), under conditions (state conditions), produces the undesirable effect (state effect)."

The contact, during descent, connects all the terminals.

Step 2-4: *Enter the elements of* Step 2-3a *into a table.*

TYPES OF ELEMENTS	ELEMENTS
a. Elements that can be changed, redesigned, or retuned (under the conditions of this problem).	The contact and terminals
b. Elements that are difficult to change (under the conditions of this problem)	The tube

Now, when we consider the friction between the contact and the terminals, both elements can equally be "a." The tube can also be changed, but to a lesser degree. It has its own function —to hold the vacuum.

Step 2-5: *Choose from* Step 2-4a *the easiest element to change, redesign,or tune.*

The contact. (We can choose the contact or the terminals. In our case, it doesn't matter because we have to consider the interaction of the frictional parts).

Step 3-1: *Formulate the **IFR (Ideal Final Result)**.*

During its fall, the contact closes the terminals without creating friction. To close the terminals requires touching, which means friction. The IFR states: Let's have friction without any friction. This is a fantastic idea, isn't it?

A strong psychological barrier appears here. Continuation of the problem solving process mainly depends upon an inventor's individuality —primarily, bravery and structured thinking process. This requires the possession of skills that don't stop at barriers —nor retreat before them, nor circumvent them.

Step 3-2: *Draw two pictures —(1) "Initial" (the condition before **IFR**), and (2) "Ideal" (condition upon attaining **IFR**).*

Hence, the ball must pass through terminals without friction! Here the idea of a *liquid* ball may appear. However, this is not a good solution because liquid will evaporate, the vacuum then disappears, and free fall will be disrupted.

Step 3-3: *In the "Ideal" picture, find the element indicated in* Step 3-1a *and highlight (by a different color, or other means) that part which cannot perform the required function under the required conditions.*

The widest part of the ball (its so-called "waist") cannot perform the required action.

Step 3-4: *Why can this element (by itself) **not** perform the required action?*

a. What do we expect from the highlighted area of the object?

We need the frictionless movement of the ball; i.e., the ball should not touch the terminals.

b. What prevents it from performing this action by itself?

To close the terminals, the ball's "waist" must press against the terminals.

c. What is the conflict between "a" and "b" above?

For "a," the ball must be movable; for "b," it must immobile.

Step 3-5: *Under what conditions can this part provide the required action? (What parameters should this part possess?)*

The ball must be in motion —and *not* in motion —at the same time.

Before, it was "friction without friction," now it is "motion without motion." Just as it is always darkest before dawn, it is the same before a new idea is found: thought hits an obstacle that seems to make the problem even more difficult. We call this the *predawn effect.* Do you remember how Maksutov arrived at the idea that a design for his new telescope must be more complex? Before, he used to stumble over this point (the darkness was getting thicker, and he did not want to think about it). However, in the train, Maksutov began to fantasize –prohibiting the possibility of complicating his design. He continued thinking until he suddenly saw that complications are *conditional.*

Step 3-6: *What must be done so that this element attains the characteristic described in* Step 3-5?

The ball has to be segmented. Let one part of the ball (its "waist"), stop upon reaching the first terminal –and another part (the rest of the ball) continue in freefall.

Step 3-7: *Formulate a concept that can be practically realized. If there are several concepts, number them with the most promising as number one. Write down all such concepts; and* **Step 3-8**: *Provide a schematic for realizing the first concept.*

Let's make the contact segmented (Figure 28). The upper ring, upon reaching the first pair of terminals, stops and closes the first circuit. The other part of the contact will continue in freefall: the termination of the first ring will not effect the other rings because the upper ring does not contact the lower rings during freefall. Side movement is excluded because there are no forces that can cause it to happen. The second pair of terminals is positioned closer to the center of the tube axis than the first pair. It will catch the second ring of the contact while the other parts of the contact continue free falling again. Let's now imagine the construction of this tube. Suppose that the tube is three meters long (this is analogous to our prototype). We will retain the first meter of the tube as a runway for the contact (no terminals are installed). The contact will pass down the next two meters in 0.2 seconds. The average distance between terminals within this interval is 200 / 40 = 5 cm. It is clear that the number of terminals can

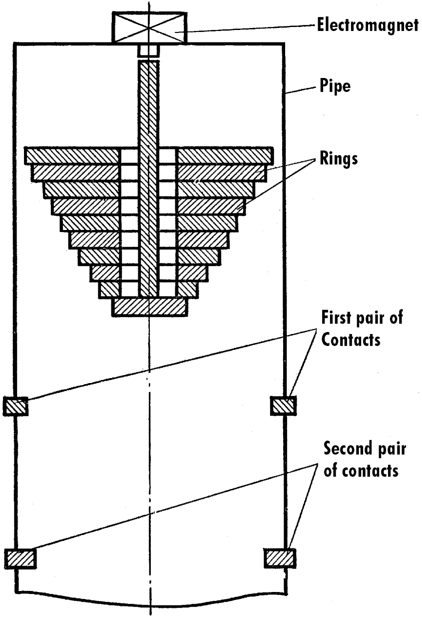


Figure 28. *Each pair of contacts will hold only "its" ring.*

> be increased. By connecting our circuit to different terminals, we can provide any required sequence of operation. The average speed of the contact is one meter per 0.1 second. This means that 0.001second represents 1 cm of tube distance, or the accuracy of our device. If the diameter of the tube is 80 mm, the average shift of terminal contact towards the center of the tube is 2mm. Just a simple flipping-over will reset the device. All rings start to fall as soon as the bottom ring supporting the other rings is released.

So, we have created friction without friction. The newfound concept is much broader than the solution to our specific problem. In essence, we found a method of supporting movement without having friction as its support. To solve this type of problem without ARIZ (by the trial and error method) is not so easy. You can prove this to yourself by giving Problem #7 to your friends. Remember that they cannot change the problem: the **original** system has to be improved (the falling weight and terminals). One more thing. The conditions of the problem must be provided in writing, not verbally. The person must first read the control answer to Problem #6, and then read the conditions for Problem #7.

Going through the several problems presented here, the reader can reach the conclusion that the typical characteristic of ARIZ is its tendency to obtain the required effect with minimal consumption. In Problem #5 we strove to break as little ice as possible: Nobody needs broken ice, it is only the "price" for a rough, inefficient —imperfect —method of navigation. In Problem #2, the wings of the sprinkler-irrigation system were suspended by themselves. In Problem #7, friction was removed by simply segmenting the contact.

It is typical that the average engineering thought process is prepared to pay a fee for an achieved effect. "It is necessary to lower a pipe into a pit," the engineer thinks. "Very well, let's install a crane —it will lower the pipe." The crane is the "payment" for the realization of action required by the problem.

An inventor thinks differently: "It is necessary to lower a pipe. Very well, we have to do something that allows us to lower the pipe into the pit by itself."

We used to pay for solutions to technical problems with the metal of machines, the complexity of electronics, and the generous expenditures of energy. ARIZ develops the habit of paying with another coin —creative thought. The problem can scream: "I am very simple, it is *very easy* to solve me —just use an existing device." However, the inventor must make an attempt to find a solution that does not require any machine, device or apparatus. Of course, in the end "something" has to be used. But that "something" must be definitely new and more effective.

Let's see how this happens in another problem.

Problem #8

A series of filtration systems tests were planned at one laboratory. These filters were designed specifically for use with internal combustion engines. During the test, particles of clay and other free flowing elements —together with air, sand, and dust —must be introduced into the intake of the filtering system. Each test has its own sequencing chart introduction of elements. Sometimes, it is necessary to introduce only one element (for example, only sand); another time it is necessary to simultaneously introduce as many as 24 elements. Each element must be introduced in accordance with its own sequencing chart. Therefore, it is prohibited to add all the elements and introduce an average mix. The weight of each element in the mix varies from 0.01 kg to 0.03 kg. Introduction time during each test is10 seconds. After that, the filtering system is disassembled and inspected.

It is required that we propose a method for introducing freeflowing materials. Our basic requirements: simplicity, accuracy and an easy system reset and adjustment (it is essential that hundreds of different types of mixtures be tested).

This problem was given to students who were just accepted to the Azerbaijan Public Institute of Inventive Creativity. The time taken to solve the problem was unlimited. The majority handled the problem within ½ to 2 hrs. All students (90 people) attacked the problem from a common design perspective: the introduction of powder was done by the application of a different dosing apparatus. In some suggestions, automation of the dosing process was accomplished by using computers.

Here is one solution: 24 pipes are attached to the apparatus. There is a rotating device in the form of a screen placed in front of each pipe. The number of holes in the screen is equal to the number of dots on the chart for a given powder. The diameter of each hole is made in such a way that it allows the introduction of a specific amount of powder every second. The speed of the screen rotation can be adjusted such that a new hole comes before the pipe every second.

Hence, we have 24 dosing devices, each with a diaphragm that changes every second. This machine is very cumbersome, unreliable (the holes and pipes can be clogged), and difficult to reset.

After six weeks, the same problem was again offered to the same students. Now, it took only half the time to solve the problem, and half the students attained the level of the control answer.

Solution to Problem #8

Step 2-2: *Use Operator STC (Size, Time, Cost).*

a. Imagine changing the dimensions of an object from its given value to zero ($S \rightarrow 0$). Can this problem now be solved? If so, how?

If the number of powders is reduced to only one, a conventional dosing device can do the job.

b. *Imagine changing the dimensions of an object from its given value to infinity (S → ∞). Can this problem now be solved? If so, how?*
Let's increase the number of powder additives by a factor of 100. Now we need 2,400 dosing devices. The machine becomes too bulky. There must only be one dosing device, and, at the same time, it should be very simple. However, from this simple device all 2,400 additives should be independently introduced into the system.

c. *Imagine changing the time of the process (or the speed of an object) from its given value to zero (T → 0). Can this problem now be solved? If so, how?*
The shorter the dosing time, the worse the device will work. If we have only 0.03 second, instead of 30 seconds, we will not have time to prepare the powder. Conclusion: dosing has to be done in advance. The main advantage here is that we can weigh the powder using any type of weighing device without being rushed; therefore, we can be very accurate. If we have powder that is measured in advance (for instance, now each unit of measured powder can be delivered within one second), then there is no need for dosing devices. Therefore, out of two required actions —the dosing and the introduction of the powder —only the second action remains to be performed during the test time.

d. *Imagine changing the time of the process (or the speed of an object) from its given value to infinity (T → ∞). Can this problem now be solved? If so, how?*
Suppose that the time available to introduce the powder is one year. Powders can then be introduced very slowly, particle after particle. Even in this case, it makes sense to measure the powder in advance —let's say by our weekly demand.

e. *Imagine changing the cost of an object or process —its acceptable expenses from its given value to zero (C → 0). Can this problem now be solved? If so, how?*
If the cost of the device tends to become zero, then there is no device, or almost no device. In reality, we do not need a dosing device: we can use a very simple method to measure the powder in advance. This means we can also get rid of the feeding device.

f. *Imagine changing the cost of an object or process —its acceptable expenses — from its given value to infinity (C → ∞). Can this problem now be solved? If so, how?*
If we have unlimited financial resources, we can try to change the

main element of our system —the powder. Let's connect each particle of powder with a ferromagnetic particle. It is now much easier to control the powder-feeding process. However, it is not clear how we can separate these powder particles from the ferromagnetic ones later.

What did Operator STC offer us? One very useable idea: measuring the powder dosage in advance; and another: that particles of metal can carry and control the particles of powder.

Let's continue our investigation.

Step 2-3: *Describe the conditions of the problem (without using special terms, and without stating what exactly must be thought out, found, or developed) in two phrases using the following format:*

a. "Given a system consisting of (describe its elements)."

There is a system comprised of *filters* and *24 additives.*

b. "Element (state element), under conditions (state conditions), produces the undesirable effect (state effect)."

It is difficult to introduce the additives into the filters in accordance with a specified schedule.

Step 2-4: *Enter the elements of* Step 2-3a *into a table.*

TYPES OF ELEMENTS	ELEMENTS
a. Elements that can be changed, redesigned, or retuned (under the conditions of this problem).	—
b. Elements that are difficult to change (under the conditions of this problem)	Filters, powder

We are prohibited from altering the filters. We are merely studying them. We are also prohibited from altering the powder—the conditions of the experiment must not be violated.

Step 2-5: *Choose from* Step 2-4a *the easiest element to change, redesign, or tune.*

The outside environment.

Step 3-1: *Formulate the* ***IFR (Ideal Final Result)****.*

The outside environment introduces the powder accurately and simply, *by itself*, in accordance with the sequencing chart. This statement essentially shows two actions: dosing (in compliance with the sequencing chart) and introduction. But *Step 2-2* already offered the idea of measuring the dosage in advance. Consequently, we can state the IFR: The outside environment, *by itself*, introduces a pre-measured dosage of powder simply and accurately.

Step 3-2: *Draw two pictures –(1) "Initial" (the condition before* ***IFR****), and (2) "Ideal" (condition upon attaining* ***IFR****).*

For simplicity we will consider only one type of powder, remembering that this concept will be applied to all 24. Hence, we measured the powder in advance (*Figure 29*). At this time, the outside environment does not introduce the measured powder into the system's funnel. However, we would like the outside environment to introduce the powder.

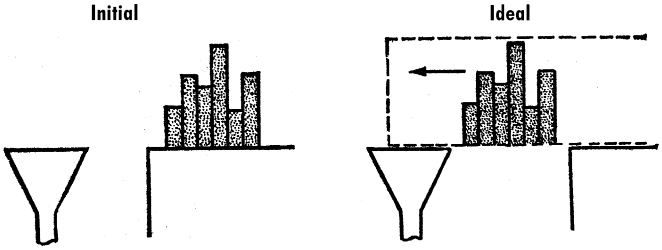


Figure 29. *The powder is measured in advance.*

Step 3-3: *In the "Ideal" picture, find the element indicated in* Step 3-1 *and highlight that part which cannot perform the required function under the required conditions.*

The part of the outside environment (from where the measured powder is located, up to the funnel) cannot provide the required action.

Step 3-4: *Why can this element (by itself)* ***not*** *perform the required action?*

a. *What do we expect from the highlighted area of the object?*

We need this part of the environment to deliver, by itself, the measured powder.

b. *What prevents it from performing this action by itself?*

It is not difficult to make this part of the environment look like a belt. We can place the measured-in-advance powder on this belt. But, where does the belt disappear over the funnel?

c. *What is the conflict between "a" and "b" above?*

There is a contradiction here, although it is not serious one: The belt must be both present and not present. However, these requirements are related to different time frames. The belt has to be present while the powder is carried to the funnel. After the powder is delivered, the belt must disappear. A similar situation occurred in *Step 2-2f* concerning the ferromagnetic particles.

Step 3-5: *Under what conditions can this part provide the required action? (What parameters should this part posses?)*

The belt must disappear while over the funnel.

Step 3-6: *What must be done so that this element attains the characteristic described in* Step 3-5?

Either the belt will disappear, or it will change its direction.

Step 3-7: *Formulate a concept that can be practically realized. If there are several concepts, number them with the most promising as number one. Write down all such concepts.*

We can make the belt like a conventional conveyor belt. Then, we will need 24 conveyors. What about 240 conveyors? This is a bad idea. A conventional, continuous cycle conveyor is good when we need to transport material over a long period of time. In our case, all the powder is pre-measured; therefore, we do not need the returning, lower part of the conveyor. The first concept remains for us — destroy the conveyor belt over the funnel. This is very close to an ideal machine: that part of the machine which has finished performing its function must disappear.

Step 3-8: *Provide a schematic for realizing the first concept.*

Where, and how, will the belt disappear? The belt can be thrown away; however, that may require a special device. The ideal concept is for the belt disappears all by itself —melting, evaporating, etc.

Step 4-1: *What is getting better, and what is getting worse, during the utilization of the new idea or concept? Write down what is achieved and what is getting more complicated or more expensive.*

We gained in accuracy (a precisely measured dosage is made in advance) and simplicity of design (all belts disappear); however, only the process of placing the powder onto the belt is added to our original concept.

Step 4-2: *Is it possible to prevent that which is getting worse by changing the proposed device or method? Make a drawing of the changed device or method.*

It is not difficult to place the powder onto the belt: dispense glue on the belt and spread a layer of powder over it. However, we need the belt to carry the powder in accordance with the sequencing chart. We can dispense the glue only over places where the powder should be according to this chart. It is simple to cut the belt in accordance with the chart. The material that the belt is made from should allow for easy cutting and glue dispensing, and easy disappearance. This material can be common paper, or paper made of benzene.

Step 4-3: *What is getting worse (more complicated, more expensive) now?*

It is difficult to find shortcomings in this concept. It is now much easier to prepare a supply of sheets covered with the powder. It is now even easier to cut these sheets in accordance with the sequencing chart. One sheet, or several, packaged as a sandwich could be introduced by a very simple device. Burning benzene paper over the funnel also provides no problem.

Step 4-4: *Compare gains and losses.*

We have found a simple concept that is easy to implement and test. Its advantage is clearly seen.

The control answer: A method for the continuous measured-dosage (by weight in volume units) of free flowing materials (i.e., abrasive powders) during wear tests of combustion engines. This method is different because the abrasive powder is placed in advanced by uniform layers on the surface of a flexible belt made from an easily ignitable material. This belt moves with a specific speed into a high heat area, and burns there while delivering abrasives to the testing area.

This allows for an increase in the accuracy of the dosage process. (Author's Certificate #305,363.)

Of course, real-life notes are much shorter. Here, for example, is the solution as written by V. Mitrofanov, a senior student of the Azerbaidjan Institute of Oil and Chemistry:

"Step 2-3. There is a system: engine and additives.

"Step 2-4.
a. —
b. Engine, additives.

"Step 2-5. An outside environment.

"Step 3-1. The outside environment introduces additives in the time, and way, we want it.

"Step 3-2. In the drawing 'initial' shows a chaotic flow of additives; in the drawing 'ideal' there is an orderly flow.

"Step 3-3. The area where additives are spread is highlighted.

"Step 3-4. The outside environment cannot weigh something, nor does it *know* the time, and so on.

> "Step 3-5. If the environment does not *know* . . . . Can we possibly do something in advance?"

From this set of statements, Mitrofanov immediately reached an answer corresponding to our control answer. It took only 20 minutes to reach this solution.

Engineer R. Sultanov reached the answer by following another path:

> "Step 3-4. Environment cannot pick-up the required amount of powder and introduce it in precise sets of time.
>
> "Step 3-5. Perhaps if the environment could have transportation abilities (for instance, the ability to introduce one container filled with the required amount of powder every second). *Container* is an arbitrary name. Let's consider a thin shell, belt, and so on. After delivery, the belt disappears."

Formulations of answers to ARIZ's questions are individualistic. However, for all powerful solutions (on the control level or higher), the general thinking process style is distinctive:

> **Directional thought.** An absence of chaotic jumps, or restless tosses and turns.
>
> **Constant orientation on IFR.** The desire to get results by using minimal devices.
>
> **Ability to easily overcome psychological barriers.** The term "container" moves us in the direction of concepts like "bag;" however, R. Sultanov immediately emphasized that "container" is a conditional name —a film, or a belt, are also containers.
>
> **Good skills at using Principles to remove technical contradictions.** When the faintest hint of analysis suggests using one, or another, Principle. (Here, the Principles of Preliminary Action, Regeneration of Parts, and Dynamization were used).

~

Here are several practice problems. These exercises contain all the information you need to solve them. They do not require any special knowledge. Because these are exercise problems, it is enough to find a concept solution in very general terms.

Do not try to find a solution by sorting out variants. You will waste time by guessing at solutions using habitual methods: "What will happen if I do such-and-such?" If you get lucky and find a solution, your creativity will not improve. Even the simplest problems should be solved using the ARIZ system; thus helping to acquire inventive habits.

When solving a problem, do it as if you will get a score not for the right answer, but for the process of attaining the answer. Consider it most important to build a ladder of answers to all the questions. This ladder has to have two special characteristics: the first is the absence of a breakdown in the logical process, the second is the presence of some sort of sudden twist. Remember the solution to *Problem #7*: We arrived at the conclusion of *friction-without-friction* early in the IFR statement. Common sense diverts us away from this idea. Yet, we continue our search for *friction-without-friction,* for *movement-without-movement.*

Problem #9

Air pumped into a fish tank allows us to keep many fish in a relatively small space. The notion to use this principle to intensify industrial fish farming in lakes and ponds floated-around for a long time. The problem was that this is a very uneconomical process: only a small portion of air has a chance to dissolve in the water, while the majority of the air returns back to the atmosphere. For home fish tanks, this is not that important — a small electric pump can provide an adequate amount of air. But a different scale applies to lakes and ponds. They require building powerful air pumping stations and the installation of complex pipeline systems.

The problem requires a different method, simple, economical and, of course, safe for fish. Therefore, it is not particularly recommended to use oxygen-producing chemicals.

This example problem is simple. Try finding a solution *without* analyzing it using the Contradiction Matrix.

Problem #10

Wood, cloth –and recently, plastic and resins –are all used to polish optical glass. A water emulsion of the polishing powder is introduced into the areas of contact between the polishing tool and the glass.

However, these traditional methods are quite far from perfect. The polishing process is done at a relatively slow speed because resins, cloth, wood, and plastics lose their required abrasive properties at the higher temperatures produced by high tool RPM.

How can the polishing speed be increased?

Probably, you immediately began to think about introducing a cooling liquid: let's have an emulsion composed of the polishing powder and a cooling liquid, instead of a plain water emulsion. This method already exists and does not provide the best result. Imagine a polishing tool in the form of small "pillow" that rotates at high speeds *tightly pressing against the glass.* How can a cooling and polishing emulsion be supplied? From the side? But, the heat is created under the "pillow" —the area where the polishing tool is pressed at this time. Make holes through the pillow? Here, we have our contradiction: the more holes, the better the distribution of cooling emulsion —and, at the same time, the worse the polishing tool performance (because it will consist mainly of holes). In another words, a polisher with holes is not the best idea.

This is also a simple problem. This time, solve it with the help of the Contradiction Matrix.

Problem #11

Rugged enclosed containers and heavy safes are used for testing the strength of materials under high temperatures and in chemically aggressive environments. A weight is attached to each testing sample, and then the container is filled with the aggressive substance. It is then hermetically sealed and heating elements attached to the container walls are turned on. The weight is between 0.02 kg to 2 kg.

The basic difficulty during such experiments is determining the moment when the testing sample breaks. Although this does not require precise accuracy, it is desirable that the breaking moment be determined within a couple of seconds because the test can continue for several days. Another complication is the difficulty of guarantying the sense reliability of devices placed inside of containers with aggressive mediums. It is necessary to generate the signal outside of the container. An apparatus for detecting the noise of the falling weight is also not acceptable —it is too complex and unreliable.

Let's say, for example, that the container has the dimensions 0.4 x 0.3 x 0.3 meters, and a wall thickness of 10 mm. We are required to find a simple and reliable method for registering the moment our sample breaks. Remember, making holes in the walls of the container is not allowed.

Begin analysis from ARIZ *Step 2-3*.

Problem #12

There is a pneumatic conveyor. It is made in the form of an inclined pipe. Small products move from the lower to upper ends of the pipe under air pressure from the bottom of the pipe. In our case, tomatoes are transported through the pipe. The pipe extends between floors of a building, and changes direction in several places. The shortcoming of this system lies in the tomatoes rubbing and hitting against each other, and finally getting spoiled.

A pneumatic transportation system is required that moves the tomatoes (or other products) under pre-set program conditions, with an absolute guarantee that the products will travel slower than a specified velocity, and with a safe distance between them. It is undesirable to remove the pneumatic transportation system because this might require new equipment that we do not have.

Start solving the problem from ARIZ Step 2-3.

Problem #13

Delay lines are used in high-frequency electronic schematics. They are used to time-shift an output signal. The delay line is a sandwich-type device: layers of low and high resistance materials (for example, sandwiched pairs of glass and steel, or Wood's Alloy and copper). The thickness of these layers must be between 0.1mm and 0.01mm, with high manufacturing accuracy.

Already known production methods (compression, roll, etc.) are expensive, low in productivity, and produce a lot of rejects. The sandwich composition cannot even be made from some pairs. Sandwiched materials in pairs usually have high differences in melting temperature (glass = 800°, and steel = 1500°; Wood's Alloy = 70°; and copper = 1,083°). Wood's Alloy will easily melt if a red hot plate of copper is placed on top of it.

A completely new concept for manufacturing the delay lines is required.

This problem is more complex than previous problems: barriers on the road to its solution are relatively high. Begin the solution process at ARIZ *Step 2-2*.

Problem #14

A petroleum pipeline does not always carry just one type of oil product. Therefore, it was proposed that an alternating "sequential" transport system be designed where different crude oils are sent through the same pipeline, one after another, in a so-called "abutting" system. This method had a significant advantage: instead of several parallel pipelines, only one need be built. However, alternating transport systems were not widely used at the time.

The reason for this is that, when transporting one fuel after another, a mixing of the products occurs in their area of mutual contact. Therefore, a complex technical problem arises. For instance, how can it be accurately determined where the pure gasoline ends and the diesel gasoline starts? Where diesel product ends and pure gasoline begins again? How can we separate the mixed from the pure product, and avoid contamination of the fuel that previously filled the storage reservoir, in a timely manner?

Until 1960, a manually operated control was used in almost all major pipelines. During each pumping cycle —both day and night, and in all kinds of weather conditions —laboratory workers in control stations sat in dismal manholes taking analysis of oil samples. It was done primatively: a sample was taken in a flask directly from the pipeline, and product density was determined by the level of a floating buoy in the flask. However, density differences in light fuels are insignificant, and therefore it was almost impossible to determine the boundary of the oil mix. As a result, during one pumping cycle of oil through a 500-meter pipeline, 800 to 1,200 tons of pure oil was spoiled.

Several concepts were proposed. In one instance, an oil-density meter was offered. This device would install at the neck of the pipeline and determine the type of oil by its density based on the float concept. A gamma-density meter was also offered. This devise is based upon the gamma radiation of radioactive isotopes, and determines the type of the product by radioactive density. There are also ultrasonic devices that measure the speed of sound transmission in fluids.

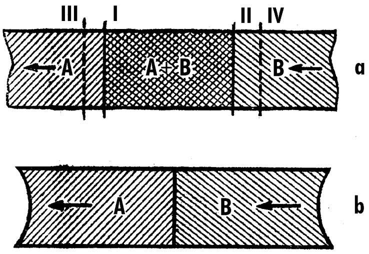


Figure 30. *How can we reduce losses of oils transported through the same pipeline?*

Look at *Figure 30.*Two different abutting oil products, *A* and *B*, travel through the pipeline. Mixture, *A+B*, is formed in the area of their contact. If it would be possible to accurately determine the boundary between I and II, then the loss would not exceed the volume of this mixture. However, because of low accuracy in controlling the boundary separation of the oil, the mixture must be started earlier (line III), and finished later (line IV), than what is theoretically possible. By improving the method for controlling the mixture, line III will come closer to line I, and line IV to line II. Losses are now reduced; however, mixture *A+B* is still there. It is better to use a by-pass direction: avoid the formation of mixture *A+B* altogether by utilizing some sort of separator between *A* and *B*.

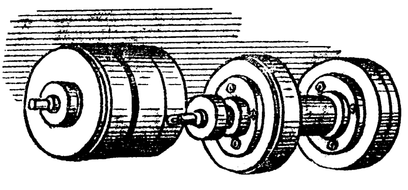


Figure 31. Separators with collar and disk seals.

There are already known separators (*Figure 31*) having collar, disk and brush seals. However, these "jags" have major shortcomings: they do not prevent the formation of a mixture —oil still seeps through the seals; "jags" stack-up inside the pipelines and, in some places, cannot pass through. Several intermediate pumping stations are located throughout the pipeline. It is clear that solid, rigid separators cannot pass through these stations.

Installing flexible partitions along the pipeline is an expensive, complex and unreliable concept.

Liquid separators, like water and ligroin (a solvent of naphtha), were proposed. At first glance, this seems to be a good solution. To prevent the mixing process, it is enough to have just a small quantity of liquid separator — 1.5% of the pipeline volume. The problem here is that water, ligroin and other liquid separators will mix with the oil products during transport. Of course, it's no loss to throw away the water after it has finished its job as separator, but how can the oil be separated from the water?

In conclusion, both solid and liquid separators have serious drawbacks. Gaseous separators are no good at all: gas rises to the top of the pipeline and stops performing its separator action.

Begin analysis of this problem from ARIZ *Step 2-3*.

