Inventive Thinking through TRIZ

Michael A. Orloff

Inventive Thinking through TRIZ

A Practical Guide

Second Edition

With 232 Figures

Springer

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Dedicated to my son Alexey
with love and respect
for his hearty generosity,
purposefulness
and
courage

A heuristic program is necessary for effective solutions to the requirements of inventing at a higher level that replaces the continuously new selection of variations with a goal-oriented movement into the area of the solution.

Genrikh Altshuller

Algorithm of Inventing
Moscow, 1973

TRIZ at the Beginning of the 21st Century

Author's Foreword

It is never too early to think about tomorrow.
Federico Mayor[*]

Humanity developed on the stepping stones of inventions. Brilliant inventions brought humanity to breathtaking heights. Millions of other inventions made these stepping stones and the entire construct of civilization secure. The rise of civilization accelerated continuously.

But, the process of inventing remained the same throughout the ages. There was intellectual torture about a problem, a search in all possible directions, countless unsuccessful attempts, stumbling, total loss in a labyrinth, circular movement in fog, and - very rarely - unexpected ideas shone like a light in the deepest darkness, like the realization of our dearest dreams or a cure for an incurable disease. This is how we invented. Sometimes inventors searched their entire lives long.

There were many enthusiasts who attempted to uncover the secret of the birth of inventing. Brilliant scientists tried to develop theories of creativity. Great pragmatists collected hordes of useful suggestions to stimulate the development of ideas and put them to use. However, all of this was only marginally successful in praxis.

It was impossible to learn how to invent!

This was only because it was impossible to explain and pass on individual and historical experience while inventing. Well-known descriptions of inventive creativity were written down in metaphors with emotional language and individual suggestions and recommendations. This was not done scientifically: there were no laws or methods. It was also not possible to treat inventing like an art because even art can be learned and taught to a great degree.

Despite this fact, civilization rose steadily. Enthusiasm about the progress exemplified by automobiles, aircraft, space rockets, by the Internet and cellular phones was so great and so universal that very few people in the 20th century also recognized the deadly threats that these devices in their complexity represent for humanity.

Even the shocking truth about coming global catastrophes caused by the destruction of nature by industry and technology was not sufficiently sobering. Lack of responsibility and egotism in many technocratic structures, the lack of critical knowledge about questions of global survival, and the lack of globally coordinated institutions, not to mention problems in the consolidation of the efforts of all industrialized countries - all of this has to be changed from the ground up as quickly as possible.

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[*] Federico Mayor – former General Secretary of the UNESCO (2002)

A secure future has to be the goal and motivation of every attempt at progress and of all politics. Engineers, teachers, and scientists can assume a part of their personal responsibility in such attempts. We should all search for organizational and technical possibilities individually and with our fellow professionals that can help avoid technogenic - and therefore - sociogenic catastrophes.

When we consider the extremely short time for inventions and the practical application of essential ideas, it is not enough to rely on the methods for finding new ideas that our wonderful, yet so imperfect civilization has created. Perhaps this civilization is sometimes so deficient because the methods that have shaped it are imperfect.

Who controls the development of humanity? Can we really make a reliable prognosis about our best way into the future? How can sociogenic, geogenic, and cosmic catastrophes be avoided? How can we insure the progress and security of coming generations?

TRIZ teaches us how to make inventions!
TRIZ teaches us how to construct the future!
TRIZ changes your thinking, i.e., all of civilization, too!

Rational decisions about the problems above cannot be made today without the use of TRIZ.

TRIZ will be an invaluable part of all the possible sciences and learning processes that remain from the 2^{nd} millennium AD. What could be more valuable than a science about *how we can learn to think effectively, to become an inventor, or even a genius!*

The following are the essential concepts of TRIZ in its modern form:

1. All systems (not only technical systems) are developed to fulfill a certain function, the system's so-called useful primary function. Systems are developed according to the certain laws that can be perceived and used to shape the development of systems.
2. All systems strive to enhance their effectiveness during their life cycle. Effectiveness can be understood as the ratio between positive factors from the implementation of useful functions and negative factors - such as compensation for harmful effects on the environment - that arise from the development, use, and application of the system.
3. All systems and components develop differently in comparison to other systems in their environment. This is the main cause of slow growth in the effectiveness of systems and of technical problems.
4. Contradictions between incompatible characteristics and requirements that prevent the achievement of the useful primary function of the components and the system create the basis for all technical problems.
5. A solution for such a contradiction with technical means is then an invention.

6. The number of different types of contradictions is limited. This allows us to perceive them precisely in real problems and to evaluate them with adequate methods for a solution.
7. Adequate methods for the solution of contradictions can be developed by investigating a sufficient number of a representative selection of real inventions along with patent descriptions and technical literature.
8. Methods for the solution of contradictions can be developed along with procedures for the development and stimulation of memory, attention, associative thinking, imagination, and various useful characteristics of the intellect and psyche.
9. Methods for the solution of contradictions can be applied along with other methods used to shape the development of complex systems - economic, system-technical, cultural-educational, and even political methods.

Several thousand inventions were examined for the development of the first navigators in TRIZ for the solution of contradictions. The number of investigated inventions is now more than 2.5 million. TRIZ navigators have proven effective for many years and continue to be applied successfully.