Part 2-6:
"Patented" in the Paleozoic Era

The number of inventive patents issued around the world totals about 13 million. Let's assume that one patent description can be read in five minutes. At this rate it would take nearly 125 years to become acquainted with the entire fund of world patents.

However, there is another "patent fund." It holds so many inventions that mankind could not know it all throughout our whole existence. This is *the patent fund of Nature.*

Humans have used ideas "patented" by Nature for a long time. The number of inventions with direct prototypes in Nature probably numbers in the tens-of-thousands. Yet, only a tiny fraction of Nature's "inventions" are used —just those that lay in plain view.

Until quite recently, the following dominating opinion existed: The same problems in Nature and technology are resolved in different ways. In fact, technical solutions are, more often than not, just like natural ones. What is quietly —and imperceptibly —attained in Nature, often is linked in technology to the use of enormous temperature, pressure, or a huge energy loss. In another words, they are associated with "big potentials." These "big potentials" appear far more impressive than the barely noticeable adaptation of a few insects.

It has long been considered a truism that copying Nature lies outside of mainstream technological development. That's why, when solving new technical problems, inventors usually never even attempt to use solutions already reached in Nature.

Which direction is more preferable: the traditionally technical, or the way that all "living machines" have developed?

As an example, let's compare the wing of an airplane with that of a bird. A contemporary airplane wing is one of humanity's greatest technical achievements. But no airplane can compete with birds for the amount of weight lifted per unit of power input. If a contemporary airplane's wings flapped, they could lift 120-130 kg of cargo per 1 horsepower generated by the engine. So far, the wings of the most perfect machines are able to lift only one-tenth this amount.

Nature's particular, and huge, superiority is in designing "control and measurement devices." A grasshopper's hearing mechanism catches vibrations having an amplitude equal to one-half the diameter of a hydrogen atom! It's no wonder that engineers designing precision instruments were the first to systematically study and incorporate Nature's principles. This is how bionics was born —as a science for solving engineering problems using methods borrowed from Nature.

Bionics initially was only occupied with modeling sense organs. Now, its list of solved problems is considerably broader. Bionics undertakes problems relating to a variety of technological fields, all with only one problem solving technique in common —the use of Nature's prototypes.

As a matter of fact, the 8th step of ARIZ —the Operating Stage —could be stated like this: *it's necessary to approach inventive problem solving from a bionic position*. Theoretically, everything here should be simple: the inventor merely borrows a pre-existing solution. In practice, one needs to find a suitable prototype in Nature before one can borrow it. It appears that, even though this method is indisputable, it cannot be practically used all the time.

Hundreds of exercises and real-life industry problems have been solved at seminars on inventive methodology —yet not once was the use of a prototype from Nature suggested! Indeed, after problems are solved, it is not often possible to identify a natural analogue for the new idea. This strengthened existing confidence that the solution was correct, but did nothing else.

Why is that?

It seems that the emergence of bionics should have immediately produced a cascade of stunning inventions in all technological fields. But, only cybernetics has yet produced any noticeable results from the use of bionics. Here, bionics has become a reliable compass for the researcher. In other technological fields, living prototypes have not been used any more than when the expression "imitating natural models" was used instead of "bionics."

All one has to do is read a few books and articles about bionics to find the same modest list of examples: ultrasonic detection as used by bats, the humming gyroscope of a fly, whale-shaped ships, dolphin skin design for reduced water resistance, and the artificial jelly-fish "ear" that warns of approaching storms.

Significantly, an invention, as a rule, had already been made. Only afterwards was its natural prototype found. For example, the principle for a method of lowering surface resistance was proposed by Kramer as far back as 1938 —and in 1955, the same Kramer discovered that dolphins had also "used his idea."

Imagine a patent library in which billions of different patents are arranged on shelves in an order unknown to you. Exactly such a "patent library" exists in Nature, and can be "imagined" by any inventor who tries solving a new technical problem.

There hasn't yet been a reliable method for selecting living prototypes. Therefore, it appears that, in the majority of cases, an inventor can more easily find a solution by himself then find a suitable "Nature patent."

And yet, the Operating Stage of ARIZ includes a bionic step. There are two approaches facilitating orientation in Nature's gigantic patent fund:

1. Search for prototypes among *ancient* animals. Old "Nature patents" are simpler and effective.
2. Examine *general tendencies* in the development of "Nature patents." It's very difficult to find a readily existing solution, but the tendencies of Nature's evolutionary can almost always reveal an analogy with technical evolution.

Let's discuss this in detail.

Ancient Greece developed splendid inventions for its time: battering rams for smashing gates of besieged fortresses were made with ends that looked like a live ram's forehead. History shows that such rams withstood their impact load perfectly . . . .

Unknown ancient Greek "bionics engineers," when they created such a ram head, probably reasoned as follows: "It's necessary that the ramming beam will not split-up and flatten under impact. Where could we find something like this? At grazing places, rams clash foreheads —and nothing happens. This is the best prototype that one can think of . . . ."

So far, this has been the method used when selecting living prototypes: try locating the best possible "original." Let us assume that a biologist points out a sufficiently perfect life prototype to an engineer. Is it usable? No, because such prototypes, as a rule, are complicated. It's very difficult to examine their designs in detail, and sometimes it's impossible to build their copies.

That's just what has happened in attempts to copy dolphin skin. In this "Nature patent" there is much that remains mysterious even today. Gradually, it became clear that dolphins possess an ingenious and complicated system of skin damping. Nerve endings penetrating the skin perceive changes of pressure, transmitting corresponding signals to the central nervous system, which then regulates the skin's damping process. In practice, it is impossible —as well as uneconomical —to imitate such a complicated prototype.

In selecting the most perfect Nature prototype we use the most recent volume of Nature's patent library. It's no wonder that Nature's technical evolution appears incomprehensible —we are reading it backwards!

Meanwhile, when solving the overwhelming majority of problems, it is not necessary to use perfect —and therefore too complicated — prototypes. It is more worthwhile to use as prototypes those Nature analogies that are relatively less perfect, but simpler "patents," like those of ancient animals studied in paleontology.

The Paleobionic method, first of all, greatly broadens the "patent fund of Nature." For example, among existing animals there are none as large as the brontosaurs and indrycotherium. But, the main advantage of paleobionics is that it offers an inventor significantly simpler (and, therefore, more easily reproducible) prototypes.

We shall consider an example: While staying at a resort, inventor A.M. Ignatiev was playing with a kitten. The kitten scratched him. The inventor became thoughtful: why are the cat's claws, woodpecker's beak, and squirrel's and hare's teeth constantly sharp? Ignatiev came to the conclusion that self-sharpening takes place, thanks to a multi-layer tooth structure. Hard core layers are surrounded by softer layers. While working, the hard layers bear a higher stress, while the soft layers bear less stress, and the initial sharpening angle has not changed. Ignatiev embodied this principle in self-sharpening cutters.

The inventor (and this is very common) was seeking the *most perfect* prototypes. That's why the "patent" of Nature he used was complicated, and self-sharpening cutting tools found only limited applications.

The rodent prototypes actually used by Ignatiev are quite ineffective compared to some dinosaurs. Large dinosaurs weighed tens-of-tons, and lived 150-200 years. It isn't difficult to imagine the large amount of food they had to grind during their lifetimes.

Especially interesting are the teeth of sauropods, a kind of "hoofed" dinosaur. Each sauropod tooth row consisted of three sets of teeth, each above the other. Triple-crown drills haven't yet been made, but tests of double-crown drills (called leading-blade crown drills) are already on the way. Using such crowns almost doubles drilling velocity.

Another special feature of the "patent" belonging to sauropods is that their cutting organs were constantly growing and replacing themselves. This principle is exceptionally interesting. Up to now, the work of inventors in making improvements to drilling instruments followed a path having a common technique: "As the drill's teeth become dull, let's quickly pull the drill out and replace it."

There are hundreds of inventions about how to "quickly pull out the drill." From the bionics point of view, there should be another approach: make the teeth more durable and self-sharpening. Sauropods suggest an even more interesting solution. Let teeth be placed in several rows. Each row rests on a soft base. When the first row's teeth wear out, several rotations of the drill bit will destroy the soft base. The drill sags, and a second row of teeth comes in contact with the ground (i.e., *new teeth are grown*).

Recently, Soviet inventors J. Bushtedt, A. Atiaekin, L. Lachian, and N. Litvinov received Author's Certificate, #161,008 for a Double Crown Drill.

The formula for this invention precisely repeats the ancient "patent" of lizards: "A two-stepped drill crown comprised of a body and two rows of cutters. This invention is different because it has a shock absorber pillow made from a soft substance placed under the lower row of cutters for temporary support. This prevents the upper row of cutters from breaking down when working under a load."

Contemporary animals yield significantly to dinosaurs in size. They are not so voracious, and manage with only one set of teeth that sometimes continue to grow throughout their lifetime. Only giant elephants have the changeable teeth "patented," once upon a time, by sauropods.

Swordtail lizards are now encountered only on the east coast of North America and in Asia. This animal was once a contemporary of dinosaurs, as well as a contemporary of dinosaur's closest "relative," trilobytes, who became extinct in the Paleozoic era. In spite of constantly changing living conditions, this lizard has survived on up to our present day –200 million years without almost any substantial changes.

The eyes of this lizard are of special interest. It has two large, complex eyes on each side of its armor shell, and two small eyes in front. Each eye has multiple separate lenses. The lizard's eyes are very sensitive. This puzzled scientists for a long time because the animal spends most of its life buried in sand.

Prolonged study of the lizard's eyes led the American scientist Hartlaine to an interesting discovery. It appears that the cells of its optical nerves are cross-connected. When one cell is stimulated, the other one shows inhibition. Thus, the retina receives a distinctly contrasted image. This discovery led to the creation of a television system with extremely contrasting images. It has been hugely significant, transmitting photographs from other planets back to earth.

Further research determined that the animal's eyes catch ultraviolet and infrared rays invisible to humans. Besides this, the American scientist Waterman discovered that the lizard also senses polarized light, allowing the animal to find its way when there is no sun or starlight. Research continues, not precluding the possibility that the lizard's eye may someday serve as a prototype for other complex electronic devices.

As a rule, ancient animals yield to contemporary ones in the development of their brain and nervous systems. In all other respects they are quite perfect and can serve as prototypes for technology. Moreover, in many instances, extinct animals surpass their descendants in all respects. Such animals became extinct not because their "construction" was worse than others; they became extinct from climatic and topographical changes. In some cases, they were exterminated by humans.

It's necessary to say that "perfect" and "imperfect" concepts are very conditional. What is imperfect from Nature's point of view often appears perfect from the technological point of view. The wings of a lizard-pterosaur, when compared with bird's wings, were imperfect only because the slightest damage to the skin membrane hindered their flight.

But contemporary technology has a different assortment of materials. With the use of these materials it is more sensible to *not* copy bird's wings, whose detailed construction has, thus far, not been understood. Instead, it makes more sense to copy the smooth wings of such perfect "flyers" as the extinct *ramphorenx*, or the still existing, although with an ancient pedigree, dragonfly.

Many extinct animals have been well-studied. Almost every Museum of Natural History has dinosaurs' teeth, for example. Inventors who solve problems associated with the processing of materials (grinding, cutting, etc.) could find many interesting ideas "patented" by Nature tens of millions of years ago.

Here is Author's Certificate #189,353:

> *"The bucket of an excavator differs by having its middle section of semicircular cutting-edged teeth placed close to each other, with a central pair of them moved forward. This allows for an improvement in the insertion of the bucket into the ground."*

Here, it isn't hard to see the familiar idea of a leading-blade in combination with a very old "patent" of Nature —a pair of teeth grown forward (i.e., incisors, fangs, and tusks).

❧

The Paleobionic method does not prohibit the use of contemporary animals as prototypes. It's only suggested that we select the most ancient prototypes.

Bionics produced substantial results only when ancient animals were used as prototypes by chance. Such a prototype that produced practical results was a device reproducing the "infra-ear" of jellyfish. And jellyfish are ancient animals —they swam in Cambrian seas.

Ship designers, when copying whales, were successful, in essence, thanks to the unintentional application of Paleobionics: long before the emergence of whales, Ichthyosaurs had the same body shape. The retinotron (a device that is able to "notice" only moving objects) is considered to be an imitation of the frog's eye. However, the precedent for this invention belongs to Tyrannosaurus Rex.

There is one more example of when an ancient animal used simple means to solve a complex problem: antiflutter adaptation of the dragonfly. These adaptations are very simple. The tips of their front wing's is thickened by a chitin (ptero-stigma) that dampens harmful wing vibrations. Engineers, by themselves, came up with the same idea. It was sufficient to attach a lead weight into the wing (in the corresponding place where the dragonfly has its ptero-stigma) to avert the danger of flutter.

Interestingly, the earliest and fastest dragonfly "models" do not have ptero-stigma. If we had chosen the most perfect prototypes, the "patent of the ptero-stigma" would still remain unnoticed because only such "outdated models" as neuropteran and dragonflies have ptero-stigma.

In general, while examining live prototypes in their historical place in evolution, we find that one Nature "patent" has often been replaced by another.

Ancient floating waterbugs had drop-shaped, streamlined bodies. But their descendents gave up this technologically traditional body shape. The bodies of contemporary waterbugs are narrow in front and wide in the rear. This is probably a very effective body shape.

Experiments show that removing two tiny ledges in the wider rear portion of the waterbug's body increases its resistance to movement by 122 %. This is a paradox: the cross section area of a "fuselage" decreases, yet its resistance increases!

A Paleobionic approach is particularly beneficial in circumstances when it's necessary to solve an inventing problem associated with little-studied phenomena. Here, natural prototypes can become principal sources of reference. This has been proven by the history of the invention of protective anticavitation layers for hydro-construction.

There is still not enough research on the cavitational disintegration of concrete dams. The numerous methods of protection offered by various inventors have turned out to be either too expensive or unreliable. V.I. Sacharov found a successful solution to this problem. Here is how it was described in an article about this invention:

> *"Once, at the Black Sea shore, V.I. Sacharov noticed that stones and boulders covered with seaweed and moss had hardly deteriorated at all from wave impact. Bald stones lying nearby were spotted with furrows and holes. Nearby tender moss had saved the stones from destruction. It was just one step from here to the technical realization of an idea already achieved in Nature."*[1]

Sacharov, with Author's Certificate #279,443, exactly reproduced an ancient "patent" of Nature:

> *"Cavitation resistance in the coating of surfaces (i.e., concrete and reinforced concrete in hydro-constructions) includes a protective layer made out of cantilevered elastic rods, fibers or plates. This prevents immediate contact of cavitational vortecies on the construction body by creating a layer of immobile water."*

---

[1] *Knowledge & Power*, 1971, #2, Page 7.

From Nature's prompt to the technical realization of an idea in just one step. So, why was this step taken so late? Was it really necessary to come into immediate contact with the existing natural solution in order to "see" it? Concrete is man-made stone. Therefore, in order to find the correct answer, it is sufficient to merely ask the question "How have stones in Nature been protected from cavitation?" Old stones covered with moss "live" to old age precisely because moss protects them from deterioration. One could come to this conclusion even being far away from the Black Sea.

Step Eight of ARIZ's Operative Stage recommends that the inventor not only find an ancient prototype, but also defines the evolution of Nature's designs. It's necessary to determine *how* and *why* Nature kept changing this or that prototype. In his letter to me, paleontologist A.G. Ponomarenko gave an interesting example of such an analyses. (*Figure 32a*)

> *"In creating a bug's elytron (wing sheath)," writes Ponomarenko, "Nature was faced with the problem of developing a light, stable, and inflexible covering. There are several stages of this development:*
>
> 1. *A thin plate reinforced with irregularly located longitudinal tubes.*
> 2. *Tubes stretch along the elytron.*
> 3. *The number of tubes decreases, and are transformed into rigid ribs.*
> 4. *The rib tips become wider.*
> 5. *The rib's upper sections unite resulting in a frame structure with vertical hollow columns.*
>
> *This structure is light and quite strong."*

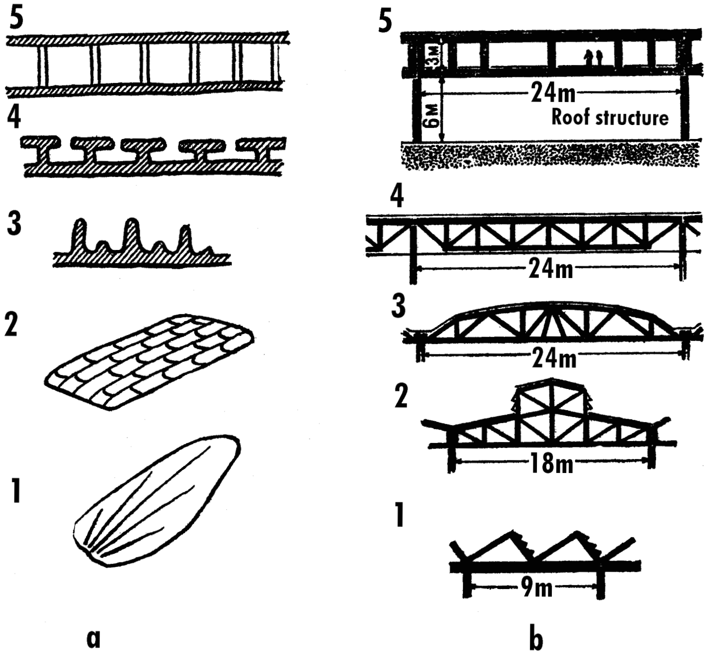


Figure 32. *Evolution of construction in Nature and technology:* ***a.*** *This is how the elytron (wing sheath) has evolved.* ***b.*** *This is how overlapping constructions evolved.*

Drawing 32b illustrates the development of floor frames. It's not difficult to notice that the development of the two structures (natural and engineered) have much in common. This is not a coincidence: the goals are the same (lightweight, strong); therefore, the solutions are similar.

There is a relatively modest role given to the bionic method in ARIZ-71. But bionics develops fast. The number of published works is increasing, more "patents" of Nature are gradually being decoded —and the general principles fundamentally used by Nature in solving inventive problems are becoming recognized.

In the near future, the possibility of significantly improving and developing this part of the algorithm will present itself. Then, the algorithm will be enriched with a quite effective table demonstrating how this or that contradiction has been removed in accordance with a "patent" of Nature.

Part 2-7:

Breaking an Old Structure

Invention is not an end in itself; it is needed to solve practical problems. Generally speaking, given two inventions providing the same technical effect, the one that improves an already existing system —and is thus supported by a proven technology —is preferable. Such an invention is easy to implement, and produces significant positive economical effects.

Then, how does a transition to a completely new and original system happen?

Some times, the development of these systems is based on new scientific discoveries. However, more often these systems emerge out of old discoveries —the same way as a butterfly emerges from a cocoon.

Let's name the initial system A_1. It is an assembly comprised of various different sub-assemblies (i.e., a car composed of the sub-assemblies engine, transmission, controls, etc.). Each one of these sub-assemblies is itself composed of sub-assemblies. The transmission, for example, includes a clutch, gears, driveshaft, and so on. And each of *these*, in turn, also consists of several components.

An invention can relate to a single element, sub-assembly, or a more complex structure. As a result of several partial innovations to the whole system, the system gradually improves. Symbolically, we can represent this with the series: A_1, A_2, A_3, . . . A_n. Finally, invention A_{n+1} appears (corresponding, as in prior steps, to only a single detail, block, or part of a system). But this invention creates the necessity, or the possibility, of substantially changing all the other parts. Thus, A_{n+1} becomes B_1, and begins a new series: B_1, B_2, B_3, . . . B_n.

Usually, a new technical idea will relate to only one portion of a basic system. However, this partial change in the system often creates the possibility (and, sometimes provokes the necessity) to change other parts — any object that works together with the newly changed part. Moreover, the possibility to change the application for which the original object was intended sometimes appears. A chain reaction has happened: an initial partial change initiates a series of more changes. As a result, an initially weak idea becomes more powerful.

An inventor starts this synthesis stage of his creative work after a technical idea is found that solves a problem. In many cases, the idea at first appears to be incomplete —model A_4 transitions to model A_5. However, the transition to model A_5 opens-up possibilities for making one or more obvious steps: alter one part (i.e., make it lighter, or more compact), or position it differently. Spending more time in making the transition from A_4 to A_5 purchases the "rights" for an easy transition from A_5 to A_6, or A_7. In some cases it is possible to jump immediately from A_5 to B_1.

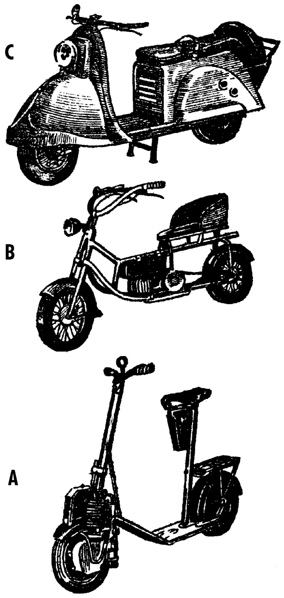


Figure 33. *How the scooter kept improving:*
a. *1920 model.*
b. *Intermediate model.*
c. *Modern scooter.*

Unfortunately, the newly found idea is often not utilized to its full capacity. The inventor makes only a transition from A_n to A_{n+1}, and then stops. Meanwhile, a new model of system A_{n+1} is ripe for substantial change: a cocoon may become a butterfly; however, it remains a cocoon because due to the inertia of the inventor's thinking ability. *Figure #33* shows the first scooter, developed in 1920. It is not difficult to see that it looks like a conventional children's scooter with an added motor. Motor scooters did not appear all at once. Using our symbols, there were models A_1, A_2, A_3 . . . . A_n. When an engine was placed on a child's scooter, model A_n became model A_{n+1}. However, the child's scooter still remained a scooter: its other parts (and the overall scooter as well) did not undergo any changes.

Of course, a child's scooter *with* a motor is better than a conventional scooter. However, the possibilities in this partially realized idea were little realized. Notice, for example, the high position of the seat. Originally, this position was dictated by the work posture of a person performing the engine function. Then a transition was made from model A_n to A_{n+1}: an internal combustion engine is placed on the child's scooter. Why does it need a high seat? It is not necessary for a driver to stand, he can sit. Lowering the seat lowers the center of gravity, making the machine more stable and easier to control. In turn, this creates the possibility of utilizing a more powerful engine, now that the space under the seat is available due to the leg room area shifting forward. It is also difficult and cumbersome to protect a standing person with a windshield. Here is another element available to a sitting driver: it is now possible to install shields that also substantially reduce air resistance.

Thus, an invention that replaces one part of a system (i.e., the engine) leads to a cascade of changes in other parts —and consequently, ripples throughout the whole system. On the other hand, instead of "*leads*," it is more precise to say "*could* lead." In practice, the fate of the child's scooter was quite different.

A partial invention (like the replacement of an engine) stays partial for a long time: A_n becomes A_{n+1}, and that's it. In later models of the motor scooter, the seat gradually lowers, and the engine gradually shifts under the seat towards the free space that was "specially" intended for this it. One of the intermediate motor scooter models is shown in Figure 33b. The engine "walked out" from the front wheel; however, it has not yet reached rear wheel. The driver almost sits on the engine, yet there is free space under the seat.

For almost three decades, the motor scooter was an uncommon toy. In reality, if it is necessary to sit on top of the engine, why do we need a motor scooter when we can ride a motorcycle? Finally, the engine, having finished its journey, has now settled under the motor scooter's seat. This machine took on a contemporary form (*Figure #33c*), as well as a new quality that the motorcycle does not have. It's possible to completely enclose the engine, creating a very comfortable space for the driver's legs. It's now possible to protect this space with a shield. The vehicle becomes more stable, and more comfortable. One can even ride it wearing white clothing. The motor scooter is now starting to successfully compete with motorcycles, particularly in cities.

The story of the motor scooter is not an exception. In the majority of cases, inventors, after solving problem and making partial changes, resist making other changes, no latter how obvious and logical they seem. So, at first automobiles were made of common carriages: the horse was "unharnessed;" the motor "harnessed." In the front part of some automobile designs, a statue of half-a-horse's body was placed.

The first motorcycle was a conventional velocipede (an early bicycle). The only difference was that its pedals were pushed not by a human, but by an internal combustion engine.

Figure #34 shows one of our newest inventions — a machine for seam welding plastic film.

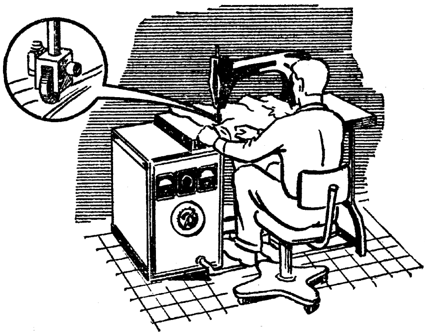


Figure 34. *A new, and contemporary, idea is dressed in an archaic design form.*

This ultra-contemporary, progressive idea utilizes high-frequency current to weld plastic parts, yet it's enclosed in an antiquated design. When plastic parts were stitched together with a thread, a common sewing machine was used. But now, the main working element of the machine has changed in principle — instead of a needle and a thread, a wheel has appeared through which high frequency current is applied. Here, using our symbolism, we don't talk about a transition from A_n to A_{n+1}, but a leap from level A to level B — or even C. However, there wasn't a jump. Instead, as is typical, the "horse-mobile" was developed.

The original design of the sewing machine was stipulated by a human functioning as an engine. The shaft of the machine was turned by the right hand. The left hand advanced the cloth toward the needle. In the foot-driven machine, the original design was appropriate. However, in the machine shown in *Figure 34*, the seam is made with a high-frequency current. Why, in this case, must a person have to sit as if they were functioning as the engine?

By hiding all electric control systems under the machine, the entire system becomes more compact, and it is possible to cover it with a single housing. Sitting can be more comfortably arranged on the left side, in immediate proximity to the working element of the machine. Here is where a person serving plastic sheets to the welding machine must sit.

* * *

The Synthesis Stage is unique. In contrast with the other stages, it is not, generally speaking, necessary. The new technical idea resolving an inventive problem appears before the Synthetic Stage. Once the idea is found it is possible to begin its design implementation. This is exactly how it is done in most cases. As a result, the invention remains only partial; although it can become the first link in a long chain of other inventions.

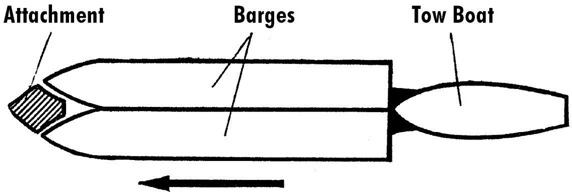


Figure 35. *Streamlined attachment*

For example, a method was proposed for pushing two barges alongside each other. However, a wide gap appeared between the bows of the barges that resisted motion. It naturally seemed the next step should be taken to cover this gap with an attachment that streamlines the caravan. (*Figure #35*). However, this idea (Author's Certificate #288,575) appeared only recently.

The Synthesis Stage adds uniqueness if its steps are simple and independent from each other. The main idea is to not forget to do them. Suppose that a new technical idea brings a machine from stage A_3 to A_4. As a result of the Synthesis Stage, *almost every inventor* can now make the transition from A_4 to A_5. Further advancement will depend completely upon the knowledge (theoretical and practical) of the inventor.

* * *

An inventor can set two different tasks when solving a problem. If the original subject is considered as A_n, the task can be formulated as follows: "Make a transition from A_n to A_{n+1}, or even further develop it into A_{n+2}." A different task may also be set: "By-pass all level steps from A_{n+1} to A_{n+m}, and immediately make the transition to level B_1."

Sometimes people ask, "What is better, to improve an existing machine (or method) or search for something completely new?" This is like asking, "Which is better —to shoot from 5 meters or 500 kilometers?"

Everything depends on the specific conditions —and most of all, on the goal set by the inventor or organization trying to solve the problem. If it is required that a problem be solved as fast as possible, it is better to improve the original prototype. The Ideal Final Result in this case has to be formulated as follows: "Whatever is present minus any shortcomings," or, "Whatever is present plus some improvements." With this type of task statement, a problem is solved relatively fast (often on the Third Level), and the implementation of the invention may not create any problems. If it is required to obtain a quantitatively new effect, it is more expedient to giveup the original prototype that ties one to the conditions of the problem. **An ideal machine (method) has to be considered as a prototype**. In these cases, the "outside environment" can very often be considered as an object in an IFR: "An outside environment provides such and such action by itself." The phrase "outside environment" helps to get rid of an old, worthless prototype —and helps us understand what the new machine (or, new method) must do, and how it has to perform.

By acting this way, it is possible to reach the fourth, or fifth, level of innovation. However, in this case, implementation of the invention will require much more time. The design has to be made from scratch, and tested and redone many times, while overcoming the doubts and skepticism of those who are used to staying within the framework of improvements to the old prototype.

Both directions are good and depend on specific circumstances. However, if after A_n there follows B_1, and not A_{n+1}, then no attempt to improve the prototype (in other words, to invent within the framework of *A* while *not* making the transition to *B*) can bring positive results.

Historians and patent attorneys have found that when a prototype is young it changes easily and fast: in fact, many invention improvements appear in a short period of time. A so-called "patent pinnacle" was also observed. Based on this fact, some scientists tried to forecast the developments of technical systems: the steeper the rise in the curve of Patents and Author's Certificates, the greater the future of the technical system. Unfortunately, when level A_1, A_2, . . . reaches B_1, the "patent pinnacle" also appears. Inventors work hard, and the numbers of inventions grow fast, but with inappreciable result.

Today, this kind of "patent pinnacle" can be seen, for example, in the cement industry. A contemporary cement kiln is made like a gigantic rotating pipe (250 meters long by 7 meters in diameter). Along the axis of the pipe, there is a slowly moving raw material above which rushes red-hot gas. Even a non-expert can visualize how difficult it is to transmit heat from the gas to the raw material because the gas only makes contact with the upper layer of the material. To improve the thermal energy transfer efficiency (upon which the kiln's productivity is depending), it was proposed a long time ago to suspend a wall of chains inside the kiln. Metal chains help transfer thermal energy from the gas to the raw material. After that, there was a pause in innovation that stretched for several decades. When someone wanted to further increase the efficiency of thermal transmission, they simply increased the number of chains. In a contemporary kiln, the total chain weight is over 100 tons. Here the "patent pinnacle" happened: a stream of inventions all proposed hanging the chains in the following ways:

> "Chain barrier is made with additional chains attached to the main chains, and then freely suspended between them." (Author's Certificate #226,453).
>
> "The end of the chains are attached to a flexible element made out of chain." (Author's Certificate #260,484).
>
> "Chains whose other ends are attached to the body of the kiln." (Author's Certificate #310,095).

Chains pile upon chains here just as, before the steam engine was invented, sails piled-up over sails.

The more chains in the kiln, the more the gas heat can be utilized. However, the more chains, the higher the resistance to gas flow. To provide better conditions for gas flow, there should be no chains at all. To provide higher heat transfer from the gas to the raw material, the entire kiln space must be filled with chains. Here is a clear technical contradiction. Therefore, if a stream of similar inventions cannot conquer contradictions, this signifies that the developmental resources of the technical system (*chain barriers*) are exhausted.

For inventors (that is, for a team solving problems on an inventive level) it is extremely important to know about the logistics of technical evolution. It is necessary to forecast new technical tasks, to choose direct or by-pass routes to a solution, to make a proper analysis of the problem, and to successfully implement the found idea.

There are many technical systems, and they are all different. However, they all have something in common: all of them are **systems**. Through a *systems* approach, technical objects can be considered as complete organisms obeying laws of evolution. A flashlight, an engine, a diesel locomotive, a chemical plant –all these are examples of technical systems. Outwardly, they have no resemblance to each other. One thing that unites them is that they are systems. This is much more than the arithmetic sum of their components. Let me explain through an analogy. A water molecule is a system, but not an arithmetic sum of two atoms of hydrogen and one atom of oxygen. A human being is a system, and not the simple sum of skeleton, muscles, heart, and so on. In the same way, any machine is a system —a complete organism —and not just the sum of its parts.

Any technical system —whether a sewing machine, coal mine or railroad network —evolves in a certain sequence. A general schematic of technical systems evolution is in Appendix 2. Let's analyze it.

The history of any technical system starts from . . . *its absence*. This is the first, pre-system, level. Inventors, little by little, improve some elements; although, by unifying these elements into a system, it is possible to obtain a new effect. Here is a typical example: It is necessary to maintain a certain temperature to preserve fodder prepared for the winter feeding of livestock. The fodder produces a lot of heat; therefore, it is necessary to cool and ventilate the silos. Inventors in different countries worked for many years in this direction. There are patents on complex (and unreliable) systems to support these requirements. Meanwhile, other inventors created a system to insulate and heat barns for cows and pigs. Finally, the idea to create an integrated new system appears in Author's Certificate #251,801:

> *"An agricultural farm consists of a building to house livestock, and a silo for the storage of fodder. This system differs by having the fodder storage in the form of a row of several silos incorporated into the walls of the building that houses the livestock. This invention allows for the utilization of bio-thermal heat from the fodder for improving the micro-climate of the livestock building."*

The system "silo/building" now possesses a new quality: it is necessary to neither cool the fodder nor heat the building.

When a system is developed it seems at first to be natural; however, to see how a future system will evolve from out of its separate elements is not quite so simple. Here special skills are required to see the problem from an ARIZ perspective —I call this ***ARIZ mind***. One similar case, described by inventor M. Sharapov, was published in the newspaper *Magitigorsk Metal* on April, 26,1969.

Sharapov writes that a plant utilized water transport to remove ash and clinker. During its design stage, engineers assumed that pipelines would wear out because of friction. To increase the pipelines life expectancy it was suggested they be periodically turned, and the transported clinker crushed in advance in special crushers. However, the pipes did not wear-out. On the contrary, crust inside the pipe built-up. Another problem arose: How can the hard crust developing inside the pipeline be removed? It was hammered off —which was very difficult work. Water containing large particles of clinker to scrape off the crust was flushed through the pipe. This was not laborious work, but it interrupted the production process.

Knowing the methods for solving inventive problems, Sharapov approached this problem differently. The IFR was clear: the pipe must clean itself. One other thing also became obvious: If the battle to remove a harmful factor is unsuccessful, it then becomes appropriate to remove "a chisel with a chisel"—in other words, remove one harmful factor by combining it with another harmful factor. There is no other harmful factor here. Therefore, this pipeline has to be connected with *something* —a system must be created where "a *minus* plus a *minus* produces a *plus.*" The simplest way is to find a pipeline that is not covered with crust, yet wears out. *Wear* plus *growing crust* will produce exactly what we need —a self-cleaning system. It was easy to find pipes that wear-out: pipes for the hydro-removal of coal waste products. They wore-out so badly that once it was even decided to get rid of the hydro-transport system completely and replace it by trucking out the waste.

Two pipelines were placed side-by-side. But, one team of experts fought with the growing crust in the pipeline used for transporting ashes and clinker, and concentrated only on that. The other team of experts wrestled with wear in the pipeline used for removal of coal waste, and also could see only their pipes.

Sharapov offered (in Author's Certificate #239,752) to run the hydro mixtures alternately. First, there was the base-water carrying the ashes and clinker, and producing crusty sediment on the pipeline walls —a protective lining. Then, this lining — not the metal of the pipe —was scraped with acid-water carrying coal waste. Then, a lining was developed again. Now it is possible to transport one material, change the acid-water for the base water, and take turns depositing and removing the lining. This invention is now successfully used in several plants.

Remember:

> **If the number of attempts to improve an object grows fast, but instead of improvements, one contradiction is only replaced with another, it is necessary to combine this object with another object to form a new technical system.**

This type of transition is not always possible to achieve right away. Very often, an unstable transitional system appears first from the separate elements. In the table in Appendix 2, formulations of these systems are shown in parentheses, and stable systems shown in brackets.

An example of system transitioning from Level One to Level Two is the steam engine submarine built in the 19th century. Inventors seem to naturally use the most advanced engine, and this steam engine was exactly that. The choice for an element to be included in the system must be based not on the efficiency of the system, but on the perfection of the main system characteristic. In a submarine, this type of characteristic was the energy reserve for each underwater run. No one could successfully created a significant reserve of steam in a boiler, and therefore a large supply of energy. Yet, an imperfect electric motor with heavy batteries was (by this characteristic) the most powerful choice. The system "submarine and steam engine" was unstable; it took a long time for another system to appear—"submarine and electric motor with batteries."

Sometimes, the missing element of a system can be replaced by a human being. The first self-propelled vehicles had steam engines. They were heavy, bulky, and largely incapacitated. A stable system of the Second Level was the velocipede, where the weight of the engine equaled zero.

The history of technology shows a great number of unstable systems appearing during the transition from Level Two to Level Three: a *comedic* steamboat, a *walking* locomotive, an *optical* telegraph with flapping levers. In attempting to replace humans with machines (i.e., make the transition to Level Three), inventors even now balk at the border, and the machine only *copies* human actions. This is caused not by the inability of system evolution, but simply by the psychological inertia of inventors. Sometimes these inventions are elegant. Their common shortcoming is a limited number of reserves for development. If this type of system happens to be a prototype, it almost always makes sense to look for a new concept of action, and not just improve the existing one.

The Third and Fourth Levels are most typical for contemporary technology. Young systems of Level Three are the most typical of contemporary technology; mature systems are specialized, and old systems are overspecialized. Narrow specialization is a sure sign of the necessity to make the transition to the next higher level —a sign for the general reconstruction of the entire system.

We can illustrate this with an example from the glass industry. During the production of sheet glass, a red-hot glass ribbon comes along a roller conveyor. Moving along the conveyor, it takes its required shape and gradually cools off. It is clear that the quality of the glass depends upon the distance between rollers. If the distance is too large, the glass ribbon will sag and become wavy. A smooth surface requires rollers of a smaller diameter placed closer to each other. However, this conveyor will be more complex and capricious in its operation. We again face a clear technical contradiction. For a long time, inventors attempted to overcome this contradiction by creating specialized conveyor lines for different types of glass (there are kinds of glass that do not require an ideal surface) while providing manufacturing plants with machines that polish the glass after it cools off. Later, a really revolutionary solution was found.

Let's imagine a reduced roller diameter —a centimeter, millimeter, one-hundredth millimeter, and so on. How complex must the conveyor be having rollers of one-hundredth of a millimeter? Here there is a psychological barrier: one-hundredth of a millimeter is frightening to think about. But, a micron, or a tenth of a micron —this is unimaginable. What if the diameter of the roller is even smaller? Like a molecule, or perhaps an atom? To manufacture a conveyor with rollers a micron in diameter is practically impossible. But, if the diameter of the rollers equals the size of an atom, everything becomes simple because it is not necessary to manufacture atoms. Let the glass roll on atoms as if on balls. Instead of a conveyor, use a tub of melted tin. The glass ribbon moves over an even layer of atoms. It is not necessary to build a conveyor, nor is it necessary to adjust and repair any rollers. Liquid metal is not only an ideal conveyor, it is also an obedient instrument. The surface of metal (and therefore, the surface of glass), can take any shape with the help of electric magnets. An excellent invention! It immediately created a "patent pinnacle." Hundreds of patents have been issued on different glass producing tubs.

At the fourth level, technical systems begin growing rapidly until they reach a certain moment when their growth can, for the first time, create conflicts with the outside environment.

From prehistoric times, technology development has been based on natural resources. Our planet has an abundance of water and air; therefore, our technology is "watered" and "aired." Water and air still remain our major technological instruments. Our planet has a lot of oxygen; therefore, our technology is "oxygenated." Oxygenation processes were, and still are, the bases of our energy. Our planet has lots of space —and technology utilized, and still utilizes, open systems. The outside environment provides substance and energy for our technical systems, which then throw back into the environment the refuse of that substance and energy. The environment then processes and destroyes our refuse.

Nature is the Universal Cleansing Mechanism that is automatically connected to any new technical system. This Universal Cleansing Mechanism possesses a seemingly gigantic, unlimited surplus of power. And now, when more and more technical systems are reaching the ceiling of the Fourth Level, the Universal Cleansing Mechanism is reaching its system limitation, and has exhausted its resources.

The conflict between technology and nature is touching the deepest primordial bases of our technical civilization. To overcome this conflict, it is necessary to make a transition from a "watered" and "aired" technology to a "waterless" and "airless" one; from "oxygenated" to "non-oxygenated;" from an open ended technical system to a closed one. This transition was inevitable from the moment humanity stepped into outer space. Even if Earth-based technology could get along with Nature, cosmic conditions will require technical systems that work in space anyway**. The bases for future technologies will be to provide closed systems**. Their "closedness" will be achieved not by merely filtering already existing systems, but by making radical changes to those system's technological foundation.

Here are untouched strata of inventive problems.

Here are hidden problems whose solutions will require great inventions.

Part 3

Man and Algorithm

We have shaken loose your mental filters,
and as a result, the answer appeared.

This method works, and it will always be effective.
What is necessary is to get rid of your excess load of prejudice
and petrified garbage in your head; change the tuning
of your mental filters in relationship to ways you're inclined
to act —and then, it will be possible to find the necessary
answer to any problem you may desire to investigate.

✑ *R. Johns*

Part 3-1

Psychological Barriers

In one of my seminars on the Theory of Inventiveness (TRIZ), the following problem was offered:

> *"Let's assume that 300 electrons, in several groups, must jump from one energetic level to another. However, a quantum transfer has already taken place by two groups less than were originally calculated; consequently, each group now has five more electrons. How many electron groups were there in total? This complex problem has not yet been solved."*

Participants in the seminar —all highly qualified engineers —declared that they were not going to tackle this problem. "This is Quantum Mechanics, but we just come from mechanical factories. Since others could not solve this problem, it would be impossible for us."

Then, I read them this algebra problem:

> *"To send 300 scouts to summer camp, several buses were reserved; however, two buses did not show up at the required time. Therefore, each bus took five scouts more than was planned. How many buses were sent?"*

The problem was solved immediately. Inventive problems always have an intimidating tinge. There is a clear subtext in any mathematical problem: "It is possible to solve me. Similar problems have been solved more than once before." If a mathematical problem is "undefeatable," then everybody believes that it cannot be solved. In an inventive problem the subtext is completely different: "People have tried to solve me, but nothing happened. It is not in vain that smart people believe nothing can be done here."

An article was published in *Inventor and Innovator* magazine about the problem of unloading frozen cargo. Its author explained this problem as follows:

> *"This is one of those eternal problems that have annoyed miners, steel workers, railroad workers and coke chemists for many years —the unloading of frozen cargo. Sometimes, the life and death of many a company depends upon this process."*

Furthermore, different suggestions were described without finding any useful applications ("There were many attempts to solve me, but nothing happened"). The article ended as follows:

> *"Time passes rapidly on. Secrets of the atomic nucleus are discovered. The sensitive ears of radio telescopes listen to the whispers of the farthest galaxies. Yet today, ore is still unloaded the old way, and the whole world still breaks it with pry-bars and sledge hammers."*

From the beginning, an inventor is warned that he is facing "one of the eternal problems." The problem was not even described, and nothing specifically said; however, the inventor is already intimidated in every respect. Not everyone can show the bravery needed to conquer an "eternal problem"—an undefeated problem, even in the time when "secrets of the atomic nucleus are discovered, and the sensitive ears of radio telescopes listen to the whispers of the farthest galaxies!"

The problem of unloading frozen cargo really is an "eternal" one. However, "eternal" does not mean difficult. It happens, of course, that for a long time the problem was not solved in spite of larger numbers of suitable attempts. These cases are very rare. An industry brings up only those problems for which conditions for solving them already exists. Marx wrote: "Society always raises only those problems for which the ability to solve them exists because, under closer scrutiny, it always happens that the problem only appears when the material conditions for its resolution exists — or, at any rate, exists in process of development"[1].

If, over a long time, the problem was still not solved, this means that the wrong search direction was chosen. In this case, even a simple problem may seem "eternal." The same thing happened, for instance, with the meniscus telescope. It could have been invented, as Maksutov mentioned, by contemporaries of Descartes and Newton; however, the invention was made only in that period when the "sensitive ears of the radio telescopes listen to the whispers of farthest galaxies . . . ."

The more eternal the problem, then usually the easier it is to solve. As a matter of fact, when the problem appears, the conditions to solve it already exist. Each unsuccessful attempt to solve it reduces the degree of uncertainty along with the search field.

Time passes by, and the degree of difficulty in solving the problem gets smaller —but, the arsenal of technology continuously grows. This means that the relationship between these powers has changed: the problem itself becomes easier, while the means to solve it increases, becoming more powerful. Rarely are there problems in industry that are impossible to solve —even in the future. It is impossible to break the basic laws of nature — the Law of Conservation and Law of Dialectics; for other types of problems, the impossibility is only temporary.

* * *

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[1] K. Marx, "Critique of Political Economy," *Gospolitisdat*, 1952, page 8.

“Whatever a human being can imagine, others can make reality.” These words belong to Jules Verne. They are true. The history of science fiction gives vivid examples of the transformation from the “impossible” to the “possible.”

In general, the following can serve as an illustration:

		Fate of science fiction ideas					
Science fiction authors	**Total number of ideas**	**Came true, or will come true in the near future**		**Confirmed possibility of the general concept realization**		**Found erroneous or unrealizable**	
		Numbers	**%**	**Numbers**	**%**	**Numbers**	**%**
Jules Verne	108	64	59	34	32	10	9
H. G. Wells	86	57	66	20	23	9	11
Alexander Beliaev	50	21	42	26	52	3	6

A hundred years of science fiction history has witnessed this:

The bold idea has a higher probability of realization than the conservative one.

Jules Verne’s idea to shoot astronaut capsules by cannon is considered a classic example of the “impossible.” Nevertheless, a young scientist, Gerald Gowll from Montreal University, announced the possibility to use a cannon for just such astronomical investigations.

In comparison with the achievements of space technology —placing multi-ton satellites in orbit, walking in space, landing on the Moon —the spaceship fired from Jules Verne’s cannon does not seem so impressive. However, cannon space technology has a good future: for each manned spacecraft, dozens of pilotless crafts are built. It is simpler, and more effective, to launch by the Jules Verne method.

An article was published about the American and Canadian experts who started project *Harp*. This project aimed at utilizing cannons with barrel diameters of 127, 178 and 408 mm to probe the atmosphere.

The completed design has a cannon with a barrel 150 meters long. It weighs 3,000 tons, with a diameter of 814 mm. According to their calculations, this cannon can send a container, with apparatus weighing 7.5 tons, to a height of several hundred kilometers —or, it can deliver a half-ton satellite into Earth orbit. The cost of such a satellite delivery is only $50,000 —including the cost of the satellite.

In other words, had Jules Verne’s idea not been considered impossible, there probably would have been satellites of several dozen kilograms sent into Earth orbit by the second decade of the 20th Century.

Here, it is worth remembering that rocket ships could have appeared much earlier. It is not without reason that the prominent Soviet researcher Yuri Vasilievich Kondratiuk wrote in 1928:

> *"Sorting through my mind the remarkable achievements of science and technology in the last few years, and asking the question of why the problem of interplanetary transport has so far not been solved, I come to this conclusion: because of a lack of audacity and initiative."*[1]

Lack of audacity and initiative held back the appearance of the quantum generator (laser). A directed thermal ray idea was expressed by Herbert George Wells in 1898. Twenty-one years later, Albert Einstein theoretically substantiated the physical process for developing the quantum generators. Lasers, in C. Town's opinion, could have appeared at the end of the second decade of the 20th Century. In 1951, the Soviet scientist V. Fabricant applied for a patent on the quantum generator and received a rejection: the patent expert considered the idea for his invention to be unfeasible. Later, the expert changed his decision, and the inventor got his Author's Certificate.

The "impossible" idea of science fiction author Alexander Beliaev –an amphibious human being –is now very close to realization. It is interesting to follow, step-by-step, the way the "rating" of his idea has changed. Here are three excerpts published at different times by the same person, who is an engineer and author of several inventions:

> **1958:** ". . . not an amphibious human, but people equipped with an apparatus for underwater diving and swimming, will conquer the unknown ocean depths."
>
> **1965:** "Amphibious humans do not exist yet, and maybe they will never appear at all . . . ."
>
> **1967:** "Today, man tries to dive very deep without any diving gear, breathing under water like whales do. Maybe someday, real "Echtianders" (the amphibious humans in Beliaev's SF story) will appear with the help of medicine, chemistry, and technology. The ocean will surrender itself to those people for whom water and air will become the same habitat element."

In less than ten years, the assessment of this "impossible" idea changed completely. Now its assessment is nearer reality.

There are no unsolvable problems; however, the history of an invention often begins with someone proclaiming, "Impossible!"

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1. Kibalchik, Tciolkovski, Tcander, Kondratiuk, *Selected Works*, M., Science, 1964, page 539.

The reasons that force people to proclaim "impossible" and proof of impossibility are different. Sometimes, simple ignorance is responsible. This is how, in the second decade of the last Century, when scores of locomotives were built, the influential British magazine *Quarterly Review* was able to flatly assert:

> *"There is nothing more funny and foolish, than to promise to build a locomotive that will move twice as fast as a postal carriage. It is also less probable that English people will entrust their lives to such machines, and allow themselves voluntarily to be blown out in a rocket."*

Soon after, the Stephenson locomotive "rocket" ran passenger trains at speeds of 40 km/hour.

When inventor Alexander Graham Bell began to sell his devices, one American newspaper requested that police stop this "charlatan cheating trusting citizens." The newspaper said:

> *"The statement that a human voice can be transmitted though conventional metal wire from one place to another should be considered highly humorous."*

In spite of this, ignorance is not the major cause behind people saying, "Impossible." More often, this is said by people who cannot really be suspected of ignorance. In O. Picard's memoirs, the inventor of the stratospheric balloon and the bathysphere wrote the following lines:

> *"Experts at the time found my concepts impossible. Things that are elementary for us today, in previous times appeared Utopian. The single objection brought up against me was that my concept did not yet exist. How many times I have heard this objection!"*

◆

What forces knowledgeable and non-conservative persons to not believe in a new development?

Here is a typical example. Several years ago, one of the leading experts in the automotive industry wrote:

> *"Suppose it is necessary to determine the diameter of a wheel for a future automobile. It is a known fact that, from year to year, a reduction of wheel diameters can be observed when considering the wheels of different automobiles during the past 50 years. However, this reduction becomes less and less pronounced, and the moment arrives when it stops completely. Meanwhile, there was a short period during which wheel diameter was sharply reduced. If the study is limited to only this period, it is possible to arrive at a wrong conclusion –that, within 20 years, the diameter of the wheel will reach zero."*[1]

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[1] Y. Dolmatovski, *Novel About an Automobile*, 1968, page 214.

Let's closely follow this thought process. The basic idea is absolutely correct: the diameter of an automobile wheel keeps getting smaller from year to year. Knowing this tendency, it is possible to look into the future. Then the logical conclusion follows that a moment will come when an automobile will loose its wheels. Here, the "impossible" appears. First of all, how can there be an automobile without wheels —if such a vehicle "does not exist yet?" Second, the actual wheel diameter reduction becomes, over time, less pronounced. This means it's also "impossible" for the diameter to reach zero.

Now, let's try to sort through these conclusions.

In reality, wheeless automobiles have never existed. We are so accustomed to this that it is difficult to imagine an automobile suspended in air over a road without "anything" supporting it. But that is not the bases for the categorical word "impossible." We simply do not know how to do this. However, getting rid of the wheels is very intriguing. They only play a service role. Therefore, the tendency toward wheel-diameter reduction is not accidental, and we should not expect this tendency to go away. It is true that wheels cannot, practically, be reduced after reaching a certain limited size. The concept itself, inherited from automobile wheel design, enters into conflict with the tendency of automobile evolution.

The history of technology has many examples of one or another design that "did not want" to continue its development. The outcome was always the same —the design was rejected. Besides, if an automobile's wheels contradict the progression of a technological tendency, this means the time has came to think about wheel-less automobiles.

This conclusion is completely supported by real life. Wheel diameter, "impossible" as it may have seemed, did reach zero size: new automobiles moving on an air suspension (hovercrafts) appeared.

There are two directions in the evolution of technology — *evo*lutionary (inside one level), and *revo*lutionary (a transition from one level to another). Schematically, this development can be shown by a complex line with a large number of turns. Experts in a narrow field sees those directions within one section of the line very clearly. Thinking about the future, they tends to see that future develop out from the present —as if, in their mind, a continuation of the last section of line. Understanding the limitations of an existing technology, experts clearly see unsolved problems as a wall into which their mental extension line abates. However, the dialectics of technological evolution are such that "unsolvable problems" are solved with the help of a by-pass method —in principle, by a new technological means. This is exactly why some experts consider those problems which cannot be solved by any means known within an industry to be unsolvable.

The "impossible" appears so only because people do not know *how it* *can happen*; therefore, they say beforehand that this *generally cannot be*. But, we must assume that it can be —we just do not yet know exactly how.

The inventor must overstep the word "impossible," and temporarily forget about it. Sometimes this is enough to almost automatically reach a new technological idea. Of course, it may happen that the road to the solution will be long and difficult. But, any long journey always begins with the first step.

* * *

Theoretically, all this is simple: just don't be afraid of the word "impossible." In practice, bravery accumulates gradually during the process of solving problems that seem unsolvable.

Let's remember the problem about winding wire on a ferrite ring. This problem was solved during seminars at the Institute of Mathematics at SO Academy of Science, USSR. Analysis led to the conclusion that the problem contained the contradiction "Productivity vs. Accuracy." The winding is actually done by hand. If we want to increase the winding speed, we sacrifice the quality or accuracy of the winding process: the wires will be positioned improperly. The Matrix[1] contains the contradiction type "Productivity vs. Accuracy of manufacturing," correlating to Principles #18, #10, #32, and #1. Principle #1 (Segmentation) is excluded by the conditions of the problem —cutting the ring is prohibited. Principle #10 (Prior Action) is also excluded because it is impossible to perform the winding before, or during, the process of making the ring. Principle #13 (Do it in Reverse): don't wind the wire, but unwind it? This is also no good. Principle #31 (Utilization of Magnets and Electromagnets) is also unworkable.

The following dialog then occurred between the instructor (**I**), and the student (**S**) attempting to solve the problem:

S: Maybe I stated the wrong contradiction?

I: Well, try to state it differently.

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[1] *Lev Shulyak comments:* While translating this section of the book, a discrepancy was found while matching suggested Principles with those printed in the Matrix. Two principles were not listed —#13 and #31. When contacted, Altshuller revealed that this was an example with historical significance. It was the first problem solved with the original ARIZ-68 Matrix. Later, ARIZ-68 showed that the Matrix can, and must, be flexibly modified. In Altshuller's words, "just like the Nautilus is mobile and immobile in Jules Verne's *Twenty Thousand Leagues Under the Sea*." What is important in this example is the logic of the thought process. We have translated and published this part exactly as it first appeared in the original edition.

S: We can say: "The smaller the diameter of the ring, the lower its productivity. The contradiction now is 'Length vs. Productivity.' The Matrix suggests Principles #13 and #28. We can try another contradiction: 'Length vs. Speed' —Principles #13, #14, #34."

I: So what?

S: (*Unresolutely*): The Matrix suggests Principle #13, which means "Do it in Reverse." But that's impossible.

I: Why?

S: We have to wind a wire, but "Do it in Reverse" means, in this case, to unwind it. To unwind requires making extra loops. Where do they come from?

I: You have to think how to get the extra loops.

S: It is impossible without winding the wire first.

I: Please, think some more. Maybe this is just the *Predawn Effect*. You need a ferrite ring with windings. How can this be done?

S: If winding is excluded . . . I don't know.

I: Think.[1] Imagine a toroid with extra loops.

S: That is simple.

I: What does it look like?

S: A ferrite ring with wire windings. I would say, with extra windings.

I: What does it mean with *extra* windings? Imagine that visually.

S: With *extra* means with many loops. Loop placed next to loop without any gap. Maybe like this: All of the ring is covered with a thin layer of metal. This is like an infinite number of loops.

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[1] In the beginning of mastering ARIZ, similar situations are often found. A person solves a problem by themself; however, it is necessary to repeat: "Please, think; please, do not stop halfway through."

I: See, this is good. It seems that an infinite number of loops can be made without winding. All that's left is to remove the extra loops.

S: Spiral thread . . . .

I: (*Without antagonism*): Is this possible?

S: Of course. There are different methods other than just mechanical ones. We remove metal, making "empty" windings over each layer of metal. This is much easier than winding the wire. It is possible to cover this ring in advance with a thin layer of photo-sensitive film, and then project on the top and the bottom of the ring an optical image of loops.

I: This means that Principle #10 ("Do it in advance") can be applied, as well as Principle #28 ("Replacement of Mechanical System with an Optical System").

S: Possibly. However, the Principle "Do it in Reverse" fits better. This is a typical example of how to do it in reverse.

You begin to solve a problem. The first step is not yet finished, but you think that everything will come together later. You think that any direction may be chosen. However, this is a delusion. Even in the case of "stripping away" the conditions of the problem from the *evident* tendency, inertia forces one to take the direction of a *non-evident* (but existing) tendency of the problem.

The problem is initially stated through known terminology. These terms are not neutral, they preserve the contents belonging to them. The real invention an come only when old terms, or their combinations, are given new contents.

The inertia belonging to technical terminology can at first be explained through the inertia of our thinking process. An inventor "thinks by way of words," and these words —invisible to the inventor —push him in a certain direction. More often, this is a direction belonging to previously known technical ideas for which this terminology was devised. It is no accident that Engels wrote, "In science, each new point of view brings a revolution in its technical terms."[1]

Let's recall the winding problem. From the very beginning, the statement of the problem forces the inventor to choose a specific search direction. It is required *to wind* a wire—as stated in the conditions of the problem. Why

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[1] K. Marks and F. Engels, *Collected Works,* Book 23, page 31.

to wind? Only because of a tendency in terminology: originally, all known methods were based precisely on the winding process. A new problem was formulated in old terms. Meanwhile, the winding is in itself not necessary, only a ring with a spiral is required. Why should we complicate the problem by introducing the additional requirement of getting a ring having spirals made only by winding?

Of course, if we had asked this question at the beginning, we would have said: "The *windings* are unnecessary —it is only required that we have a ring with a wire spiral . It is unfortunate, however, that this dangerous tendency of terminology only becomes visible after the problem is solved. In the beginning, everything seems natural: the winding must be required —what else?

At one of the seminars, the problem of bringing an oil pipeline over a canyon was analyzed. Conditions of the task stated that the presence of pillars and a suspension support were excluded. Usually, in this case, the pipeline takes the form of an arch (with upward curvature, or, for long spans, downward curvature). However, the condition of the problem also stated that the pipeline must span the canyon without curvature.

The solution was trivial: "The cross-section of the pipeline must be increased."

Next time, the same problem was formulated differently: "An oil line has to be installed 'without anything' and 'without curvatures.'" Therefore, only one word was replaced: instead of "pipeline," "oil line" was mentioned.

Now, this was among the solutions:

> *"The strength depends on the area and shape of the oil line's cross-section. The cross-section area is prohibited from increasing under the stated conditions of the problem (*weight increase*). We can change the line's cross-sectional shape. Let's have a hollow I-beam. Then, with the same metal consumption for one unit of length, the carrying capacity of the oil line increases. However, this shape is difficult to manufacture. The I-beam shape in this part of the line can be made out of two pipes (smaller in diameter than the main line) positioned one over the other, and connected with vertical ties."*

Here is the result of the replacement of only one technical term with a common word! In the first case, the word "pipe" was present in the formulation of the problem. Although it is not necessary for an oil pipeline to be shaped as a pipe, engineering train of thought is such that it has difficulty "derailing," in spite of the less prospective solution direction chosen. As soon as the word "pipe" disappears from the formulation of the problem, the inertia of the thinking process is extinguished. In the inventor's field of vision, it's now easy to find a simple —and, in this case, new thought — **an oil line may not have to be shaped like a pipe.**

An inventor must consider the tendencies of terminology in order to direct thought through a conventional channel. It is necessary to have control over all the stages of ARIZ; when following through a process, prevent the "seepage" of special terminology. The formulations of every step must be simple, and free from technical terminology.

Experience with solving inventive problems during seminars shows that the best results are obtained when common words are used instead of jargon. Then, after a new idea is found, it is possible (and necessary) to return to precise terminology.

* * *

It was noticed long ago that many inventions were made in three steps. First, an inventor intensely and unsuccessfully searches for a solution. Then, having not solved the problem, he stops thinking about it. Some time passes, and suddenly, as if a delayed-action mechanism goes off—"as if by itself"—the required solution appears. Here is what Helmgoltz said:

> *"Each time, I first have to turn my problem over on all sides, examining it in such a way that all its turns and intertwining are strongly stored in my memory and could be again recalled by heart, without the help of notes. To reach that state is usually impossible without long preliminary work. Then, when my tiredness is gone, it is necessary for one hour of complete physical refreshment and feelings of wellness—and only then the good ideas come. Often, they come in the morning, after awakening, as mentioned by Gauss (who established the Induction Law in the morning, before arising)."*

We can offer another typical example. The prominent Russian bacteriologist, S. N. Vinogradski, for a long time tried learning the physiology of sulfur bacteria when there was little known about it. "I learn," wrote Vinogradski, "how to feed them with hydrogen sulfide, watch how fast they fill with sulfur, and then how fast the sulfur disappears without the presence of hydrogen sulfide." However, the working function of sulfur bacteria was not revealed for a long time. "There was no progress. I felt tired from that. Then, as a relaxation, I spent more time in the chemical laboratory, were I did analytical exercises. One day, I was walking home for dinner and, while reaching an embankment, I recalled the hydrogen sulfide water that remained in a glass on the table. It became cloudy from the precipitated sulfur, and then cleared up due to oxidation by the same sulfur. At that moment, as if tipped by this trivial fact, suddenly, vividly and brightly, the thought sparked in my head: My bacteria burns the sulfur into sulfuric acid. Then, their entire physiology opened-up in my mind. Furthermore, everything now went smoothly, and in several days the work was finished."

The three phases of an inventor's creativity (search, waiting period, illumination) are revealed very clearly. This is the only characteristic of creativity that can be seen from the outside. It's no accident that this three-phase process serves (obviously, or not) as the basic point for all those explanations of creativity that focus the whole process down to one thing. Usually, only the last phase is highlighted: "*suddenly an idea appears*." Others, on the contrary, see only the first phase: "you must search, try, test. . . ." Finally, there is one more "explanation" —stressing the second phase: "You must observe, look into surroundings, keep the problem constantly in your mind —and something will trigger a solution . . . ."

Now, having learned about inertia of the thinking process, we can objectively examine the mechanics of the creative process.

A problem is formulated with terminology possessing inertia, and secretly forces thought into the direction opposite to where new ideas are present. This is why the first phase of the creative process (if done unsystematically) usually does not lead to the solution.

Let's show the conditions of the problem as follow:

A⇆B⇆C⇆D

Each letter can represent, for example, a part of a system, while the arrows between them symbolically show an existing interaction. As a result of the first phase of the creative process, the basic structure is not yet broken. The interaction between the parts of a system is slightly reduced, or loosened. New conditions can be written, like:

A↔B↔C↔D

The second phase starts. The inventor almost doesn't even think about the problem. Here, the positive role of inertia appears. A weakened interaction between the parts continue to get weaker, until they are broken completely:

A B C D

Now the inventor can easily reposition the parts, change the character of the interaction between them, and so on. As a result, (without difficulty) a new formation of the system appears:

C⇆A⇆D⇆B

When an inventor works at random, a lot of time is needed to break the habitual "bonds." ARIZ does the breaking process deliberately and systematically.

Part 3-2

The Power of Fantasy

It has become a textbook maxim that fantasy plays a large role in any creative activity, and in technical science as well. But there is a surprising paradox here. The recognition of fantasy's importance has not been accompanied by a systematic effort focused towards its development.

So far, the only widespread, and practically effective means for developing fantasy was the reading of science fiction literature (SF). Incidentally, a clear correlation is seen here: scientists and engineers are more attracted to SF than other readers. Several years ago, the Committee of Technical-Scientific Literature of the Azerbaijan Writers Union conducted a survey that resulted in the following: 20 percent of all engineers and physicists preferred SF to other literary genres.[1] There are half as many SF readers among doctors —nine percent.

Fifty-two percent of the engineers and physicists surveyed mentioned that they value SF first of all for its new technical-scientific ideas. Really, in this regard, SF can give the thinking engineer quite a lot: a project that can be developed, or even a ready solution that can be transferred into engineering language.

Recently, there was issued patent #1,229,969 in the FRG (Federative Republic of Germany) having the following formulation: "A method of mining mineral resources from an astronomic source. This invention differs by choosing as a site an asteroid with a small mass, and having such an orbit that it is economically possible to transport the asteroid to the Earth." The person familiar with SF literature will immediately notice that Jules Verne ("The Golden Meteor") and Aleksandr Beliaev ("Star KEZ") should be co-inventors of this patent.

This can be reinforced with many similar examples. For instance, in the novel *20,000 Leagues Under the Sea,* Jules Verne for the first time expressed, and substantiated, the idea of a double-shelled hull for a submarine. The patent on double-hulls was issued 30 years later to the French engineer Leboeux. His description of the idea in the patent did not have any more detail than Jules Verne's novel. A similar fate befell another idea described in the same novel: provide electric power through the

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[1] G.Altov, "*Fantasy and its Readers*," in *Problems of Sociology* #2, Novosibirsk, Science, 1970, page 79.

temperature differential between ocean surface water and deep water. Thermoelectricity was known, of course, before Jules Verne. But he was the first who suggested the idea of using the temperature differential of the ocean. Later, at the opening ceremony of the power station utilizing this principle, the designer pointed directly to the Jules Verne novel as the basis for his work.

There are well-known cases of the close interaction between science fiction and technology. In one of M. Shiverov's SF novels, a device for sleep learning was described. At Shiverov's request, the engineer E. Brown designed and built the "Sleep-phone" —a combination of clock-driven gramophone and audio head set, and R. Eliot used this device to teach students during sleep.

Very often, the ideas of fiction writers are directly used during the early development stage of a new field of science and technology. At some period (although, for a very short time) fiction becomes one of the main sources for an emerging new area of knowledge. A similar thing happened, according to testimony by V.V. Parina and R.M. Baevskogo, with astrobiology: "Our fiction writers described in their novels many 'Cybernetic' ideas that can, and must be, used in astrobiology. For instance, the problem of controlling anabolism plays an important role, not only for enabling interplanetary flights, but also for space flights of long duration in the same solar system that are possible even during this Century. Unfortunately, most detailed investigations of this problem were not done in scientific literature, but in Ivan Yfremov's novel *Nebula of Andromeda*."[1]

Of course, science fiction does not always contains correct and mature ideas. Often, they are most doubtful from a scientific-technological point-of-view. Or, they are completely symbolic ideas offered to readers. Moreover, often fictional ideas are completely wrong. In spite of that, because of their singularities and brilliance, they attract the attention of researchers, and force intensive research that sometimes leads to important discoveries or inventions.

The Lenin Prize winner, Yri Denisiuk, once said "I decided to create an interesting project for myself by undertaking a gigantic —verging on the impossible —problem. I recalled an almost forgotten Yfremov story . . . ." He is talking about the novel *Shadow of the Past.* In a cave, as the result of a rare combination of circumstances, a photo-camera effect appeared: a narrow entrance into the cave played the role of lens, and the wall opposite the entrance, covered with a resin, became a gigantic photo film, memorializing moments of a long past epoch.

Denisiuk looked at this phenomenon differently: Is it possible to get an image without a lens? Research led to discovering a holographic application. The first stimulus, however, was made by the novel. "I am not discarding,

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[1] News of Science Academy of USSR, Biology series, #1, 1963, page 13.

on the contrary, I am confirming with pleasure the unusual participation of Efremov in my work."

SF helps overcome psychological barriers on the road to "crazy" ideas without which science cannot continue its development. This is an admirable, and so far, little acknowledged function of SF that becomes a component of the professional training of scientists.

Usually, the impact of fantasy resides in its reaction with real "working" thoughts. The essence of this reaction can be understood when Academician B. M. Kedrov's schematic of the creative process is used.[1]

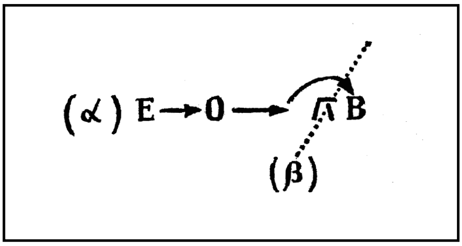

Figure 36. *Diagram by academician Kedrov.*

While searching for a solution to a problem, human thought follows along a certain direction (α) from single facts (E), revealing something special (0) that these facts possess. The next step has to be the determination of commonality (B), in other words, the formulation of a law, theory, etc. The transition from (E) to (0) should not present any difficulty; however, the further step from (0) to (B) presents a psychological barrier. This requires a springboard (λ) that allows us to overcome the barrier. Very often, an accidentally appearing association can become this springboard. This association appears at the intersection of line (α) and another line of thought (β).

Science fiction literature works very well as line (β).

When *Problem #7* was presented during a seminar, one of the listeners formulated an IFR as follows:

> *"The contact, by itself, closes the terminals with minimal friction."*
>
> *I asked, "Why not without any friction, instead of "minimal friction?"*
>
> *They answered that "The conditions of the problem stated that the contact must touch the terminals. If a physical contact is present, friction must be present as well. We cannot get rid of friction completely —why should we state an unrealistic IFR?"*
>
> *"Why," I insisted, "can we not imagine a touch as tight as possible, yet without any friction —and at a normal temperature without super fluidity?"*
>
> *Some other seminar attendants began to object: "It looks like the substance of the contact must penetrate through the substance of the terminal … . How can this be imagined?"*

A strong psychological barrier arose, and the solution went on hold.

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[1] B.M. Kedrov, The Theory of Scientific Discovery, Series of *Science Creativity*, M. "Science" 1969, pages 78–82.

Then, I told a story from the science fiction novel of E. Voiskunckogo and I. Lukodianova, *Mekong Crew*. This novel described a device that gives to any being or object the characteristic of permeability. The hero of the novel, being permeable, was crossing a street, pondering, when he collided with a moving bus. To the surprise of those around him, the man passed through the bus as if nothing had happened!

Somebody recalled other fictional novel –another "permeable man." A movie was recalled about a man that moved through walls . . . . In three minutes, everyone clearly imagined "permeability," and it was possible to return to our problem. "Now you can see that the contact must (in its ideal state) go through the protruding terminals. Let's make a drawing. *Step 3-2*."

SF plays a role in the experimental field of modeling problematic ideas. Some of these ideas, in time, develop into scientific hypothesis (when speaking about technology, they develop into improvements, projects, inventions, and so on); in other words, they completely transpose into areas of science and technology. Often, SF effects the creative process from the side, slowly reducing psychological inertia, and increasing sensitivity to something new. On Kedrov's diagram, this increasing openness to something new can be shown as a reduction in the height of the perceived psychological barrier, and the development of an ability to create a self-springboard; in other words, to overcome a barrier without the immediate outside influence of line β.

It is wrong to say that SF is an irreplaceable creative tool for science and technology. However, it is, without doubt, one of the most important tools. The recording and careful analysis of SF ideas is long overdue.

In 1964, I started to create a *Registry of Contemporary Science Fiction Ideas*. Today almost all interesting ideas are registered in the list. They are separated into12 Classes, 75 sub-classes, 406 groups, and 2,360 sub-groups. This analysis answers the question: "When has a fictional idea become successful, and when has it not?" Moreover, some of the patterns in the generation of fictional ideas become clearer.[1]

❧

Reading science fiction undoubtedly helps to develop the creative imagination; however, it cannot replace systematic training. Imagination must be systematically developed through special exercises.

An attempt in this direction was made by John Arnold, a Professor at Stanford University. Arnold's method suggests solving inventive problems while in the environment of an imaginary planet, Arktur IV. This imaginary planet is different because it has some very unusual conditions: Its surface

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[1] G Altov, *Paints for Fantasy*, Fantastic-71, M. Molodaia Guardia, 1971.

temperature is 100° lower than on Earth, its atmosphere consists of methane, its oceans are made of ammonia, its gravity is ten times stronger than Earth's, and its intelligent beings are birds. It is necessary to overcome many psychological barriers to think about automobiles, or houses, for Arktura IV. Systematically solving problems, Professor Arnold's listeners gradually developed the knowledge to overcome their psychological barriers.

Unfortunately, Arnold's method is very narrow. In essence, this is only an exercise with variations.

To provide for an effective development of the fantastic imagination requires a special system of exercises —mainly, the teaching of fantasy methods. It is not enough to say, "extend your imaginative thinking about something"—the methods for achieving this must be explained. (*Methods* here play the same role as *paint* to painting; we cannot say that the "paint" interferes with the freedom of fantasy. Experiments along these lines were made by the Public Laboratory of Inventive Methods, at the Central Committee of the All Union Society of Inventors and Innovators. A course, *Development of the Creative Imagination*, was produced and functionally tested. Students studied a method for generating fantasy ideas and a method for overcoming psychological inertia, and used them during special exercises or problem solving processes.

While working out the course, all exercises were first tested with writers of science fiction. This created standards for comparison, allowing for the development of a "the scale of fantasy." As a rule, the degree of fantasy imagination before training was relatively low. The spark of fantasy is struck with difficulty, and soon dies. This is not by chance. During the course of human evolution, the brain has adjusted to act with customary notions about many things. It requires hundreds, and thousands, of attempts for thought –shackled by these customary notions, to overcome psychological barriers.

A person with no knowledge of gymnastics probably, upon seeing exercises for the first time, finds it difficult to understand what is happening on the gym floor —adult people gather together, without any perceived goal, waving their hands, jumping around, and then suddenly leaving without making or producing anything. Fantastic imagination exercise classes may look just as strange to the outside observer. Meanwhile, this is very serious and intensive work. From session to session, methods for fantasy development are learned. In the beginning, they are simple (*increase*, *reduce*, *do it in reverse* and so on). Then, they become more complex (*change characteristics of an object through time*, *change the interactions between an object and the environment*), and thought eventually learns to overcome its psychological barriers.

When asked to think of a fantastic plant, ten out of ten people will surely begin by modifying a flower or tree. In other words, change a whole organism. But, it is possible to get down into the micro-level –change the cells of the plant –and then make even smaller changes within the cellular level to produce remarkable plants that do not exist even in super-fantasy novels. It is also possible to go up to the macro-level and change the characteristics of a forest –again, making very interesting discoveries.

Each object (animal, plant, ship, lathe, and so on) possesses certain principal characteristics: chemical composition, physical design, micro-structure ("cell"), and macro-structure ("association assemblies"), energy support, directions of development, and so on. All these characteristics can be changed, and there are also dozens of methods for making these changes. Therefore, the fantastic imagination development course has a section on learning how to create and use *phantograms*. The phantogram is a table with one axis representing the changing characteristics of an object, and the other axis the main methods used to change them.

The richness of fantasy is characterized, for the most part, by the amount of these accumulated combinations, which essentially represent the *phantogram*. Before this type of training, the brain stored only separate pieces of such combinations. Only science fiction writers combine these pieces into the *phantogram* as the result of their professional training.

Studying the fantasy technique does not resemble learning the conventional methods by heart. The same exercise can be done differently, depending on the individuality of each person. Here, as in music, technical methods help uncover individual qualities –and very well done exercises can sometimes bring genuine aesthetic satisfaction, just like a very well played piece of music.

Part 3-3
Over Barriers

Let’s now return to our exercise problems and analyze their solutions.

Solution to Problem #9

It is required that we increase the oxygen in a pond as much as ultimately possible up to complete saturation. Consequently, we want to increase the **amount of a substance** (oxygen). This is line 26 in the Matrix

Suppose we use a common method to saturate water with oxygen: Install a powerful compressor on the bank of the pond, with pipelines placed at the pond’s bottom, introducing a lot of air or oxygen. The oxygen contents of the water will, of course, increase; however, we lose because of the complexity of the equipment —see the Matrix, column 36. The recommended Principles are #3, #13, #27 and #10. If chemicals are used, they will not only be sources of oxygen, but cause water pollution. See column 31 — **“Harmful factors developed by an object:”** *Principles #3, #35, #40 and #39.*

We can approach this problem differently. Suppose we want to reduce the **loss of a substance** (line 23), and we are also losing in degree of concentration —“ **Amount of substance**” —column 26: *Principles #6, #3, #10 and #24*. Conclusion: Reducing the loss of a substance by conventional means (slowing down the introduction of compressed air), we loose **capacity** (column 39): *Principles #28, #35, #10 and #23*.

Thus, the Matrix persistently recommends the Principles “**Local Quality**” (#3), and “**Do it in Advance**” (#10). From this, it is not difficult to come up with a solution. Let’s take some water in advance and create an environment favorable for dissolving oxygen in it. This coincides with the control answer (Author’s Certificate #168, 073).

Oxygen is dissolved under pressure in a small volume of water, then the water, saturated by oxygen, is introduced from the bottom of the pond. Before, oxygen jumped out of the water without enough time to be dissolved into the water. Now it has more than enough time.

Solution to Problem #10

It is required that we increase machining **speed** (line 9); however, we have to pay the price of an increase in temperature (column 17). *Principles #28,*

#30, #36 and #2. *Principle #36* is directly related to our situation: phase transition can accompany significant heat absorption. The polishing wheel should melt, or evaporate, in the area of heat dissipation.

We can say this differently: "Harmful factors developed by an object" have to be reduced. This can be done by reducing the "speed," or "capacity." *Related Principles are: #35, #28, #3, and #23 or #22, #35, #18 and #39*. *Principle #35* suggests the transformation of a property —change the physical state of the system, leading to the correct solution.

The control answer (Author's Certificate #192,658): "A polishing wheel is made of ice containing abrasive particles. During the polishing process, the ice gradually melts, absorbing the dissipated heat."

Solution to Problem #11

Step 2-3. There is a given system: a container —sample (wire, rod) — weight —an internal aggressive medium. It is difficult to determine the moment when the sample breaks, or the weight falls.

Step 2-4.

a. *Container*, *weight*;

b. *Sample*, *aggressive medium*. (*Sample* and *medium* are given by the conditions of the problem. They cannot be changed. The weight can be changed, as long as the required load on the sample is preserved; container can be changed as we wish, as long as it remains hermetic).

Step 2-5. *Container.* (The container is easier to change than the weight. And besides, the container is stationary: See Note "a" to *Step 2-5* of ARIZ).

Step 3-1. A container without any holes in its walls, by itself, sends information about the broken sample or the fallen weight.

Step 3-2. Make a drawing of the system.

Step 3-3. The walls of the container cannot perform the required action. The answer to *Step 3-3* can be formulated more precisely by indicating the outside surface of walls.

Step 3-4. When the sample is broken, or the weight falls, the walls of the container (or their outside surface) must somehow, change by themselves.

We can more precisely answer *Step 3-4* like this:

a. A wall (the bottom) of the container must be movable to send a signal outside about the motion of the weight.

b. A wall must be stationary to retain the pressure of the aggressive medium inside the container.
c. A wall must be mobile and stationary at the same time.

Step 3-5. To impose both *mobility* and *immobility*, the wall must move together with the other walls. Then it will be immobile relative to the other walls, and mobile relative to its support.

Note: The weight's fall cannot be seen because the walls are not transparent. This means that the walls must not dampen the fall: let the weight, after reaching the bottom, continue moving with the container.

Step 3-6. The fall (movement) of the weight must provoke the fall (movement) of the container. Now, the weight of the sample is compensated by the counteraction of the support. This means that the weight's fall must disturb the container's balance.

Step 3-7. The falling weight shifts the center of gravity, disturbing the balance of the container, and provoking its movement.

Step 3-8. We are arriving at a design (*Figure 37*) that coincides with the control answer: *Author's Certificate #260,249*. A weight is suspended over an inclined surface inside the container. The bottom of the container is made in the form of two planes. When the sample breaks, it falls onto the inclined surface, shifting towards the container's wall, and changing the balance of the container. The latter changes its original position, closes the contacts, and sends a signal.

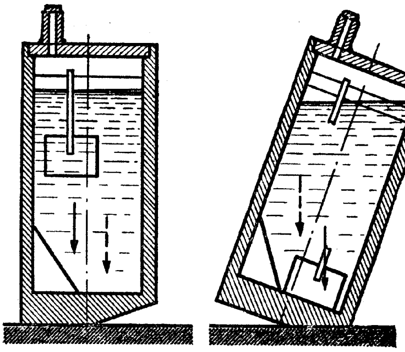

Figure 37. *The solution is correct, and coincides with the IFR. The container sends, by itself, a signal about the falling weight.*

Step 4-1. This solution coincides with the IFR. The container, by itself, sends a signal about the fallen weight. At the same time, the design does not get more complex. However, the device will work only if the shifting weight produces enough tilting moment. What if the weight of the sample is very small in relation to the weight of the container? The size of the horizontal bottom part can then be reduced: let's create a container closer to an unstable state of balance. However, this is not the best solution: the container will tilt from minor shakes and jerks.

Step 4-2. We need a **small** weight attached to the sample. After the sample is broken, the weight should then increase before interacting with the container. Again, contradictory requirements are set forth for one object.

Of course, it is possible that the small weight could trigger the sliding of a large weight (like in an avalanche) —but that will complicate the design. It's better if the same weight will be both light (when interacting with the sample) and heavy (when interacting with the container). While the weight is attached to the sample, part of its mass needs to "disappear." For this, the weight must be placed on the inclined surface in an angle such that only that weight required will be transmitted to the sample. When the sample breaks, the weight will slide down the inclined surface and, with its full mass, force the container to tilt. The incline of the surface can be made adjustable.

Step 4-3. We achieved our required effect —extending the area of application for this device without paying a price. The device preserved its simplicity; however, it becomes more universal. Now, it can be used for testing thin wire threads, and so on.

Step 4-4. The solution can be considered as complete; the requirements of the task are fulfilled.

Solution to Problem #12.

Step 2-3. There is a system comprised of a pipeline, air stream, and tomatoes. The air stream, during transport, collides tomatoes into each other.

Step 2-4.

a. Pipeline, air stream.
b. Tomatoes.

Step 2-5. Pipeline. (This choice is made based upon Note "a" to *Step 2-5*).

Step 3-1. The pipeline during the transporting of tomatoes, by itself, slows down the fast-moving tomatoes while accelerating the slow-moving tomatoes.

There are two actions in our IFR: *slowing* and *accelerating* — but the IFR must indicate only one action. Different actions can be performed differently. Therefore, we have to separate our problem into two parts, and reformulate the IFR. We keep only one action: "pipeline slows down." If it can accelerate, then we do not need an air stream —the pipeline will transport the tomatoes by itself. In accordance with the conditions of the problem, we have to preserve the air system to transport the tomatoes; therefore, a bypass method is not acceptable.

Step 3-1. The pipeline, while transporting the tomatoes by air stream, slows down the fast moving tomatoes by itself.

Step 3-2. See picture 38.

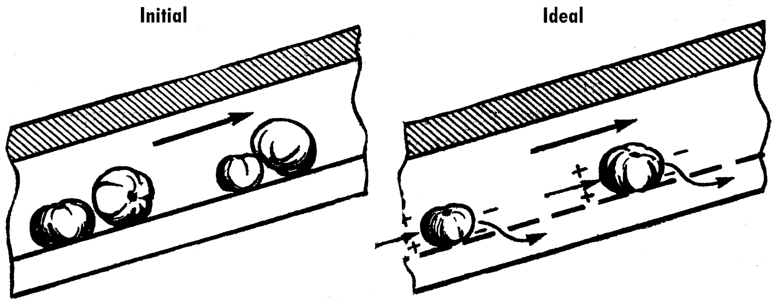

Figure 38. Problem 12, Step 3-2.

Step 3-3. The bottom part of the pipeline cannot slow down the fast moving tomatoes.

Step 3-4.

a. This requires that the tomato reaching some point in the pipeline too early could not move further on.
b. The bottom part of the pipe, at this point, is not an obstacle, and lets the tomato pass by.
c. The same part in the pipeline should be both "transmittable" and "not transmittable" at the same time.

Step 3-5. Obstacles in the pipeline have to appear and disappear when needed.

Step 3-6. The tomato moves under the pressure of the air stream. To stop a tomato at a certain place, the air pressure must be lowered behind that tomato, or increased before it. At the required time, a hole has to appear in the bottom of the pipeline, and the air will move into this hole. Thus, the bottom part of the pipe must have a hole that periodically opens and closes.

Step 3-7. It is too complicated to open and close holes. The holes must be open *all the time.* To prevent the tomatoes from falling through the holes, they need to be small. Air can be pumped in, or sucked out, through these holes. It is more reliable to draw-off the air, allowing the stopping of each tomato at one or another hole, as necessary.

Step 3-8. The bottom of the pipeline has small holes (*Picture 39*). The air is drawn off through holes: in the beginning from the first hole, then from the second one and so on. Running wave of negative pressure is created; Tomatoes will not move faster than this wave.

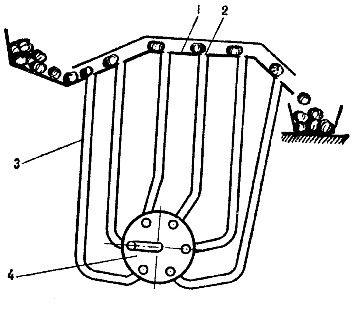

Figure 39. Pneumatic transportation. 1. Pipe; 2. Holes; 3. Pneumatic lines; 4. Source of vacuum.

This coincides with the control solution. (*Author's Certificate #188,364*).

Step 4-1. Our gain is the ability to control the tomato movements through an adjustable wave motion. We lost, in this case, by complicating the system.

Step 4-2. We can simplify the system by removing the need for supplying air into the pipeline. Let's allow a moving wave of negative pressure to transport the tomatoes from one hole to another. If we switch the suction faster between the first and second holes, then the air sucked off the second hole will pull the tomato towards it. Then, the suction will be switched to the third hole —and the tomato moves towards it, and so on. When a tomato moves over holes three or four, the cycle begins all over again with the first hole. The bottom part of the pipeline can be made wider to move a row of tomatoes.

Solution to Problem #13.

Step 2-2. The thickness of each plate tends toward zero. Suppose the thickness of each plate is equal to the diameter of an atom. This means that the plate can be assembled out of separate atoms.

a. If the thickness of each plate equals 1,000 km, each plate must be assembled from separate assemblies as well.

b. The time needed to assemble each plate tends to become zero. Here, the elements have to be made in advance, and assembly must be made by some "magic" power.

c. If the time needed to assemble each plate is 100 years, it may be possible to use a slow, natural process —like the sediment of particles from a solution.

d. The cost to produce the product equals zero. Here, the plates must appear and bond by themselves —but, how? Maybe through some harmful forces? Then, we will not only achieve zero cost, but we will also provide an additional effect at no further cost.

e. Suppose the cost is great. In this case it is possible to work under conditions where the property of the material is constantly changing. For instance, bond the plates at a normal temperature, but under high pressure.

Operator STC did not produce a ready solution. This almost always happens. The essence of Operator STC is to broaden barriers, and this way makes the process of finding a solution easier.

Step 2-3. There are two substances — *A* (low melting) and *B* (high melting). It is difficult to produce a thin "sandwich" out of these materials.

Step 2-4.

a. Substance *A*; substance *B*.

b. —

Step 2-5. Substance *A*. (It is easier to melt, meaning change).

Step 3-1. Substance *A,* by itself, produces the "sandwich" with substance *B*.

Step 3-2. See Figure 40. It is clear now that the process for obtaining a "sandwich" consists of two actions. Substances *A* and *B* are located in separate areas and must produce one common mass. Then, they have to each take a specific position within this space. This means that we can now state the IFR.

Here is how the IFR was refined while solving this problem at the Azerbaijan Institute for Inventive Creativity (substance *B* was chosen as the object):

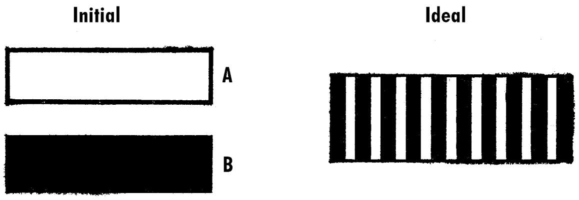

Figure 40. *Problem 13, Step 3-2.*

Student: Substance *B,* by itself, enters substance *A* and is orderly arranged within it.

Instructor: There are two actions here: "enters" and "orderly arranged." This means that two tasks also exists here.

Student: The first problem is easy to solve. For substance *B* to enter substance *A*, we can pour *B* into a molten *A*.

Instructor: Therefore, we can reformulate the IFR.

Student: *B* is broken-up, and its particles positioned by themselves in the shape of planes.

Instructor: Here there are again two tasks —"break-up" and "position in the shape of planes."

Student: The "break-up" task is easy: The poured substance *B* is in the form of a powder. The final formulation of the IFR is: Powder *B*, by itself, is orderly positioned within the molten material *A* (*Picture 41*). . . . However, if *B* is a magnetic material, then a magnetic force can be used. This can position particles *B* in a certain order. Hardening is then allowed, and the problem is solved.

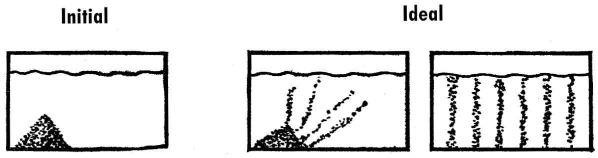

Figure 41. *Problem 13. The final concept of Step 3-2.*

Instructor: What if substance *B* is a non-magnetic material?

Other students: Utilize optical forces –or, acoustical, electrical . . . .

Student: The following forces exist: electrical, magnetic, optical, mechanical, acoustical, nuclear. . . .

Other students: Acoustical! Create standing waves in the container. Particles of *B* will be collected in planes corresponding to each wave's crest. Substance *A* will only exist in the wave trough areas.

This corresponds to the control answer: "A method to produce laminated materials with assigned positions of layers. This method differs by having a suspension of high-melting temperature particles in a low melting temperature substance. This suspension is subject to the action of a field of ultrasonic standing waves of specific frequency, then removing the field while the alloy cools. This allows for the production of a thin, periodical, three-dimensional structure." *Author's Certificate #108,894.*

The process of solving this problem is interesting because it clearly shows the mechanics of analysis. For a task with a large search area, the degree of indefiniteness gradually reduces, and the search area becomes smaller and smaller. In the end, one question is left: What forces can be used to control a non-magnetic powder placed in a liquid medium? A complex inventive problem turned into a simple one solved by sorting only several variants.

In the control answer, pre-known Principles are combined (the Principles of Segmentation and Dynamicity) along with a physical effect based on the utilization of standing waves. This is a typical situation. A simplified problem, obtained as the result of analysis, is solved utilizing one or another physical effect.

* * *

There are inventive problems that are solved only through the utilization of physical effects. *German Federative Republic Patent #51,194*, for example: The influence of an electromagnetic field on the surface tension of liquid metal is used to change the diameter of a pellet. By changing the intensity of the field, the surface tension also changes; therefore, changing the size of the droplets out of which the pellets are made.

Sometimes an invention comes directly from a discovery. Many such inventions are based upon the electric-hydraulic effect.

Sometimes, inventions use discoveries that were made in time immemorial. For instance, Author's Certificate #306,036: "A drawing pen comprised of a handle with two plates and a screw to adjust the capillary gap between them. This invention differs by having an adjusting device made out of a double lever with one shoulder attached to the screw, and another to a plate on the pen. This allows an increase in accuracy of the plate adjustments." The inventor, as we can plainly see, used a lever —a discovery made thousands of years ago. Here is a basic discovery (although made in ancient times).

Sometimes, for a basic discovery, we have neither a date nor the name of its inventor —nor even a clear description. Let's take, for example, *Author's Certificate #184,219*:

> *"A method for continuously pulverizing mountain rocks by explosions. This invention differs by utilizing micro-explosions of the surface layer. This allows us to obtain small fractions of rocks."*

Here, the basic discovery was made by someone in an unknown time, and can be formulated thus: A small hammer breaks out small chips; a large hammer —large chips . . . .

Sometimes people tend to say that all inventions (or, at least, significant inventions) emerge out of discoveries. If we can interpret the term "discovery" as defined in the *Russian Manual of Patenting*, we can immediately show that a large number of inventions are not related to discoveries, while at the same time being significant and original. Take for instance *USA Patent #3,440,990*: A ship consists of separate interchangeable blocks —the "lead" blocks do not stand still awaiting the loading and unloading of "cargo" blocks. Or, *Author's Certificate #305,974*: The capacity of a machine that produces multi-layered spiral pipes is limited by the welding process; however, it is suggested that we tack weld the seam in several places, remove the pipe from the machine, and provide for the completed welding outside of the machine. This allows no delay in the production of the next pipe. Here, neither physical effects nor phenomena are used; although, an inventive approach to the solution is clearly present.

There is also an opposite tendency —narrow down the group of inventions based on physical effects to only those that directly relate to recent (or previous, but unique and little known) discoveries .

Both tendencies are wrong. "Physical inventions" represent significant groups of inventions, but not the only groups. Today, there is no chance of precisely defining the term "physical invention" (more accurately, inventions based directly upon the utilization of physical effects and phenomena); however, this is no reason to not study such inventions.

Physical effects and phenomena are the basis of the physics that contemporary inventors have studied for many years in school. Unfortunately, the inventive application of physics is not learned there. Therefore, physical phenomena and effects, although residing in the engineer's memory, do not correlate with information about inventive problems. The inventor holds in his hands a set of keys, yet cannot use them to open the ingenious secret locks of inventions because he has not been taught how. Sometimes, he must randomly sort out these keys. Sometimes, he chooses the correct key but inserts it the wrong way —and pays for this with a loss of time.

The inventor has to look for familiar effects and phenomena, and train himself to see these work instruments as a creative approach to solving inventive problems. Knowledge in these areas has to be constantly replenished because the number of discovered effects and phenomena grows fast. And besides, old, little known effects are more and more often being continuously being.

It would be good to have a table showing the effects and the phenomena relative to problem specifics that can be used in a given situation. This work is in progress by the Laboratory of Methodology of Inventiveness at CC AUII (Central Commission for All Union of Inventors and Innovators).

Solution to Problem #14.

Step 2-3. There is a system consisting of a pipeline, pumps and liquids *A* and *B* (moving inside the pipeline). There are also dividers between *A* and *B.* The dividers cannot pass through the pumps, and often get stuck inside the pipeline.

Step 2-4.

a. Divider.

b. Pipeline, pumps, liquids *A* and *B*. (The pipeline and pumping stations are already built, therefore it is difficult to change them).

Step 2-5. Divider.

Step 3-1. A divider, by itself, easily passes through the pumps. Dividers that can easily pass through the pumps are already known — *liquid dividers*; however, they have their own shortcomings. It is difficult to separate them out at the end of the pipeline. We took solid dividers as the prototype to narrow the task. If we consider a liquid divider as prototype we may come to a the erroneous conclusion that solid dividers *must* be used. In *Step 2-3*, both types of dividers must be stated.

Step 2-3. There is a system consisting of pipeline, pumps, liquids *A* and *B* that travel along inside the pipeline, and dividers (liquid or solid) separating the liquids. Solid dividers do not pass through the pumps, and liquid dividers are difficult to separate out at the end of the pipeline.

Now, we have a precise formulation of the task. Moreover, within the conditions of the problem, there is a clearly stated contradiction: it is easy to have a *liquid* divider through the whole length of the pipeline, and a *solid* divider at the end of the pipeline. Therefore, the object must be changed throughout its working performance. This is *Dynamization, Principle #15* which is already known to us. Let the divider be a liquid inside the pipeline — and solid, or gaseous, at the end of the pipeline. The latter is even more appropriate: when the liquid reaches the reservoir (the pressure in the reservoir is lower than in the pipeline), the divider disappears all by itself. The mixing of the divider with liquids is no longer dangerous. We can now allow the divider to mix with liquids — like different grades of oil — even in large quantities because it will still turn into gas at the end of the pipeline and be easily collected.

We found the solution concept. Now we have to formulate the requirements for the substance of our divider. The substance must:

- dissolve in oil;
- be chemically inert in relation to hydrocarbons;
- while in a liquid state, have a density about the same as that of the pumped liquid;
- not to freeze at temperatures of –50 C;
- be safe and inexpensive.

Consulting various handbooks, it is not difficult to find that the best fit for these requirements is ammonia. It does not dissolve in oil, nor does it interact with oil. It possesses the required density, easily compresses to a liquid state, and will not freeze even at –77C. Liquid ammonia is relatively inexpensive, and used in agriculture as fertilizer.

Part 3-4:
Scientific Structure of Creative Work

While analyzing the process of solving inventive problems we ignored questions about an inventor's previous creative training. Meanwhile, the problem solving process depends, for the most part, on that training. When the inventors' questionnaires were analyzed, it was discovered that the more experienced [1] the inventor, the more thorough his answers were about any preliminary preparations before solving an inventive problem. For example, inventor V. Iahimovich, who has 23 Author's Certificates, wrote the following in his survey answer:

> *"It is necessary to have a collection of different interesting designs, methods, devices and so on. This is a bank with no specific purpose —just a collection of facts and experiences. You must study information that does not directly relate to your major specialty. A machine designer has to know a lot of general information (polygraph industry, food industry, shoes industry, and so on), as well as electric and electronic technologies."*

In studying the creative process we started out from one leading subject: a rational system of problem solving. Now, after examining "the technology of creativity," and having found new technical ideas, we will follow once again the entire creative process, beginning with any preliminary creative preparations.

Study "leading" industries

The word "leading" is in quotation because its meaning, from an inventor's perspective, is relative. Each industry is a relative leading industry in some area of technology, and at the same time a relative "follower" in others. Sometimes the relationship between industries is more complex: the same industry appears to be the leader in some areas, and a follower in others. For instance, machine building is a leading industry when considered from the perspective of manufacturing, technology, and productivity. These areas are all ahead of the construction industry. However, in the area of the utilization of pre-stressed elements, construction technology has experience that the machine manufacturing industry does not yet have.

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[1] Of course, an inventor's experience is determined not by the inventor's age and time at work. An inventor's experience, to some degree, is proportional to the time he directly was occupied with creative work.

It is necessary for an inventor to study the leading industries —their main achievements, trends, and new methods —from an inventive point of view. In other words, the inventor must constantly keep track of problems solved today in leading industries because similar problems can appear in the inventor's own industry tomorrow.

Study "follower" industries' fields of technology.

Knowledge about "follower" fields of technology is required primarily for the Synthetic Stage of the creative process, to which inventors do not pay enough attention.

In "follower" fields, the lagging areas are those most interesting to inventors. The better the inventor understands these lagging areas, the wider he can utilize a new technical idea obtained from within a problem's solution.

In addition, studying "follower" fields of technology makes it easy to determine any common tendency in technological progress. Leading and following fields are like two points through which only one line can be drawn —the line establishing the direction of technical evolution.

Collect information about physical effects, new materials, methods for solving technical problems, and so on.

We have learned forty basic principles for removing technical contradictions. It is not difficult to notice that these principles represent pairs: "*direct* principle and *opposite* principle." For example, the Principle of Segmentation and its opposite, the Principle of Consolidation; the Principle of Continuity of Useful Action, and the Principle of Periodic Action. Immediately the question arises: "Is it possible to complete the list of Principles by finding the missing second half of a pair?" Suppose the Principle of Rushing Through must match an anti-Principle that can be called "Go on Tiptoe"—a harmful, or dangerous, process should be overcome slowly and carefully.

Here it must be emphasized once more that the table we use reflects a generic (or, more precisely, *average*) technical characteristic. Algorithms for specific fields of industry do not yet exist; therefore, the inventor (with reference to his profession) can correct the list of principles by remove, or add, some of them. This is an important part of the preliminary preparation of an inventor's creative process. In order to make corrections to those Principles relative to an inventor's profession, he must look into his creative experience, then analyze and organize it.

It is more complicated when making corrections to the table. When finding a new Principle, do not rush to move it into first place within a cell because it may seem to you to be more powerful. These Principles are best appended behind those that already exist. It can be moved to first place only after solutions of many —at least ten —problems support the power of the new Principle.

It is possible to add Principles without having to change the table — simply write each poweful (i.e., new and successful) Principle one after the other. In this book there are over 150 Principles. If 250-300 principles are accumulated, then every fourth problem will "surrender without a fight"— you will find an almost-ready solution. (Of course, such principles must be diverse and original. But, most importantly, they should be broad and general.) Having a card index of 500-600 principles, it is possible to attack problems with the confidence of finding the correct answer fast.

It is not necessary to increase the number of principles unlimitedly. After collecting 300 –400, one's main attention should focus on increasing their quality. Replace principles with analogous, more precise ones.

The source of examples are patents, technical literature, scientific magazines (both specialized and popular), journals, one's own professional experience, and so on.

Study patent information

The study of patent information plays an extremely important role in the preliminary preparation of the inventor.

There are two methods for working with patent information. The first method suggests studying patent information *after* the problem is chosen. This is how many experienced inventors work. The second method suggests looking at patent information systematically, independent of the inventor's problem. In other words, the inventor must study relevant areas of patent information before beginning work on the problem.

The first method has an important, but narrow, goal: avoid wasting time and energy on an invention that is already invented.

The second method (recommended by the Theory of Inventiveness — TRIZ) foresees a multi-goal utilization of patent information.

Reading patent information increases an inventor's creative potential. Inventions are, in essence, technical problems and their successful, or sometimes not successful, solutions.

Of the numerous amounts of patent literature, the most interesting from this point of view is the bulletin issued three times a month: *Discovery, Inventions, Manufacturing Samples, and Trade Marks*. In each issue are hundreds of different inventions, with at least two or three that can be added to our collection of examples.

Looking through the bulletin on a regular basis, an inventor can get an idea about a tendency in technology evolution, and also become familiar with the different branches of technology —in other words, get a clear view of the frontier of technological thought.

Finally, patent literature is an excellent problem informant. It gives priceless information about problems that attract an inventor's attention, and the levels on which these problems were solved.

Keep track of literature on inventive creativity theory.
There is not much special literature on the theory of inventiveness; yet, there are some books and articles that cover different aspects of the technology of creativity.

Inventive creativity is a complex process, and it is not surprising that statements related to this subject can be either deep and valuable in practice, or superficial and sometimes incorrect.

For example, take the article "Technology of Creativity," by A. Studentsova, PhD.[1] The author's position is very simple: "Not any erudition, nor any training, can replace an absence of talent. For instance, if Elias Howe had not replaced the well-known handmade seam with a new double seam, the sewing machine wouldn't have been invented in the form we know it today." So, if Howe had not been born, the contemporary sewing machine would not exist? Following this logic, without Gutenberg and Fedoseev, printing would not have been invented —and acceptance of the crankshaft by the technical world was a miracle because its inventor almost died during his childhood.

I have no doubt that similar statements will appear in the future. These statements will appear, but they will be less categorical, and they will still highlight the same old idea that the creative process cannot be learned. Nevertheless, you have to read these articles as well: they also may contain interesting and useful examples.

Special attention must be paid to literature relating to the methodology of creativity. However, this material should be critically analyzed. It is a matter of fact that old thoughts often hide within new terminology. The American physicist John Pierce once noticed —not without bitterness — "I have read much more about theories of information and psychology than I can, and want, to remember. In most cases, they were simply attempts to merge new terminology with old, foggy ideas. The authors of these works probably hoped that juggling new terminology, like waving a magic wand, would clear up all that was hazy and unclear." These words, unfortunately, can relate fully to some books on the methodology of creativity. The old method of "trial-and-error" is often presented in new, contemporary dress.

At the beginning of this century, the French mathematician Jules Henry Poincare wrote:

> *"I will use a simple comparison. Let the elements of our future combinations remind us of something resembling the hooks in Epicure's atoms. Then, during complete mental relaxation, these atoms are immobile ... during invisible subconscious work, some of the atoms . . . start to move . . . like gaseous molecules ... now their collisions can produce new combinations . . . .*

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[1] *Inventor and Innovator*, 1961, #12, page 4

> *Because we did not* randomly *select the atoms, but instead willfully pursued a specific goal, there will emerge from these mobilized elements ones capable of producing our solution."*[1]

As you can see here, the theory of "trial-and-error" is described without a mask, and even with some modifications: Poincare stressed that the trials are not made randomly. Here, the contemporary American psychologist Lawrence Fogel notes: "In the human being, the process of inventing is the result of the combination of internal mental noise with thorough deductive searching. This is directed into determining which of the generated results can be used immediately (which result satisfies those limitations imposed by necessity)."[2]

This terminology, as you can see, is very modern — on the level of cybernetics — but the idea is an old one. The brain generates several accidental ideas ("noise"), and someone sorts out those that are usable.

I hope the reader can recognize an old theory, even if it looks like a modern one. Do not let yourself be hypnotized by terminology — look for the ideas hidden by the terminology. We have a very reliable criterion — experience.

Those theories and methods are valid that help our work, organize our thoughts, and produce real results.

Accumulate experience in solving exercise problems.

When using the "trial-and-error" method, and inventor draws from experience by recalling similar problems, referring to patent information, and using scientific-technical literature and industrial experience.

Depending on the problem's level, there are three possible situation:

1. For First and Second Levels, the previous experience is **helpful**.
2. For the Third Level, previous experience, in general,is **neutral.** On lower sublevels of the Third Level, it is helpful to a certain degree; on the higher sublevels, it sidetracks the process away from the solution.
3. For the Fourth and Fifth Levels, previous experiences **interfere** with the inventor, directing the "trials" via inertia vector away from the solution.

The essence of ARIZ is to provide the inventor with an experience that is useful on the higher Levels. In other words, ARIZ must make the thinking process skilful, and must provide *controllable* "intuition" conforming

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[1] J. Poincare, *Mathematical Creativity*, Iuriev, 1909, page 9.

[2] L. Fogel, "Intellectual Levels of Solutions," from the collection " *Engineering Psychology,*" M., Progress, 1964, pages 138-139.

with needs, and working reliably. All parts of ARIZ are aimed at providing this, especially ARIZ's informational elements (Principles and Matrix). If a single inventor's experience usually leads to a lower Level solution, then the collective inventive experience, revised and concentrated by ARIZ, facilitates solutions on the higher Levels.

However, while studying ARIZ an inventor accumulates new personal experience based on solving inventive exercise problems and other ARIZ applications. The ARIZ experience, with its concentrated powerful inventive ideas, is capable of helping on the highest Levels.

Psychological inertia, making personal experience harmful when solving technical problems of the highest Levels, becomes useful when using ARIZ. Here, the inertia vector leads towards strong solutions. It can be said that a limited personal experience can suggest poor examples; the ARIZ experience suggests good examples (out of unexpected, distant areas of industry).

ARIZ experience accumulates gradually as the inventor learns. At first, it is almost intangible. After working thirty to forty exercise problems, learning the 40 Principles and examples, and filling a card index with interesting inventive solutions, then some problems can be solved even without ARIZ —with the direct utilization of ARIZ experience.

After studying thirty to forty exercise problems, ARIZ-71 can be supplemented with Step 2-0:

Step 2-0. *How were exercise problems similar to the given problem solved?*

a. State the essence of the new problem.
b. State the technical contradiction in the problem.
c. State an analogous problem.
d. State the technical contradiction in the problem-analogue.
e. What are the analogues in "b" and "d".
f. State the solution concept of the problem-analogue.
g. How can this concept be changed in relation to the given problem.

Remember that, when using ARIZ experience, it is necessary to transfer the **essence** of the concept, and not a specific design.

Let's look at the following example:

There is a method for tunneling under a functioning construction (for example, the embankment of a railroad). This method suggests pushing a pipe (with, or without, the help of vibration) through the ground, and then removing the earth from the inner part of the pipe.

The wall thickness of the pipe depends on its diameter: the larger the diameter, the thicker the wall. However, increasing the wall thickness unacceptably increases the force required for the pipe's penetration.

We need to develop a method without this shortcoming.

Let's use ARIZ experience to solve the problem.

Step 2-0.

a. Essence of the problem: A thick-walled pipe has difficulties penetrating the ground.
b. Technical contradiction: Increased penetration speed requires an exorbitant increase in machine power.
c. Analogous problem: Movement of the icebreaker through the ice.
d. Analogous problem technical contradiction: Increasing the speed through the ice requires an exorbitant increase in engine's power.
e. Analogues in "b" and "d:" In both cases, an increase in the speed of movement though the solid medium requires an unacceptable increase in power.
f. Analogous problem solution concept: The hollow hull, not the solid one, must move though the ice.
g. The hollow wall, not the solid one must penetrate the ground.

The control answer: A method for cutting-out a tunnel under a construction which is already functioning (for example, railroad embankments) using penetrating jacket elements, and removing the earthen core. This invention is different because it uses hollow jacketing elements whose length is equal to the length of the tunnel. These elements are pushed along the axis of the tunnel, then the dirt is removed from the hollow area of the jacketing element —which then fills with concrete. This method allows for a reduction of the force necessary for the elements to penetrate earth. (*Author's Certificate #271,555*).

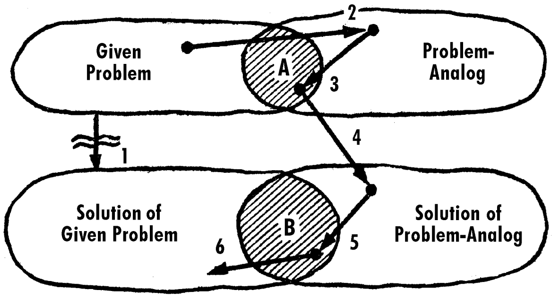

Figure 42. *Problem-analogue helps to solve a new problem.*

The meaning of Step 2-0 can be illustrated by following *Figure 42*. The immediate transition *1*, from the given problem to its solution, is difficult to make. The better way may be: *2 → 3 → 4 → 5 → 6,* from the given problem to the problem-analogues (*2*); then to area "A" that is common for both problems (*3*); further, to the known solution of the problem- analogue (*4*); then to area "B," which is common to both solutions (*5*), and finally to the solution of the given problem (*6*).

The more precisely chosen the problem-analogue, the greater areas "A" and "B," and the easier it is to make the transition *2 → 3 → 4 → 5 → 6.* As the "transition" experience increases, **area "A" becomes smaller and smaller** —and the inventor starts noticing the less obvious similarities between the problems. Sometimes, a fine similarity is difficult to express in words. Sometimes it cannot even be perceived by the inventor — it can only be "felt." To an outside observer, this seems like "inspiration," or "intuition."

Regular exercise improves the ability to work with very small "A" and "B" areas — in other words, making the thinking process sharper and more skillful.

Learn creative thinking

The first seminar on the method for solving technical problems (TRIZ) was conducted in Baku in 1959. Today, teaching creativity is done in many towns of our country. Practice shows that, after several classes, students already use some elements of ARIZ: the concept of technical contradiction, IFR, and some typical principles. The process of problem solving is still performed though methods of trial-and-error, but these trials are more directed and effective.

To possess a complete knowledge of inventive problem solving with ARIZ, twenty to thirty lessons in seminars are required. This is followed by independent personal training over the next several months that consists of analyzing exercise problems, solving new problems, and studying new educational literature.

As the skill of thought focussing grows, the inventor uses his detailed notes on the process less and less for problem solving. The complicated ARIZ thinking process is accomplished within the inventor's mind in the style of freeform reflection. Problems are solved increasingly by utilizing separate fragments of ARIZ. **Many things become immediately obvious even before the process starts**. Reasoning (including the steps of analysis) appears later, after the solution is found. Some of ARIZ's elements create (whether voluntarily or not) a "personal signature," the personal style of the inventor. He systematically stores answers to as yet unknown problems — collecting in a card index principles and information about the most powerful solutions.

The ARIZ thinking process — or *ARIZ mind* — can now become the object of scientific investigation. We can highlight here some of its features:

Ordinary inventive thinking process	ARIZ thinking process
1. Tendency to make the problem easier, simpler.	1. Tendency to make the problem heavy, more complex.

When solving Problem 7, an ordinary inventor thinks, "Of course, it is impossible to completely remove the friction. My goal is to reduce the friction." The inventor who is accustomed to the ARIZ thinking process, thinks differently: "The contact moves with the friction. The less friction, the better. This means there should be no friction. IFR = contact touches terminals without friction."

Ordinary inventive thinking process	ARIZ thinking process
2. Tendency to avoid "fantastic" (crazy, wild) steps.	2. Tendency to follow the path of increasingly "fantastic" (crazy, wild) steps.

There is a grain of truth in people saying inventors are crazy: The path of thought of a good inventor is abnormal from the non-inventor point of view. Unfortunately, inventors usually have depressingly normal thoughts. ARIZ teaches how to possess an "abnormal" thinking process.

The ordinary inventor thinks, "It is necessary to melt, or blast, the ice." The possibility for the ship to swim, or to blow-up, cannot appear in his mind —or, if it does appear, it is immediately discarded. This is clearly seen through experiments during which Problem 5 was solved with the Matrix by inventors having little knowledge of ARIZ. Matrix hint: use *Principle #35* (*Transformation of Properties*; i.e., its aggregate state). This principle always refers to the ice, and not the ship. In these cases, when the teacher asked the direct question —"what if we change the property of the ship?" —it always provoked bursts of laughter.

Ordinary inventive thinking process	ARIZ thinking process
3. Visual image of an object is unclear and related to the object-prototype.	3. Visual image of an object is clear and related the object-IFR.

The ordinary inventor sees an icebreaker — vaguely, and in general outline —rapidly breaking through the ice. The ARIZ thinking process paints a very different picture: *something* carries a cargo, and goes through ice as if the ice were not there.

Ordinary inventive thinking process	ARIZ thinking process
4. A flat image of an object.	4. A 3-D image of an object: not only the object itself is imagined, but simultaneously its subsystems and super-systems.

The inventor, with an ARIZ mind, sees not only "an icebreaker in general," but simultaneously sees three images:

a. the icebreaker.

b. its parts (hypertrophied engine section and very small cargo section —and a sudden thought: it should be just the opposite in the ideal machine!), and

c. the caravan of which the icebreaker is one part (one more sudden thought: even if we crush the ice into a powder, it will still freeze again behind the ship; one problem continues to lead to another — this is a dead end!).

Ordinary inventive thinking process	ARIZ thinking process
5. The object's image is in a frozen time frame.	5. The object is seen in an historically mobile process: as it was yesterday, it is today, and will be tomorrow (if the line of evolution is preserved).
6. The image of an object is rigid	6. The image of an object is elastic, open to significant changes in space and time.

In Problem 7, the contact can be imagined to be "rigid," in the shape of some falling body (the same as in the answer to the Problem 6). However, it can also be imagined as a weight that significantly changes during each tenth-of-a-second during its fall. "Significantly changes" includes reaching zero substance.

Ordinary inventive thinking process	ARIZ thinking process
7. Memory prompts a familiar (and, therefore, weak) analogy.	7. Memory prompts a distant (and, therefore, powerful) analogy. At the same time, the reservoir of information constantly grows through the collection of new methods, principles, and so on.
8. Over the years the barrier of specialization grows.	8. The barrier of specialization disintegrates.
9. The degree of control over the thought process does not increase.	9. The thought process becomes more controllable: and the inventor can see the path of the thought as if an outsider; he easily controls the thought process (for instance, he has no problem diverting from "suggested variants," to easily making imaginary experiments, and so forth.

These are some characteristics of ARIZ mind. Of course, an ordinary inventor may possess some of these features; however, they are obtained very late —and the best time for creativity is lost. What is important is that the power of these features is greater when they are together, than when separate.

Make correct the choice of task.

In this book, it has been said more than once that inventive skills are mostly determined by the ability to recognize a tendency in technical evolution. When choosing the task associated with a technical object, it is first necessary to determine the direction toward which this object evolves.

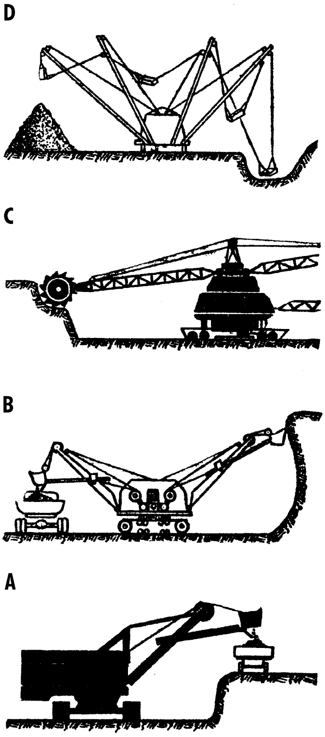

Figure 43. *Metamorphosis of the excavator.*

Let's look at the following example. The one-bucket excavator (*Figure 43a*) appeared back in 1836. This excavator works with long pauses, taking time to transport the load, unload the bucket, and return it to a working position. More than 100 years passed, when in 1949 the inventor T.G. Gedick offered an idea for an excavator with two crane arms (*Figure 43b*). This interesting idea came late and did not find —or, more precisely, did not have time to find —its application because the rotor excavator soon appeared (*Figure 43c*). The line of evolution is thus very clear: one bucket, two buckets, many buckets (rotor). Suddenly, in 1958 it dawned on someone to ask what about four buckets?

The four-bucket excavator (*Figure 43d)* is one step back in relation to a rotor one. An attempt to return technology to the past is always hopeless. Here, there is impartial testimony: "There are large numbers of similar applications that draw our attention. In the USSR alone, from the period of 1952 to 1954, the number of applications for similar inventions amassed to several dozens. Other inventors assumed that single-bucket excavators —especially strip mining excavators —must have an even larger number of similar sets of working elements." [1] Of course, none of these ideas were implemented.

Technology moves only forward; its evolution can neither be turned back nor stopped. Even in those cases when it seems the next step is impossible, that step will certainly happen.

The tendency of technical system evolution is irresistible. A system must reach its logical conclusion, breaking and by-passing the "impossible." Later, its evolution may appear to have stopped. It is exactly at this time that interesting inventive tasks appear.

The main indication of this "pre-revolutionary" state is that, from some moment, the technical object grows only quantitatively. The new effect is reached by either increasing the size of the object, or the number of

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[1] P.A. Nadaliak, *Single-Bucket Excavators*, 1960, pages 55-56.

simultaneously working elements —the qualitative characteristics are unchanged.

Let's take the turbo drill as an example. Its resources, inherited by its design, are used up almost to their limit. This is why the turbo drill is perfect, and explains why a significant increase in power of this single system is impossible. As a result, it was necessary to pile one turbo drill over another —two sectional turbo drills appeared consisting of two sequentially connected machines. Today, five-sectional drills are used.

Perfection of turbo drill design should not confuse the inventor, nor bring to the inventor fear. To drill a well requires a machine utilizing a completely different concept.

A useful tool for searching out new inventive tasks can be the table "General Tendencies of Technical System Evolution" (Appendix 2). The process of solving problems with ARIZ allows us to make corrections in the original formulation of the problem. An inventor can start with a wrong statement of the problem, but the precise use of the algorithm will lead you to the correct formulation, even if during the process of solving the problem it becomes necessary to replace one problem with another.

Search for the by-pass methods of the solution.

A rational schematic for solving inventive problems was developed in detail in the previous chapters. I would like to stress here that new directions are, for the most part, by-pass methods.

Let's look at a problem about washing a factory's windows. Here is how it is written: "The world's technical thought, while confidently conquering the heights of cybernetics, gave up in front of the 'so simple' problem of developing machines for washing very tall windows and glass fixtures in factories.[1] Let's imagine that the world's technical thought, so to speak, did not "give up." The washing machine is built. Then what? We will require large numbers of these machines. Most likely they will "eat" more energy than they will save because, under factory conditions, many windows must be cleaned almost continuously.

Let's assume that an almost magical machine is created: it costs nothing, it works without consuming energy, and does not require maintenance. Is this good enough? No! If the sun is covered by clouds, significantly changing the illumination of the factory work area, then eyes already adapted to one illumination intensity must begin immediately adapting to a new one. The sun's rays light one part of the factory area, and create dark shadows in another part (probably where the light is needed most). This illumination will change relative to the time of year, time of day, and weather conditions.

This may sound paradoxical, but dirty windows play, to some degree, a

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[1] *Knowledge —Power*, 1962, page 2.

positive role by leveling the fluctuating light rays that pass through them!

It is no accident that "the world's technical thought" gave up in the beginning of this problem, because **the problem should not be solved at all**. Energy savings, and improvements of factory conditions (illumination of the working area) must be done by other means.

When starting to solve the problem, it is necessary to search for by-pass directions (*Steps 1-2 &1-3* of ARIZ).

One reason why inventors avoid "by-pass" direction is their unwillingness, or fear, to leave their customary boundaries of narrow specialization. Everybody knows that something new appears more often at the junction of different sciences —but, inventors are somehow afraid these junctions. A mechanical engineer is afraid to consider "chemical solutions," a chemist to use "electrical concepts."

Higher Level solutions (Fourth and Fifth) are almost always involved with stepping out of one's own field of specialization.

When starting to solve a problem, an inventor does not yet know to what field of technology the logic of analysis will lead. Therefore, the inventor must rapidly learn areas beyond his specialization. The degree of this learning can never be too extensive. While breaking into a "foreign" area of technology, the inventor initially remains a *dilettante*. This is not dangerous when searching for a solution, but it is another situation entirely when engineering implementation starts. Here, a professional level of knowledge is required. The inventor must always learn "new" fields of technology —besides, it's better, and more effective, to work collectively.

Do not rely on easy implementation

Very often, in problems implementing a new technology, people will align themselves along the conflicts between innovative and traditional engineers. Really, in some cases, tradition appears to be the only barrier on an invention's road to implementation. However, in the majority of cases, the implementation is on hold for other reasons.

The Soviet inventor has everything in his shop for overcoming any difficulties on the road of innovation; however, he cannot rely on that implementation happening by itself.

The fate of a new idea can be determined even during the process of solving a problem. The problem must be solved in such a way that the new technical solution becomes easily implementable, or even self-implementable. **First of all, the solution must be as simple as possible**.

At times, the difficulty in introducing a good concept resides in a wrong, irrational engineering implementation.

There is a science of how to design and build machines. It is good for the inventor to possess some skills and knowledge in machine design. However, if such skills are absent, it is recommended that one does not do it oneself. Inventors can always find qualified help to make a correct engineering design of their concepts.

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The theory of invention is not a random discovery, but a logical step in the evolution of science.

In May of 1962, in Topolchianka, Czechoslovakia, the first International Symposium on Creativity methods was conducted. The following appeared in its program: "We acknowledged the universally accepted fact that contemporary qualitative and quantitative developments of the technical-scientific revolution creates a need for scientists, engineers, and inventors to possess not only a knowledge of science, but also of methods for working creatively." The problem of how to increase the efficiency of the creative thinking process gradually became one of the leading problems of modern science. The development of innovation algorithms is only one area of attack lead by science. Advancement in this direction is moving at a fast pace. Every year, the algorithm gets more efficient and reliable. The directions of its further development are very clearly seen, and its potentials are far from being exhausted.

Is ARIZ the only possible algorithm of inventing?

I think it is not. Creation of other algorithms is not excluded.

There are two possible designated directions of algorithm development. It is possible to develop ARIZ as a program to solve problems by *human beings*. It is possible to turn ARIZ into an algorithm for *machines.*

The first direction leads to the development of specialized algorithms initially for problems in the areas of chemistry and electronics. Such specific algorithms must be (for localized problem areas) more effective than general ARIZ, although seen from the outside, they will have some similarities.

The second direction is to extract tables from ARIZ, make the transition to the table system, and use the Matrix method to solve problems. That finally will lead to the utilization of computers. We are not talking about a simple increase in the number of lines and columns in the Matrix. To create "invention machines," it is necessary to change the principle for constructing these matrices.

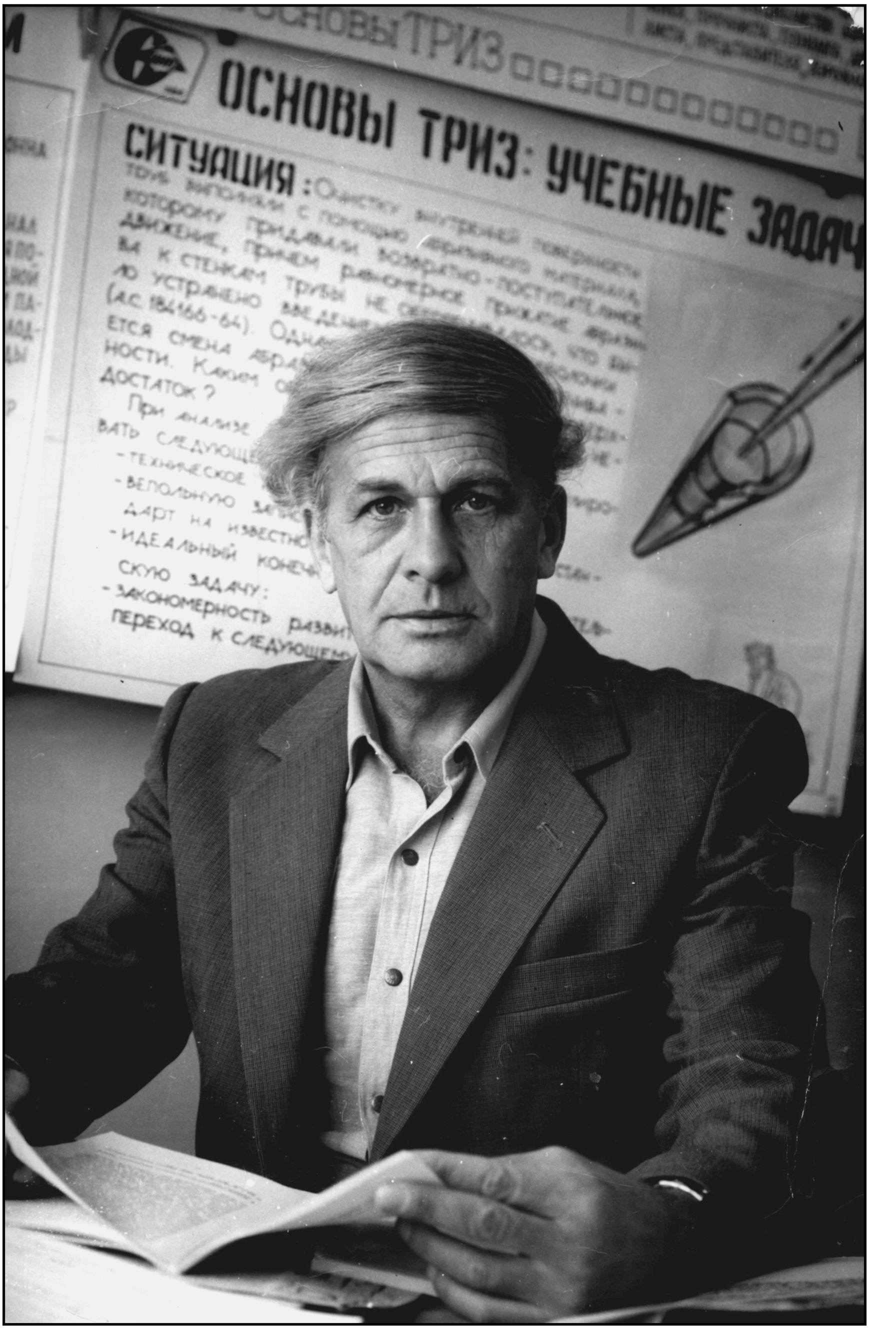
Utilization of computers to solve inventive problems does not abolish creativity.

Imagine a person digging in the ground with his bare hands —this is the model of inventing by the "trial and error" method. Let's now give this person a tool —a shovel, a pick, or maybe a pneumatic hammer. This is the model of inventing with ARIZ. Now, the model of an inventing process using computers is to place the person on a power shovel. In all these cases, the *person works.* The progress arms the person with better tools: in one case, it is his hands; in another —his brain.

Today, most inventors work by the "trial and error" method, sorting all kinds of "what if we can do this?" questions. The ground is getting harder and harder; however, the inventors scrape it with their bare hands. The tragedy of this situation is deepened by the fact that scientists study the psychology of a person scraping the ground and hope to discover the so-called secrets of fortunate digging. Meanwhile, we can already give the digger more effective tools today —and tomorrow, place him at the excavator's controls.

The theory of inventiveness is still in its formative stage. It can be compared with aviation at the beginning of the 20th Century when flight seemed like a wild dream. The majority of people prefer marching in place —the same old familiar place. Nevertheless, we are beginning to grope at new ideas that will lead us to our highest flights.

And so, our work continues.

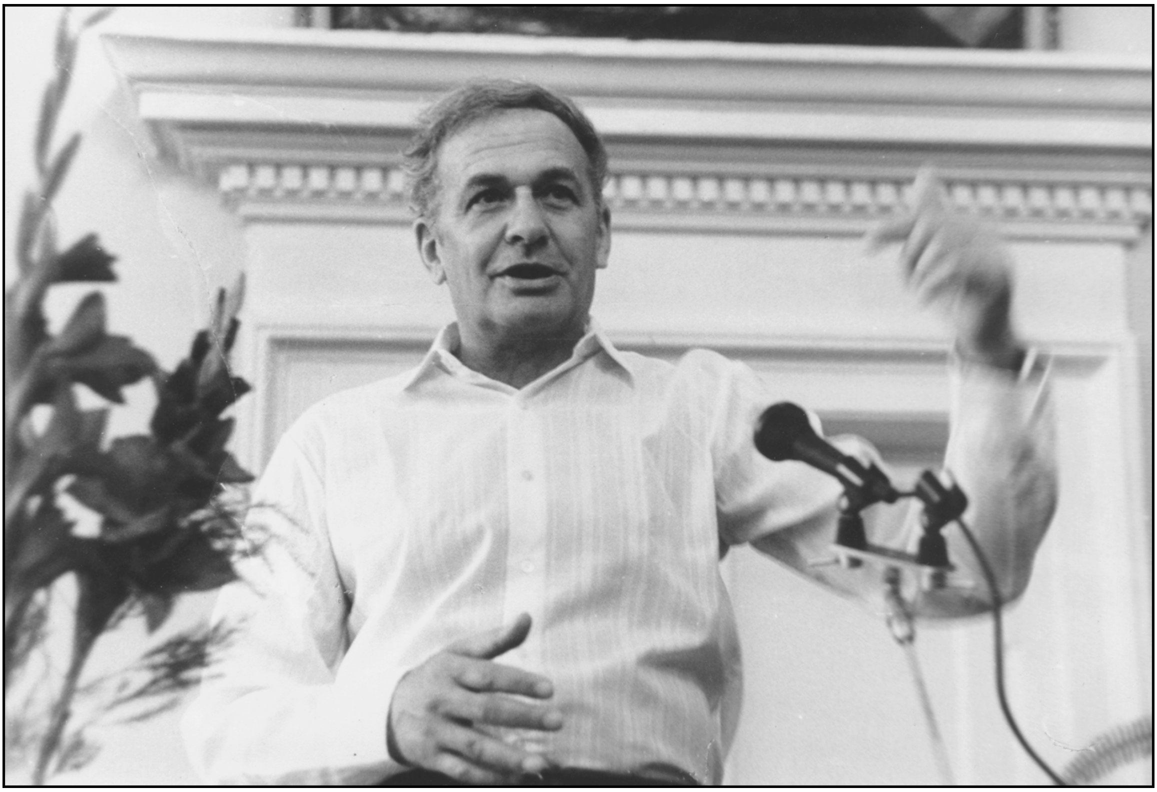


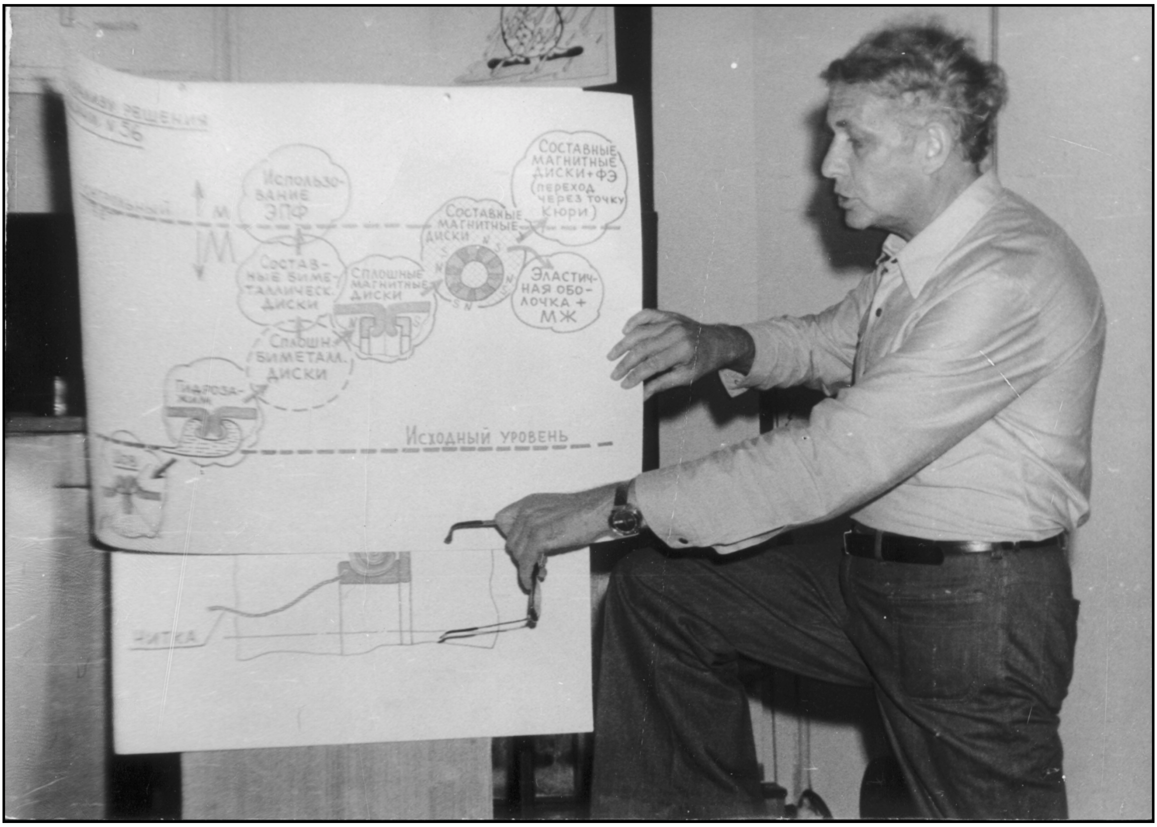
Photographs of Genrich Altshuller provided by Simon Litvin, Aleksandr Selioutski, and extracted from the video "The Interesting Problems Club," produced in 1974 by Central Screen Film Production, Baku, Azerbaijan.

Appendix 1

Contradiction Matrix

with the 40 Principles



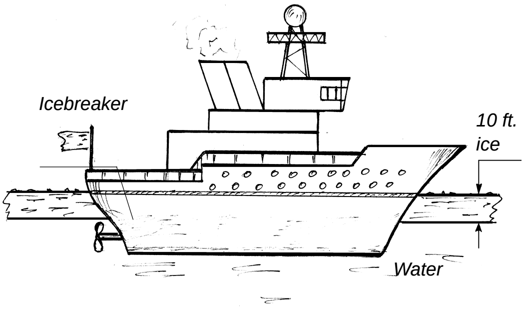

РЕШЕНИЯ
№56
Использование ЭПФ
М
Составные биметаллическ. диски
Сплошн. биметалл. диски
Гидрозажим
Сплошные магнитные диски
N
S
Составные магнитные диски
Составные магнитные диски + ФЭ (переход через точку Кюри)
Эластичная оболочка + МЖ
Исходный уровень
НИТКА

Using the Contradiction Matrix

A step-by-step walkthrough of the Contradiction Matrix using a sample problem

❧

by Lev Shulyak



Icebreaker: It is necessary to move cargo in the winter through waterways that can be covered by as much as 10 feet of ice. Traditionally, icebreakers have been used to open a channel through the ice for a convoy of ships to follow. The icebreaker can only advance at a speed of 2 km/hr. We need to increase this rate to at least 6 km/hr, although faster would be even more desirable. Alternative means of transportation are not acceptable. Our investigation shows that the icebreaker has the most efficient engine available in industry at this time.

Answer*: The main goal is to increase the ship's speed from 2 km/hour to at least 6 km/hour (i.e., increase the ship's productivity). A common way of achieving this is to increase the power of the ship's engine. Increasing the power produces chain-effects on other parameters of the ship (power train area, total weight of the ship, and so on). These changes are undesirable. Therefore, the existing technical contradictions (TC) are:

TC-1: *"Speed"* versus *"Power."*
TC-2: *"Productivity"* versus *"Power."*

In the Matrix we find the appropriate lines and columns. Line 9 for Speed, line 39 for Productivity and column 21 for Power. In the table below, the two contradictions are shown.

Let's analyze some of the suggested principles. All numbers in bold indicate the "best" suggestions.

1. **Principle #19, Periodic Action,** reads:
   a. Replace a continuous action with a periodic one (impulse).
   b. If the action is already periodic, change its frequency.
   c. Use pauses between impulses to provide an additional action.

Utilizing either of these principles can provide an ice breaking action. **Example:** Instead of continuously pushing the ship through the ice, a rocking motion can be used to break the ice and then move forward.

Technical Contradictions	Matrix Coordinates	Suggested Principle	Principle Name
1. Speed / Power	9 x 21	19 **35** 38 **2**	Periodic Action Transformation of Properties Accelerated Oxidation Extraction
2. Productivity / Power	39 x 21	**35** 20 **10**	Transformation of Properties Continuity of Useful Action Prior Action

2. **Principle #35, Transformation of Properties,** reads:
   a. Change the physical state of the system.
   b. Change the concentration or density.
   c. Change the degree of flexibility.
   d. Change the temperature or volume.

These principles suggest changing the physical state or density of that part of the ship which interacts with the ice. This suggestion is repeated in both contradiction statements. How can the density or physical state of the ship be changed? We will come to that later. Meanwhile, lets examine Principle #2:

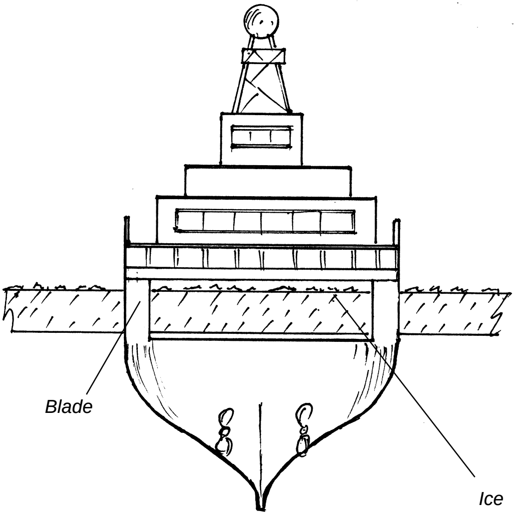
3. **Principle #2, Extraction,** reads:
   a. Extract the "disturbing" part or property from an object.
   b. Extract only the necessary part or property from an object.

This principle suggests removing that part of the ship interfering with the ice.

4. **Principle #10, Prior Action,** reads:
   a. Perform required changes to an object completely or partially in advance.
   b. Place objects in advance so that they can go into action immediately from the most convenient location.

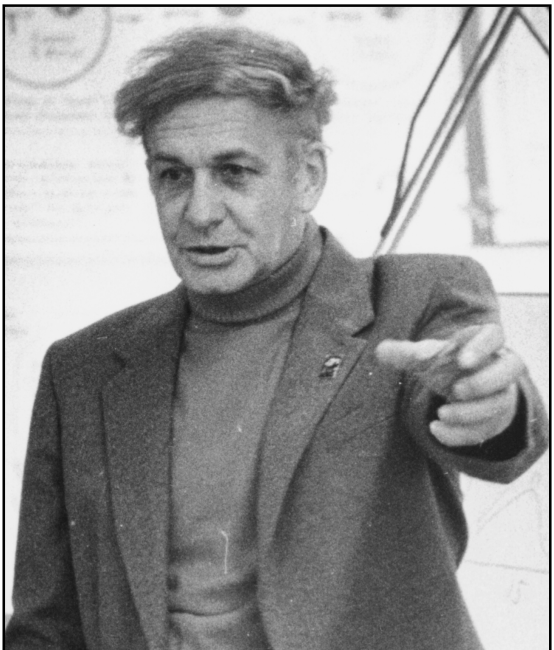
Principle #10 suggests doing something with the ship in advance of its interaction with the ice.

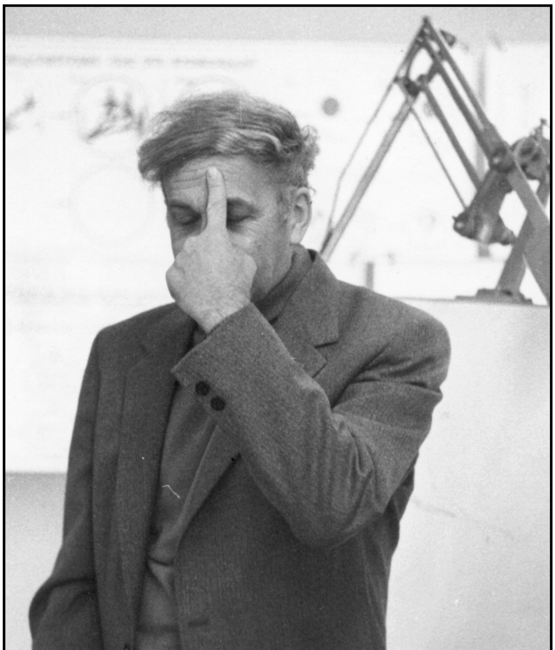
Conclusion: The majority of principles suggest changing that part of the ship which contacts the ice. Removing the part completely allows the ship to move through the ice with no problem — except that the bottom part of the ship will sink to the ocean floor. To prevent this, both the upper and lower parts of the ship can be connected by two thin vertical blades that cut the ice much more easily. Minimizing the profile of the ship reduces its drag as it cuts through the ice. The bottom part of the ship will stay below the ice while carrying cargo. Now the icebreaker also doubles as a cargo ship.

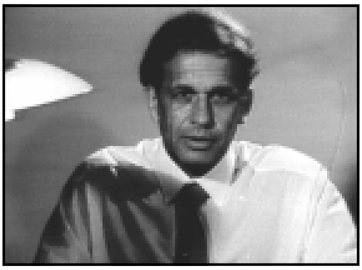


* Here is an analysis of the icebreaker problem. However, we do not intend to provide an engineering implementation of the proposed concepts. Our goal is to point out the directions of possible engineering design.


8
БЫЙ ВЕТЕР НЕ ЗАКРЫВАЕТ ЛЕПЕСТКИ, НО И
ПЕРЕНОСИТ ПЫЛЬЦУ. НЕОБХОДИМО ПРИ МИНИ-
МАЛЬНЫХ ИЗМЕНЕНИЯХ В СИСТЕМЕ ОБЕСПЕЧИТЬ ПЕ-
РЕНОС ПЫЛЬЦЫ ВЕТРОМ ВОЗДУХОДУВКИ.
ТП-1
ТП-2
(ВКЛЮЧАЯ И
ОПЕРАТИВНАЯ ЗОНА
3.4. Оперативное время.
Все время действия
ильного ветра.
3.5. Усиленный ИКР
Измененный в
лепестков сам обеспе-
чивает раз
е положение лепест-
ков, не м
осу пыльцы очень
сильн
ИКР. Лепестки сами
тся при очень сильном ветре).








ПРИНЦИ
СНОГО ДЕЙ
ПРИНЦИ


ПРИНЦИП
СНОГО ДЕ
ПРИНЦИП


PORSCHE

Contradiction Matrix

CHARACTERISTICS			Characteristic that is getting worse									
			1	2	3	4	5	6	7	8	9	10
Characteristics to be improved	1	Weight of a mobile object	■	–	15, 8 29, 34	–	29, 17 38, 34	–	29, 2 40, 28	–	2, 8 15, 38	8, 10 18, 37
	2	Weight of a stationary object	–	■	–	10, 1 29, 35	–	35, 30 13, 2	–	5, 35 14, 2	–	8, 10 19, 35
	3	Length of a mobile object	8, 15 29, 34	–	■	–	15, 17 4	–	7, 17 4, 35	–	13, 4 8	17, 10 4
	4	Length of a stationary object	–	35, 28 40, 29	–	■	–	17, 7 10, 40	–	35, 8 2, 14	–	28, 10
	5	Area of a mobile object	2, 17 29, 4	–	14, 15 18, 4	–	■	–	7, 14 17, 4	–	29, 30 4, 34	19, 30 35, 2
	6	Area of a stationary object	–	30, 2 14, 18	–	26, 7 9, 39	–	■	–	–	–	1, 18 35, 36
	7	Volume of mobile object	2, 26 29, 40	–	1, 7 4, 35	–	1, 7 4, 17	–	■	–	29, 4 38, 34	15, 35 36, 37
	8	Volume of a stationary object	–	35, 10 19, 14	19, 14	35, 8 2, 14	–	–	–	■	–	2, 18 37
	9	Speed	2, 28 13, 38	–	13, 14 8	–	29, 30 34	–	7, 29 34	–	■	13, 28 15, 19
	10	Force	8, 1 37, 18	18, 13 1, 28	17, 19 9, 36	28, 10	19, 10 15	1, 18 36, 37	15, 9 12, 37	2, 36 18, 37	13, 28 15, 12	■
	11	Tension/Pressure	10, 36 37, 40	13, 29 10, 18	35, 10 36	35, 1 14, 16	10, 15 36, 28	10, 15 36, 37	6, 35 10	35, 24	6, 35 36	36, 35 21
	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
	13	Stability of composition	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
	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
	15	Time of action of a moving object	19, 5 34, 31	–	2, 19 9	–	3, 17 19	–	10, 2 19, 30	–	3, 35 5	19, 2 16
	16	Time of action of a stationary object	–	6, 27 19, 16	–	1, 40 35	–	–	–	35, 34 38	–	–
	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
	18	Brightness	19, 1 32	2, 35 32	19, 32 16	–	19, 32 26	–	2, 13 10	–	10, 13 19	26, 19 6
	19	Energy spent by a moving object	12, 18 28, 31	–	12, 28	–	15, 19 25	–	35, 13 18	–	8, 35	16, 26 21, 2
	20	Energy spent by a stationary object	–	19, 9 6, 27	–	–	–	–	–	–	–	36, 37
	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	Loss 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
	23	Loss of a 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
	24	Loss of an information	10, 24 35	10, 35 5	1, 26	26	30, 26	30, 16	–	2, 22	26, 32	–
	25	Loss 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
	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
	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
	28	Accuracy of measurement	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
	29	Accuracy of manufacturing	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
	30	Harmful factors acting on an object from outside	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
	31	Harmful factors developed by an object	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
	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
	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
	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
	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
	36	Complexity of a device	26, 30 34, 36	2, 26 35, 39	1, 19 26, 24	26	14, 1 13, 16	6, 36	34, 26 6	1, 16	34, 10 28	26, 16
	37	Complexity of control	27, 26 28, 13	6, 13 28, 1	16, 17 26, 24	26	2, 13 18, 17	2, 39 30, 16	29, 1 4, 16	2, 18 26, 31	3, 4 16, 35	36, 28 40, 19
	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
	39	Capacity / 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

Characteristic that is getting worse														Characteristics to be improved
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	
10, 36 37, 40	10, 14 35, 40	1, 35 19, 39	28, 27 18, 40	5, 34 31, 35	–	6, 29 4, 38	19, 1 32	35, 12 34, 31	–	12, 36 18, 31	6, 2 34, 19	5, 35 3, 31	10, 24 35	1
13, 29 10, 18	13, 10 29, 14	26, 39 1, 40	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	2
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1, 14 35	13, 14 15, 7	39, 37 35	15, 14 28, 26	–	1, 40 35	3, 35 38, 18	3, 25	–	–	12, 8	6, 28	10, 28 24, 35	24, 26	4
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6, 18 38, 40	35, 15 18, 34	28, 33 1, 18	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	9
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19, 3 27	14, 26 28, 25	13, 3 35	27, 3 10		–	19, 35 39	2, 19 4, 35	28, 6 35, 18	–	19, 10 35, 38	–	28, 27 3, 18	10	15
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35, 39 19, 2	14, 22 19, 32	1, 35 32	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	–	17
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2, 32 12	15, 34 29, 28	32, 35 30	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	33
13	1, 13 2, 4	2, 35	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	–	34
35, 16	15, 37 1, 8	35, 30 14	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
19, 1 35	29, 13 28, 15	2, 22 17, 19	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	–	36
35, 36 37, 32	27, 13 1, 39	11, 22 39, 30	27, 3 15, 28	19, 29 39, 25	25, 34 6, 35	3, 27 35, 16	2, 24 26	35, 38	19, 35 16	19, 1 16, 10	35, 3 15, 19	1, 18 10, 24	35, 33 27, 22	37
13, 35	15, 32 1, 13	18, 1	25, 13	6, 9	–	26, 2 19	8, 32 19	2, 32 13	–	28, 2 27	23, 28	35, 10 18, 5	35, 33	38
10, 37 14	14, 10 34, 40	35, 3 22, 39	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	39

CHARACTERISTICS			Characteristic that is getting worse									
			25	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**
Characteristics to be improved	1	Weight of a mobile object	10, 35 20, 28	3, 26 18, 31	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
	2	Weight of a stationary object	10, 20 35, 26	19, 6 18, 26	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
	3	Length of a mobile object	15, 2 29	29, 35	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
	4	Length of a stationary object	30, 29 14	–	15, 29 28	32, 28 3	2, 32 10	1, 18	–	15, 17 27	2, 25	3
	5	Area of a mobile object	26, 4	29, 30 6, 13	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
	6	Area of a stationary object	10, 35 4, 18	2, 18 40, 4	32, 35 40, 4	26, 28 32, 3	2, 29 18, 36	27, 2 39, 35	22, 1 40	40, 16	16, 4	16
	7	Volume of mobile object	2, 6 34, 10	29, 30 7	14, 1 40, 11	26, 28	25, 28 2, 16	22, 21 27, 35	17, 2 40, 1	29, 1 40	15, 13 30, 12	10
	8	Volume of a stationary object	35, 16 32, 18	35, 3	2, 35 16	–	35, 10 25	34, 39 19, 27	30, 18 35, 4	35	–	1
	9	Speed	–	10, 19 29, 38	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
	10	Force	10, 37 36	14, 29 18, 36	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
	11	Tension/Pressure	37, 36 4	10, 14 36	10, 13 19, 35	6, 28 25	3, 35	22, 2 37	2, 33 27, 18	1, 35 16	11	2
	12	Shape	14, 10 34, 17	36, 22	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
	13	Stability of composition	35, 27	15, 32 35	–	13	18	35, 24 30, 18	35, 40 27, 39	35, 19	32, 35 30	2, 35 10, 16
	14	Strength	29, 3 28, 10	29, 10 27	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	Time of action of a moving object	20, 10 28, 18	3, 35 10, 40	11, 2 13	3	3, 27 16, 40	22, 15 33, 28	21, 39 16, 22	27, 1 4	12, 27	29, 10 27
	16	Time of action of a stationary object	28, 20 10, 16	3, 35 31	34, 27 6, 40	10, 26 24	–	17, 1 40, 33	22	35, 10	1	1
	17	Temperature	35, 28 21, 18	3, 17 30, 39	19, 35 3, 10	32, 19 24	24	22, 33 35, 2	22, 35 2, 24	26, 27	26, 27	4, 10 16
	18	Brightness	19, 1 26, 17	1, 19	–	11, 15 32	3, 32	15, 19	35, 19 32, 39	19, 35 28, 26	28, 26 19	15, 17 13, 16
	19	Energy spent by a moving object	35, 38 19, 18	34, 23 16, 18	19, 21 11, 27	3, 1 32	–	1, 35 6, 27	2, 35 6	28, 26 30	19, 35	1, 15 17, 28
	20	Energy spent by a stationary object	–	3, 35 31	10, 36 23	–	–	10, 2 22, 37	19, 22 18	1, 4	–	–
	21	Power	35, 20 10, 6	4, 34 19	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
	22	Loss of energy	10, 18 32, 7	7, 18 25	11, 10 35	32	–	21, 22 35, 2	21, 35 2, 22	–	35, 32 1	2, 19
	23	Loss of a substance	15, 18 35, 10	6, 3 10, 24	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
	24	Loss of an information	24, 26 28, 32	24, 28 35	10, 28 23	–	–	22, 10 1	10, 21 22	32	27, 22	–
	25	Loss of time		35, 38 18, 16	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
	26	Amount of substance	35, 38 18, 16		18, 3 28, 40	3, 2 28	33, 30	35, 33 29, 31	3, 35 40, 39	29, 1 35, 27	35, 29 25, 10	2, 32 10, 25
	27	Reliability	10, 30 4	21, 28 40, 3		32, 3 11, 23	11, 32 1	27, 35 2, 40	35, 2 40, 26	–	27, 17 40	1, 11
	28	Accuracy of measurement	24, 34 28, 32	2, 6 32	5, 11 1, 23		–	28, 24 22, 26	3, 33 39, 10	6, 35 25, 18	1, 13 17, 34	1, 32 13, 11
	29	Accuracy of manufacturing	32, 26 28, 18	32, 30	11, 32 1	–		26, 28 10, 36	4, 17 34, 26	–	1, 32 35, 23	25, 10
	30	Harmful factors acting on an object from outside	35, 18 34	35, 33 29, 31	27, 24 2, 40	28, 33 23, 26	26, 28 10, 18		–	24, 35 2	2, 25 28, 39	35, 10 2
	31	Harmful factors developed by an object	1, 22	3, 24 39, 1	24, 2 40, 39	3, 33 26	4, 17 34, 26	–		–	–	–
	32	Manufacturability	35, 28 34, 4	35, 23 1, 24	–	1, 35 12, 18	–	24, 2	–		2, 5 13, 16	35, 1 11, 9
	33	Convenience of use	4, 28 10, 34	12, 35	17, 27 8, 40	25, 13 2, 34	1, 32 35, 23	2, 25 28, 39	–	2, 5 12		12, 26 1, 32
	34	Repairability	32, 1 10, 25	2, 28 10, 25	11, 10 1, 16	10, 2 13	25, 10	35, 10 2, 16	–	1, 35 11, 10	1, 12 26, 15	
	35	Adaptability	35, 28	3, 35 15	35, 13 8, 24	35, 5 1, 10	–	35, 11 32, 31	–	1, 13 31	15, 34 1, 16	1, 16 7, 4
	36	Complexity of a device	6, 29	13, 3 27, 10	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
	37	Complexity of control	18, 28 32, 9	3, 27 29, 18	27, 40 28, 8	26, 24 32, 28	–	22, 19 29, 28	2, 21	5, 28 11, 29	2, 5	12, 26
	38	Level of automation	24, 28 35, 30	35, 13	11, 27 32	28, 26 10, 34	28, 26 18, 23	2, 33	2	1, 26 13	1, 12 34, 3	1, 35 13
	39	Capacity / Productivity	–	35, 38	1, 35 10, 38	1, 10 34, 28	18, 10 32, 1	22, 35 13, 24	35, 22 18, 39	35, 28 2, 24	1, 28 7, 19	1, 32 10, 25

35	36	37	38	39	
29, 5 15, 8	26, 30 36, 34	28, 29 26, 32	26, 35 18, 19	35, 3 24, 37	1
19, 15 29	1, 10 26, 39	25, 28 17, 15	2, 26 35	1, 28 15, 35	2
14, 15 1, 16	1, 19 26, 24	35, 1 26, 24	17, 24 26, 16	14, 4 28, 29	3
1, 35	1, 26	26	–	30, 14 7, 26	4
15, 30	14, 1 13	2, 36 26, 18	14, 30 28, 23	10, 26 34, 2	5
15, 16	1, 18 36	2, 35 30, 18	23	10, 15 17, 7	6
15, 29	26, 1	29, 26 4	35, 34 16, 24	10, 6 2, 34	7
–	1, 31	2, 17 26	–	35, 37 10, 2	8
15, 10 26	10, 28 4, 34	3, 34 27, 16	10, 18	–	9
15, 17 18, 20	26, 35 10, 18	36, 37 10, 19	2, 35	3, 28 35, 37	10
35	19, 1 35	2, 36 37	35, 24	10, 14 35, 37	11
1, 15 29	16, 29 1, 28	15, 13 39	15, 1 32	17, 26 34, 10	12
35, 30 34, 2	2, 35 22, 26	35, 22 39, 23	1, 8 35	23, 35 40, 3	13
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15, 17 13, 16	2, 29 27, 28	35, 38	32, 2	12, 28 35	19
–	–	19, 35 16, 25	–	1, 6	20
19, 17 34	20, 19 30, 34	19, 35 16	28, 2 17	28, 35 34	21
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15, 10 2	35, 10 28, 24	35, 18 10, 13	35, 10 18	28, 35 10, 23	23
–	–	35, 33	35	13, 23 15	24
35, 28	6, 29	18, 28 32, 10	24, 28 35, 30	–	25
15, 3 29	3, 13 27, 10	3, 27 29, 18	8, 35	13, 29 3, 27	26
13, 35 8, 24	13, 35 1	27, 40 28	11, 13 27	1, 35 29, 38	27
13, 35 2	27, 35 10, 34	26, 24 32, 28	28, 2 10, 34	10, 34 28, 32	28
–	26, 2 18	–	26, 28 18, 23	10, 18 32, 39	29
35, 11 22, 31	22, 19 29, 40	22, 19 29, 40	33, 3 34	22, 35 13, 24	30
–	19, 1 31	2, 21 27, 1	2	22, 35 18, 39	31
2, 13 15	27, 26 1	6, 28 11, 1	8, 28 1	35, 1 10, 28	32
15, 34 1, 16	32, 26 12, 17	–	1, 34 12, 3	15, 1 28	33
7, 1 4, 16	35, 1 13, 11	–	34, 35 7, 13	1, 32 10	34
	15, 29 37, 28	1	27, 34 35	35, 28 6, 37	35
29, 15 28, 37		15, 10 37, 28	15, 1 24	12, 17 28	36
1, 15	15, 10 37, 28		34, 21	35, 18	37
27, 4 1, 35	15, 24 10	34, 27 25		5, 12 35, 26	38
1, 35 28, 37	12, 17 28, 24	35, 18 27, 2	5, 12 35, 26		39

Characteristics to be improved

PRINCIPLES	
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The 40 Principles

1. **Segmentation**
   a. Divide an object into independent parts.
   b. Make an object sectional (for easy assembly or disassembly).
   c. Increase the degree of an object's segmentation.

2. **Extraction**
   (Extracting, Retrieving, Removing)
   a. Extract the "disturbing" part or property from an object.
   b. Extract only the necessary part or property from an object.

3. **Local Quality**
   a. Transition fromhomogeneous to heterogeneous structure of an object or outside environment (action).
   b. Different parts of an object should carry out different functions.
   c. Each part of an object should be placed under conditions that are most favorable for its operation.

4. **Asymmetry**
   a. Replace symmetrical form(s) with asymmetrical form(s).
   b. If an object is already asymmetrical, increase its degree of asymmetry.

5. **Consolidation**
   a. Consolidate in space homogeneous objects, or objects destined for contiguous operations.
   b. Consolidate in time homogeneous or contiguous operations.

6. **Universality**
   a. An object can perform several different functions; therefore, other elements can be removed.

7. **Nesting** (Matrioshka)
   a. One object is placed inside another. That object is placed inside a third one. And so on . . .
   b. An object passes through a cavity in another object.

8. **Counterweight**
   a. Compensate for the weight of an object by combining it with another object that provides a lifting force.
   b. Compensate for the weight of an object with aerodynamic or hydrodynamic forces influenced by the outside environment.

9. **Prior Counteraction**
   a. Preload countertension to an object to compensate excessive and undesirable stress.

10. **Prior Action**
    a. Perform required changes to an object completely or partially in advance.
    b. Place objects in advance so that they can go into action immediately from the most convenient location.

11. **Cushion in Advance**
    a. Compensate for the relatively low reliability of an object with emergency measures prepared in advance.

12. **Equipotentiality**
    a. Change the condition of the work in such a way that it will not require lifting or lowering an object.

13. **Do It in Reverse**
    a. Instead of the direct action dictated by a problem, implement an opposite action (i.e., cooling instead of heating).
    b. Make the movable part of an object, or outside environment, stationary — and stationary part moveable.
    c. Turn an object upside-down.

14. **Spheroidality**
    a. Replace linear parts with curved parts, flat surfaces with spherical surfaces, and cube shapes with ball shapes.
    b. Use rollers, balls, spirals.
    c. Replace linear motion with rotational motion; utilize centrifugal force.

15. Dynamicity

- a. Characteristics of an object or outside environment, must be altered to provide optimal performance at each stage of an operation.
- b. If an object is immobile, make it mobile. Make it interchangeable.
- c. Divide an object into elements capable of changing their position relative to each other.

16. Partial or Excessive Action

- a. If it is difficult to obtain 100% of a desired effect, achieve more or less of the desired effect.

17. Transition Into a New Dimension

- a. Transition one-dimensional movement, or placement, of objects into two-dimensional; two-dimensional to three-dimensional, etc.
- b. Utilize multi-level composition of objects.
- c. Incline an object, or place it on its side.
- d. Utilize the opposite side of a given surface.
- e. Project optical lines onto neighboring areas, or onto the reverse side, of an object.

18. Mechanical Vibration

- a. Utilize oscillation.
- b. If oscillation exists, increase its frequency to ultrasonic.
- c. Use the frequency of resonance.
- d. Replace mechanical vibrations with piezo-vibrations.
- e. Use ultrasonic vibrations in conjunction with an electromagnetic field.

19. Periodic Action

- a. Replace a continuous action with a periodic one (impulse).
- b. If the action is already periodic, change its frequency.
- c. Use pauses between impulses to provide additional action.

20. Continuity of Useful Action

- a. Carry out an action without a break. All parts of the object should constantly operate at full capacity.
- b. Remove idle and intermediate motion.
- c. Replace "back-and-forth" motion with a rotating one.

21. Rushing Through

- a. Perform harmful and hazardous operations at a very high speed.

22. Convert Harm Into Benefit

- a. Utilize harmful factors —especially environmental —to obtain a positive effect.
- b. Remove one harmful factor by combining it with another harmful factor.
- c. Increase the degree of harmful action to such an extent that it ceases to be harmful.

23. Feedback

- a. Introduce feedback.
- b. If feedback already exists, change it.

24. Mediator

- a. Use an intermediary object to transfer or carry out an action.
- b. Temporarily connect the original object to one that is easily removed.

25. Self-service

- a. An object must service itself and carry-out supplementary and repair operations.
- b. Make use of waste material and energy.

26. Copying

- a. A simplified and inexpensive copy should be used in place of a fragile original or an object that is inconvenient to operate.
- b. If a visible optical copy is used, replace it with an infrared or ultraviolet copies.
- c. Replace an object (or system of objects) with their optical image. The image can then be reduced or enlarged.

27. Dispose

- a. Replace an expensive object with a cheap one, compromising other properties (i.e., longevity).

28. Replacement of Mechanical System

a. Replace a mechanical system with an optical, acoustical, thermal or olfactory system.
b. Use an electric, magnetic or electromagnetic field to interact with an object.
c. Replace fields that are:
  1. Stationary with mobile.
  2. Fixed with changing in time.
  3. Random with structured.
d. Use fields in conjunction with ferromagnetic particles.

29. Pneumatic or Hydraulic Constructions

a. Replace solid parts of an object with a gas or liquid. These parts can now use air or water for inflation, or use pneumatic or hydrostatic cushions.

30. Flexible Membranes or Thin Films

a. Replace customary constructions with flexible membranes or thin film.
b. Isolate an object from its outside environment with flexible membranes or thin films.

31. Porous Material

a. Make an object porous, or use supplementary porous elements (inserts, covers, etc.).
b. If an object is already porous, fill pores in advance with some substance.

32. Changing the Color

a. Change the color of an object or its environment.
b. Change the degree of translucency of an object or its environment.
c. Use color additives to observe an object or process which is difficult to see.
d. If such additives are already used, employ luminescent traces or trace atoms.

33. Homogeneity

a. Objects interacting with the main object should be made out of the same material (or material with similar properties) as the main object.

34. Rejecting and Regenerating Parts

a. After completing its function, or becoming useless, an element of an object is rejected (discarded, dissolved, evaporated, etc.) or modified during its work process.
b. Used-up parts of an object should be restored during its work.

35. Transformation of Properties

a. Change the physical state of the system.
b. Change the concentration or density.
c. Change the degree of flexibility.
d. Change the temperature or volume.

36. Phase Transition

a. Using the phenomena of phase change (i.e., a change in volume, the liberation or absorption of heat, etc.).

37. Thermal Expansion

a. Use expansion or contraction of material by changing its temperature.
b. Use various materials with different coefficients of thermal expansion.

38. Accelerated Oxidation

a. Make transition from one level of oxidation to the next higher level:
  1. Ambient air to oxygenated.
  2. Oxygenated to oxygen.
  3. Oxygen to ionized oxygen.
  4. Ionized oxygen to ozoned oxygen.
  5. Ozoned oxygen to ozone.
  6. Ozone to singlet oxygen.

39. Inert Environment

a. Replace a normal environment with an inert one.
b. Introduce a neutral substance or additives into an object.
c. Carry out the process in a vacuum.

40. Composite Materials

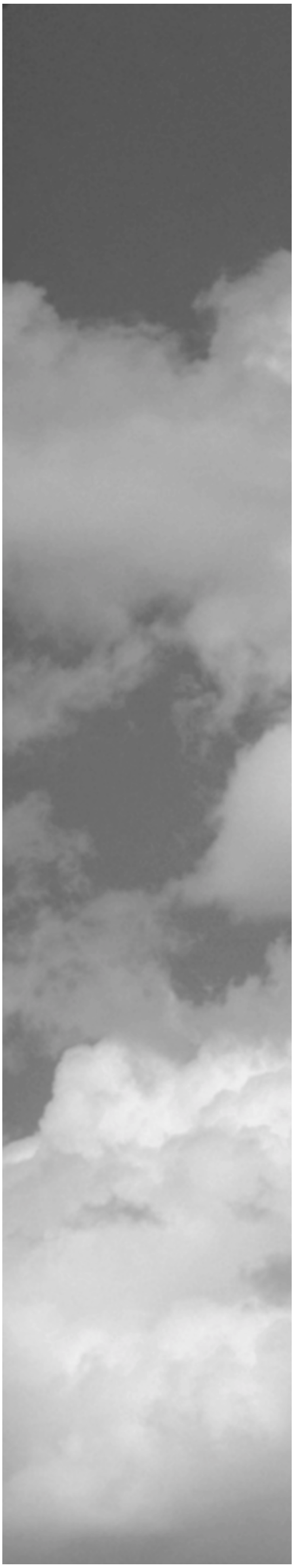
a. Replace homogeneous materials with composite ones.

Appendix 2

General Tendencies of Technical System Evolution

General Tendencies of Technical System Evolution

Levels	Structure of the System	Problems, Difficulties, Conflicts: the Sources of the Problem	Typical Mistakes while Solving the Problem	Basic Directions of Evolution
1	A | B | C . . . . Pre-system level Independent objects.	Some objects reach the plateau of their development and utilization.	The desire to continue improving these objects.	Consolidation of independent objects into a system.
Transition from Level 1 to Level 2	A + B . . . Primary unstable system.	Absence of necessary system parts. Wrong parts are incorporated. Parts interact poorly.	Introduce the most highly developed object from the series A_1, A_2, A_3, ... However, this is not always the proper object for a given system.	Search for a “Cinderella” object. Replace missing object with a human (*H*).
2	[A + *H* + B + *H* + C . . .] Stable system. Objects become part of the system, with each part working independently; however, the system produces its product only when all parts are in action.	Resources of system development limited only by capacity of the human portion of the system.	Desire to improve parts A and B . . . while preserving *H* - parts	Replacement of human (*H*) parts with device (*D*).
Transition from Level 2 to Level 3	(A + *Dh* + B + *Dh* + . . .) Unstable system. Device D_h copies human actions.	Devices *Dh* (copying human action) limits the ability for development of entire system.	Improvements of each separate element without considering that they now compose a complete system.	Transition from mechanical set of parts to organically interwoven synthetic system of elements.
3	$[E_1 + E_2 + E_3 + E_4 + . . .]$ Stable, continuously developing system. Some of its parts become element E of the system, and as rule, can work only together.	When one element improves while significantly worsening other elements (or the entire system), the technical contradiction appears.	Desire to gain in one area without consideration of loses in another.	Development of specialized systems.
3^1	$[E_1' + E_2' + E_3' + E_4' + . . .$ $E_1'' + E_2'' + E_3'' + E_4'' . . .]$ Specialized, continuously developing, stable systems.	As the system specializes further, its area of utilization shrinks, down time increases, and efficiency declines.	Desire to continue specialization; development of various specialized systems.	Reconstruction of complete system: transition to other physical or chemical principles of action. For instance, from mechanical to electrical.
Transition from Level 3 to Level 4	$[E_1'\ E_1'' + E_2'\ E_2'' + E_3'\ E_3'' + . . .]$ Combination becomes an unstable system.	Significant increase in system complexity. Reduction of ability for development.	Continuous search for different combinations of elements (subsystems).	Transition to other physical or chemical principles of action.
4	$[SuS_1 + SuS_2 + SuS_3 + . . .]$ Stable, continuously developing system based upon new principles. Elements of the system rapidly develop into subsystems, (SuS.)	System development at some point gets into conflict with outside environment by creating in it unacceptable changes.	Desire to smooth out conflict by adding intermediate subsystems	Transition from an open system to a closed one, independent from outside environment.
Transition From Level 4 to Level 5	Unstable system. During working cycle (or part of cycle) an enclosed system is activated.	Complication of design. Limited time of action.	Continuous development of different subsystems.	Reconstruction of com-plete system: Transition to new principles of action. For instance, from macro- to micro-process on molecular, nuclear, or elementary particle level. Transition from “substances” as an instrument to utilization of electromagnetic and other fields.
5	Stable, continuously developing closed system.	The number of subsystems rapidly grows.	Continuous development of a system and its subsystems.	Transition to super-system: the given system becomes an element of another system at a much higher level.
	$[S_1 + S_2 + S_3 + S_4 + . . .]$ The self developing system.			



Appendix 3

Supplemental Material

СОЮЗ СОВЕТСКИХ СОЦИАЛИСТИЧЕСКИХ РЕСПУБЛИК

КОМИТЕТ ПО ДЕЛАМ ИЗОБРЕТЕНИЙ И ОТКРЫТИЙ
при СОВЕТЕ МИНИСТРОВ СССР

АВТОРСКОЕ СВИДЕТЕЛЬСТВО

№ 211116

На основании полномочий, предоставленных Правительством СССР, Комитет по делам изобретений и открытий при Совете Министров СССР выдал настоящее свидетельство

Всесоюзному институту по проектированию организации энергетического строительства

на изобретение Весовой порционный дозатор для трудносыпучих материалов.

по заявке № 1102202 с приоритетом от 10 сентября 1966 г.

автор изобретения ШУЛЯК Лев Абрамович,
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Начальник отдела

Московская печатная фабрика Гознака. 1967. Зак. 17132.

An example of a Soviet Author's Certificate.
This certificate dated September 10, 1966 was awarded to Lev Shulyak
and other inventors for a batching system for hard flowing materials.

Altshuller's "TRIZ Masters"

Just before his death, Genrich Altshuller made a list of what he called "TRIZ Masters." The list was submitted by his wife, V. Zuravliova, to the Russian newsletter *News of the TRIZ Movement*, where it was published in an extensive email sent by the TRIZ-Info Publishing Center, Cheliabinck Russia, for the period of July–September 1998.

The publishers feel that it is important that these people receive the recognition due them, so we are including the list as it appeared in the newsletter.

* * *

"I am supporting, and granting, the following list of candidates to receive the

Diploma of TRIZ Master:

To some candidates from this list I would give the Diploma "TRIZ Master Plus." However, we have only one blank form of Diploma.
This list, with small corrections, was made a year and a half to two years ago. Today, this list can be expanded, and we could consider that, for the first approximation, this work is complete. The list contains candidates without consideration of whether they are members of the International TRIZ Association. All of them did a great job towards developing the *Theory for Solving Inventive Problems, TRIZ."*

Г Альтшуллер

The list of candidates for the Diploma of "TRIZ Master" is on the following pages.

Amnuel, Pesah —Baku (now in Israel)
Bdulenko, Margarita —Krasnogorsk
Beliltzev, Baleri —Voronez
Bukhman, Isak —Riga (now in USA)
Vikentiev, Igor —Sankt-Petersburg
Vertkin, Igor —Baku (now in England)
Gasanov, Aleksandr —Moscow
Gerasimov, Vladimir —Sankt-Petersburg (now in USA)
Gorin, Yri —Penza
Gorchakov, Igor —Ribinsk
Golovchenko, Georgi —Ekaterinbourgh
Gubanov, Sergei —Novosibirsk
Gin, Anatoli —Gomel
Gafitulin, Marat —Zukovski
Zlotin, Boris —Kishinev (now in USA)
Zusman, Alla —Kishinev (now in USA)
Zlotin, Fira —Sankt-Petersburg (now in Israel)
Zinovkina, Miloslava —Moscow
Ivanov, Gennadi —Angarsk
Ilovaiski, Igor —Novosibirsk
Kaloshin, Nikolai —Moscow
Kriachko, Valentina —Sankt-Petersburg
Kaner, Vadim —Sankt-Petersburg
Kislov, Aleksandr —Sankt-Petersburg
Kravtzov, Sergei —Semipalatinsk
Kolchev, Nikolai —Sosnovi Bor
Linkova, Nina —Moscow
Litvin, Semeon —Sankt-Petersburg (now in USA)
Limarenko, Anatoli —Vladivostok
Ladoshkin, Victor —Novosibirsk
Liubomirski, Aleksandr —Sankt-Petersburg (now in USA)
Magidenko, Vladimir —Komsomolsk na Amur
Meerovoch, Mark —Odessa
Mikhailov, Valeri —Cheboksari
Mitrofanov, Boluslav —Sankt-Petersburg
Murashkovski, Yli —
Nikashin, Aleksandr —Rostov na Donu
Harbut, Aleksei —Saporozie
Narbut, Natalia —Saporozie
Podkatilin, Alaksei —Moscow
Pigorov, Georgi —Dnepropetrovsk
Pevsner, Lev —Ekaterinbourgh
Petrov, Vladimir —Sankt-Petersburg (now in Israel)

Rubin, Michail —Petrosavodsk
Royzen, Zinovy —Kishinev (now in USA)
Salamatov, Yri —Krasnoiarsk
Sibiriakov, Vissarion —Novosibirsk
Selioutski, Aleksandr —Petrosavodsk
Sichev, Valeri —Rostov na Donu
Salnikov, Vadim —Samara
Sklobovski, Kiril —Obninsk (now in USA)
Stupniker, Yri —Dnepropetrovsk (now in Israel)
Srigub, Aleksandr —Petrosavodsk
Simohov, Victor —Gomel
Corgashev, Aleksandr —Novosibirsk
Fey, Victor —Baku (now in USA)
Fedosov, Yri —Sankt-Petersburg
Filkovsk,i Gennadi —Baku (now in USA)
Khomenko, Nikolai —Minsk
Kholkin, Igor —Moscow
Tzourikov, Valeri —Minsk (now in USA)
Shusterman, Michail —Norilsk
Shulyak, Lev —Moscow (now in USA)
Sharapov, Michail —Magnitogorsk
Shargina, Larisa —Odessa

TRIZ Providers

Ideation International, Inc.
21800 West 10 Mile Road
Suite 119
Southfield, MI 48075
Boris Zlotin,
Chief Scientist and TRIZ Master
Tel. (248) 353-1313.

Invention Machine Corp.
200 Portland Street,
Boston, MA 021114-1722
Val Tsourikov,
CEO and TRIZ Master.
Tel. (617) 305-9250.

Renaissance Leadership Institute, Inc.
P.O. Box 659
9907 Camper Lane,
Oregon House, CA 95962
Jim Kowalick, President.
Tel. (916) 692-1944.

Pragmatic Vision, Inc.
200 Portland Street,
Boston, MA 021114-1722
Simon Litvin,
Vice President and TRIZ Master
Tel. (617) 305-9260

Strategic Product Innovation, Inc.
7591 Brighton Road,
Brighton, MI 48116
Steven Ungvari, President.
Tel. (810) 220-8440.

Technical Innovation Center, Inc.
60 Prescott Street
Worcester, MA 01605
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Tel. (508) 799-6700
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Email: tic@triz.org
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TRIZ Consulting, Inc.
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Seattle, WA 98177
Zinovy Roysen,
President and TRIZ Master
Tel. (206) 364-3116

The Altshuller Institute for TRIZ Studies
www.aitriz.org

About the Author, Genrich Altshuller

by Leonid Lerner

The person we are going to discuss is unique.
He is unique not just because he developed an amazing science.
He is unique because he never asked for anything in return.
He never said, "Give me."
He always said, "Take this."
His name is Genrich Altshuller.

* * *

LETTER TO STALIN

In December of 1948, while a Lieutenant of the Caspian Sea Military Navy, Genrich Altshuller wrote a dangerous letter addressed: "Personally to Comrade Stalin." The author pointed out to his country's leader that there was chaos and ignorance in the USSR's approach to innovation and inventing. At the end of the letter he expressed an even more "outrageous" thought: There exists a theory that can help any engineer invent. This theory could produce invaluable results and revolutionize the technical world. The harsh answer to this letter did not arrive until two years later. Meanwhile, let's introduce this brash young Lieutenant.

Genrich Altshuller was born on October 15, 1926 in Tashkent in the former USSR. He spent many years in Baku, the Capital of Azerbaidzhan. Since 1990 he has resided in Petrozavodsk, Karelia.

Altshuller received his first Author's Certificate [internal Russian patent] for an underwater diving apparatus while a student in the ninth grade. In the tenth grade he built a boat having a rocket engine that used carbide for fuel. In 1946 he developed his first mature invention, a method for escaping from an immobilized submarine without diving gear. This invention was immediately classified as a military secret —and Altshuller was offered employment in the patent department of the Caspian Sea Military Navy.

The head of that patent department was a man who indulged in fantasies. He asked Altshuller to find a solution to one fantasy: find a military diversion to help a soldier trapped behind enemy lines with no resources. In response, Altshuller invented a new kind of weapon —an extremely noxious chemical substance made from common medical drugs. This invention was a success, and the inventor was brought to meet Mr. Beria, the head of the KGB in Moscow. Four years later, while in one of Beria's prisons, Altshuller would be charged with disrupting a parade in Red Squire with this same invention.

Altshuller was a successful young inventor. What triggered his desire to write a letter to Stalin that would destroy his carrier and change his life forever?

"The point is, " Altshuller says, "not only did I have to invent, I had to help those who wanted to invent as well."

Dozens of people came to his office. "Here is a problem," they said. "I cannot solve it. What can I do?" In response, Altshuller searched all the scientific libraries but did not find even the most elementary text book on the subject of inventing. Scientists claimed that inventions were the result of accidents, mood, or "blood type." Altshuller could not accept this —if a methodology for inventing did not exist, one should be developed.

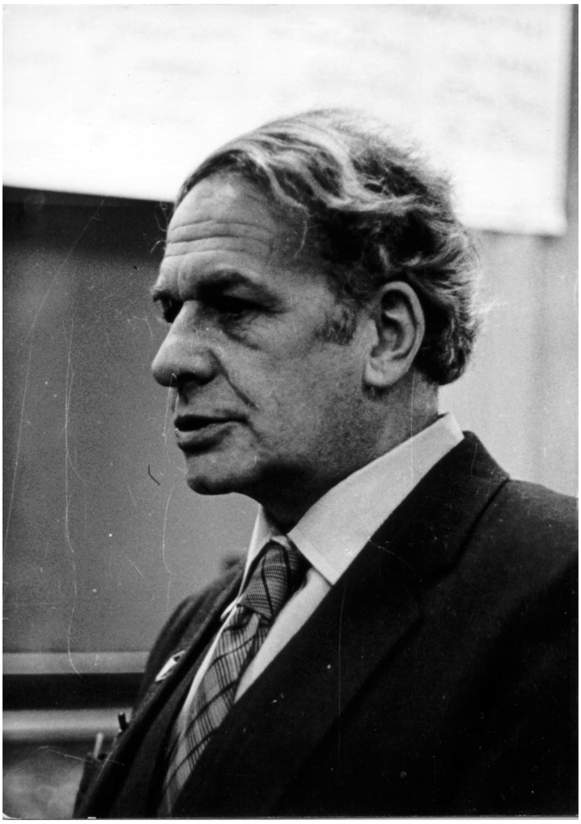
Altshuller shared his ideas with his former schoolmate Rafael Shapiro, an inventor driven to achieve maximum success. By this time, Altshuller had already learned that invention is nothing more than the removal of a technical contradiction with the help of certain principles. Invention is certain if an inventor possesses knowledge of these principles. Shapiro was exited about this discovery and suggested that they should immediately write a letter to Stalin to get his support.

Altshuller and Shapiro prepared themselves. They searched for new methods, studied all the existing patents and took part in inventing competitions. They even received a National Competition Award for inventing a flame and heat resistant suit. Suddenly, they were asked to come to Tbilisi, a town in Georgia. They were arrested as they arrived and, two days later, their interrogation began. They were charged with "inventor's" sabotage and, as was usual in those days, sentenced to 25 years imprisonment.

This happened in 1950. The reader may think this is the beginning of a story about "a martyr for his ideas." However, Altshuller views his arrest differently.

"Before prison, I struggled with simple human doubts. If my ideas were so important, why weren't they recognized? All my doubts were resolved by the MGB [Moscow Committee of State Security]." After his arrest a series of situations occurred where, in order to stay alive, Altshuller utilized TRIZ (The Theory of Solving Inventive Problems) concepts as his only means of defense.

In a Moscow prison, Altshuller refused to sign a confession and was placed on an "interrogation conveyor." All night he was questioned. During



the day, he was not allowed to sleep. Altshuller understood that he could not survive under these conditions. He stated the problem: How can I sleep and not sleep at the same time? The task seemed unsolvable. The most rest he was permitted was to sit with his eyes open. This meant that, in order to sleep, his eyes must be open and closed at the same time. This was easy. Two pieces of paper were torn from a cigarette package. With a charred match, he drew a pupil on each piece of paper. Altshuller's roommate spit on the papers and stuck them to Altshuller's closed eyes. After that he sat across from the door's peek hole and calmly fell asleep. He was thus able to sleep for several days in a row. His interrogator wondered why Altshuller seemed fresh every night.

Finally, Altshuller was sentenced to Siberia's Gulag where he worked 12 hours every day logging. Knowing that he could not survive working so hard, he asked himself the question: "Which is better —continue to work, or refuse and be put into solitary confinement?" He choose confinement and was transferred to a section with criminals. Here survival was much simpler. He befriended the prisoners by telling them many fictional stories he new by heart.

Later, Altshuller was transferred to a camp were the older intelligentsia —scientists, lawyers, architects —were slowly dying. To cheer up these desperate people, Altshuller opened his "One Student University." Each day, for 12 to 14 hours, he attended classes and seminars that the revived professors gave him. This is how Altshuller received his "college education."

In the Varkuta coal mines —another gulag camp —he spent 8 to 10 hours a day developing his TRIZ theory while constantly resolving emergency technical situations in the mines. Nobody believed that this young inventor was working in the mines for the first time. Everybody thought he was tricking them. The chief engineer did not want to hear that TRIZ methods were helping.

One night, Altshuller heard that Stalin had died. A year and a half later, Altshuller was released. Upon his return to Baku he learned that his mother, having lost all hope of ever seeing her son, committed suicide.

In 1956, the first paper written by Altshuller and Shapiro, "Psychology of Inventive Creativity," was published in the journal *Voprosi of Psihologi* [Problems of Psychology]. For scientists who study the creative process it was as if a bomb had exploded. Until that time, Soviet and foreign psychologists believed it a fact that inventions were born through accidental enlightenment —the sudden spark of an idea.

After analyzing a fund of worldwide patents, Altshuller offered a different method based on the results of human inventive activity. Invention derives from a problem analysis revealing a contradiction.

After studying 200,000 patents, Altshuller concluded that there are about 1,500 technical contradictions that can be resolved relatively easily by applying fundamental principles.

"You can wait a hundred years for enlightenment, or you can solve the problem in 15 minutes with these principles," he said.

What would Altshuller's opponents say if they knew that the obscure "H. Altov" [Altshuller's pen name] was making a living writing science fiction stories utilizing TRIZ concepts? Altov wrote his fictions utilizing his inventive ideas. In 1961 Altshuller wrote his first book *How to Learn to Invent*. In this small book he laughs at the popular opinion that one must be born an inventor. He criticizes the trial and error method used to make discoveries. Fifty thousand readers, each paying only 25 kopecks [25 cents], learned the first 20 inventive methods of TRIZ.

In 1959, trying to get acceptance of his theory, Altshuller wrote a letter to the highest patent organization in the former Soviet Union —VOIR [All Union Society of Inventors and Innovators]. He asked for a chance to prove his theory. Nine years later, after writing hundreds of letters, he finally got his answer. His requested seminar on inventive methodology would be held in Dsintary, Georgia, not later than December of 1968.

It was the first ever seminar on TRIZ. There for the first time he met people who had considered themselves his students. Alexander Selioutski from Petrosavodsk, Voluslav Mitrofanov from Leningrad, Isaak Buchman from Riga, and others. These young engineers —and later many others — would open TRIZ schools in their cities. Hundreds of people that went through Altshuller's schools asked him to come and conduct seminars in different towns of the Soviet Union.

In 1969 Altshuller published a new book: *Algorithm of Inventing*. In this book he gave his readers and students 40 Principles, and the first algorithm to solve complex inventive problems.

Voluslav Mitrofanov, the founder of Leningrad University of Technical

Creativity, told a story about Robert Anglin, a prominent inventor from Leningrad. Once, Anglin —who has over 40 inventions developed through the agony of trial-and-error creativity —came to a TRIZ seminar. He was very quiet during the TRIZ training session. After everyone had left, he was still sitting at the table, covering his head with his hands. "How much time was wasted!" he was saying. "How much time ... If I only knew TRIZ earlier!"

The Russian TRIZ Association was established in 1989 with Altshuller as President.

This is an excerpt from an article written by Leonid Lerner and published in the Russian Magazine Ogonek in 1991. It was translated and originally published in English as part of the book *40 Principles.* Mr. Altshuller died September 24, 1998

* * *

About the Translators

Lev A. Shulyak, an inventor for almost four decades, was born in Moscow, USSR.

In 1954, he received his degree as a Mechanical Engineer from the Moscow College of Highway Construction.

He worked as a mechanical engineer on the construction of BRATSK, the biggest hydropower station of its time, helping to design, manufacture and implement the first automatic system for producing wet concrete mix.

In 1961 he bought Genrich Altshuller's first book on the subject of inventing: *How to Become an Inventor*. This book helped him in the problem solving process and, within a year, he received his first patent for an electromechanical transducer.

From 1961 to 1974, he received 15 patents on automatic control systems and mechanical equipment. These inventions helped save millions of *rubbles* in the construction of several hydropower stations.

In 1973, Shulyak completed his Masters Degree in Mechanical Engineering. The following year, he emigrated to the United States. Settling in Worcester, Massachusetts, Shulyak was employed by Norton Company as a Project Manager from 1976 to 1983. Using his knowledge in TRIZ he saved hundreds of thousands of dollars for this company by redesigning process equipment.

Shulyak has received four American patents on different consumer products, some of which he has successfully manufactured and marketed.

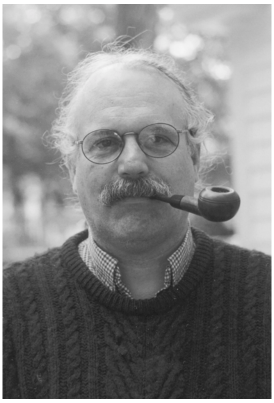
In 1984, he was the first person in the United States to teach engineers and children TRIZ methodology.

In 1991, he founded the Technical Innovation Center and began teaching courses on TRIZ-based Systematic Innovation to inventors, engineers and children. He has co-translated, with Steven Rodman, several books by Altshuller, including *And Suddenly the Inventor Appeared (1995)*, *40 Principles (1998)*, and *The Innovation Algorithm (1999).* In September, 1998, he was named a TRIZ MASTER by Genrich Altshuller.

Today Mr. Shulyak is dedicating himself to fulfilling his dream of building a center for innovation and creativity —the Altshuller Institute for TRIZ

Studies. On October 15, 1998 the Institute was officially founded. It will continue to promote TRIZ while furthering its development and dissemination around the world.

* * *



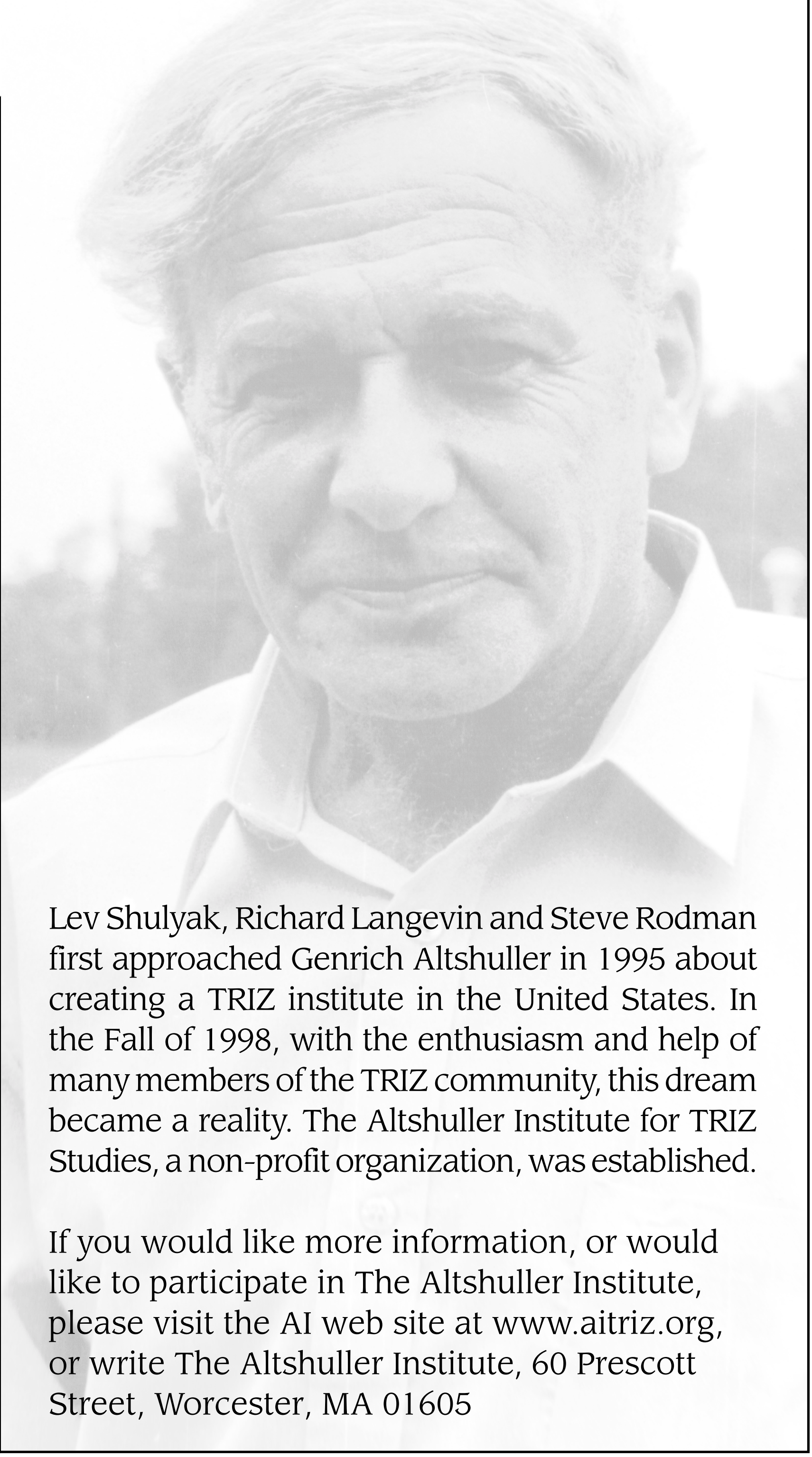
Steven Rodman is a writer, educator, and computer and media consultant. His interest in TRIZ began soon after meeting Lev Shulyak in 1993.

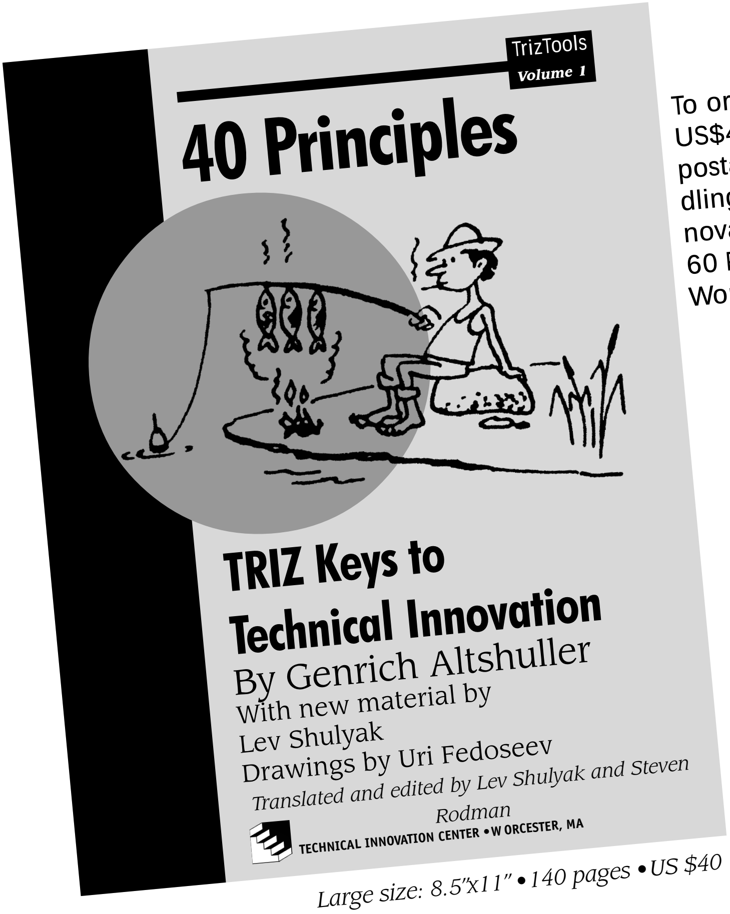
In addition to being a founder and principal in Technical Innovation Center, Inc., where he is Vice President of Publications and Technology, he is also a founder and member of the Windchime Group and ConVergence: New Media Design.

Previously, he was a Senior Technical Instructor at Prime Computer in Ireland, Puerto Rico and Framingham, U.S. (where he was also the Systems Administrator for the Advance Manufacturing Training Department). After ten years with Prime, he served five years as Director of Information Systems and Technologies at *Worcester Magazine*, *Worcester Business Journal*, and the *Hartford Business Journal*. He has also been a senior staff writer for *Worcester Business Journal*, and a contributing writer to *Worcester Magazine* and other publications.

Rodman has studied TRIZ since 1993, primarily under the tutelage of Lev Shulyak. He has also studied under several other Russian TRIZ masters. He was instrumental in the formation of The Altshuller Institute for TRIZ Studies.

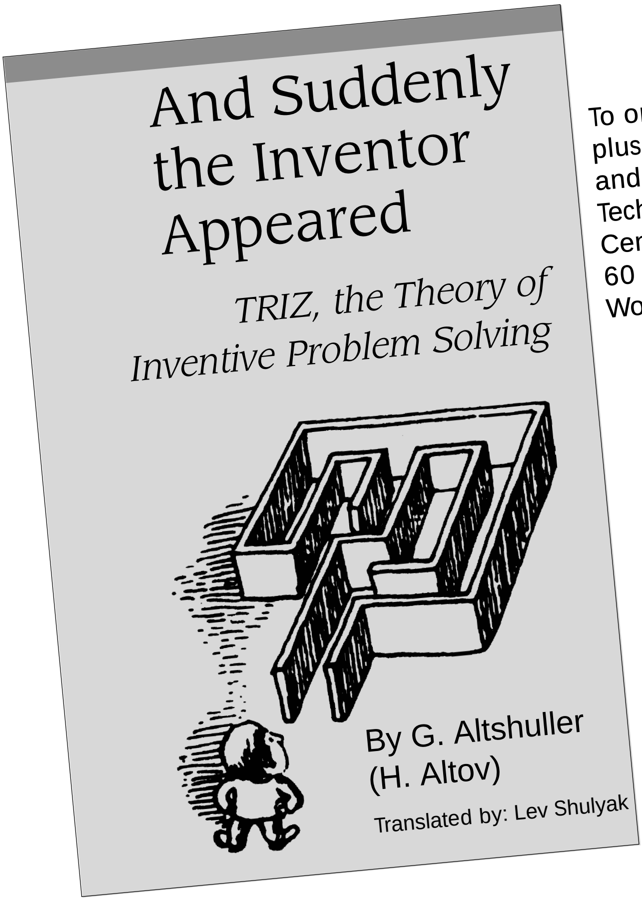
This is the third TRIZ book by Genrich Altshuller he has collaborated on with Lev Shulyak.





"A landmark text, the best introduction to TRIZ available in English"

— Larry R. Smith, *Ford Motor Company.*



And Suddenly the Inventor Appeared

TRIZ, the Theory of Inventive Problem Solving

By G. Altshuller
(H. Altov)

Translated by: Lev Shulyak

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— George M. Prince, *Co-founder of Synectics, Inc.*

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* * *

________________ of 250