At the beginning of the 21st century, TRIZ is the only constructive theory of invention and, based on its essence, of engineering creativity. TRIZ has in no way been developed fully. It must be further developed, structured, and supplied with axioms. Special and combined theories and methods can be developed along with TRIZ, such as the integrated theory **CROST – Constructive Resource-Oriented Strategy of Thinking & Transforming** that was developed by the author of this textbook. In accordance with the model of TRIZ, still more patents and scientific-technical literature should be examined. However, the main principles of TRIZ are still invariable, just like with every other effective theory. They can therefore be considered as classical principles.

Although time and a special praxis are required for a study of the basis of TRIZ, this theory will prove itself in your future activities, regardless of your profession. The methods of TRIZ allow you to find valuable solutions more quickly and with less effort. TRIZ is simply irreplaceable for solutions to extremely difficult problems. In my almost 40 years of TRIZ praxis since 1963 when I read my first small book [1] by Genrikh Altshuller, I have heard of no one who had abandoned it after studying its methods and models. At this point, I would like to quote a statement by the author of TRIZ:

"TRIZ supports thinking, it doesn't replace it".

I would like to thank many specialists who have supported my idea to write the first textbook on the principles of classical TRIZ. Conversations with Prof. H.-J. Linde (FH Coburg) and Dr. R. Thiel, Dr. D. Zobel as well as Dr. M. Herrlich were especially helpful.

Meetings with Prof. W. Beitz and Prof. G. Seliger (Technical University Berlin) helped me become familiar with the creative components of university education in Germany. Prof. G. Ropohl's (J. W. Goethe-University, Frankfurt am Main) ideas about the problems and the role of technocracy in the maintenance and further development of civilization - impossible without environmental protection and humanistic social ethics - and his supportive letters reinforced my plans.

I cannot mention everyone here who helped enable us to live and work in Germany. However, my special thanks go to Udo Matusch (engineer and entrepreneur, head of the firm AMT Automatisierungstechnik GmbH, Essen) who was the first person to invite me to Germany and who allowed me to work on an adaptation of the TRIZ methodology for Germany at his company for 2 years.

My heartfelt thanks go to the engineer and inventor Katharina Koterewa, head of the firm ZWEK Vakuumtechnik GmbH in Apolda, who provided ideal conditions for me at her home in Thueringia's mountains to order my thoughts and maintain hope and optimism in a very difficult situation during my move to Berlin. I would like to thank my friend Heinrich Kochs (recently specialist at VOLKSWAGEN) for the many days for thought and discussion, for my first introduction into the German everyday, and for the use of his garden house with a large library and the best conditions for my work in a wonderfully quiet region in the woods near Hannover. My great thanks go to Dr. Lydia Dessau, the manager of Innovation Centre IGZ-OWZ Berlin, who allowed me to work in her firm and who worked together with us to deal with the difficulties in establishing my first German firm. I would like to thank her husband, Hartmut Dessau, an employee at SIEMENS who always supported us with his constructive criticism. I thank both of them that they offered us their idyllic weekend house on the river Dahme for a long time.

My thanks also go to my colleagues Harald Lemanski and Siegfried Helling. And I hope that the translation of this textbook into English in creative cooperation with Dr. Cary Henderson - a translation that reproduces the spirit of TRIZ - helps my readers connect positively with the book.

I am especially thankful to Prof. Dr. Martin Moehrle (University Bremen) whose energetic and timely support first made it possible for me to continue working in Germany and to publish my most important works.

I am extremely thankful to the Springer Publishers, especially to Mrs. Eva Hestermann-Beyerle, Editor of Textbooks Engineering, who made the suggestion to write a textbook on the essential principles of classical TRIZ.

I am hearty thankful to my son Nikolai for contribution to improvement of this book, for subtle understanding TRIZ and belief in TRIZ future.

I wish success to everyone who is not afraid to search for new ideas in the creation and development of technical systems and who remembers that all of our solutions changes humanity in some way.

Michael A. Orloff
Berlin, November 2002 – December 2005

Table of Contents

The methods of inventive creativity are not a recipe for inventions. They can also not replace technical knowledge.

But, it helps to apply the methods called knowledge very effectively.

To study these methods does not guarantee that an inventor will surpass Popov or Edison.

On the other hand, university seminars don't guarantee that a student will exceed Newton or Einstein with time, either.

Genrikh Altshuller

Wings for Icarus
Petrosavodsk, 1980

Introduction

NATURA NIHIL EST CALLIDIUS[1]

1 Invention of Civilization

This is a textbook about inventiveness in technical creative work. Above all else, it is about the highpoint of technical creative work - invention. Humanity has developed on the stepping-stones of inventions[*].

Today, discoveries and inventions move humanity forward faster and faster, as if we stood on a great escalator.

If we assume that today the productive age of an individual is up to 40 years and we then consider the number of generations that have lived through this span of time, we will then be able to correctly assess the developmental speed of civilization for the first time.

Of **1000** generations in the last 40,000 years:

NB {
- more than **800** generations lived without artificial shelters in woods and caves;
- only **120** generations have known and used the wheel;
- about **55** generations have known and used the Archimedes' law;
- about **40** generations have used windmills and watermills;
- about **20** generations have known and used timepieces;
- about **10** generations have known printing;

NNB {
- **5** generations have traveled with ships and trains;
- **4** generations have used electric lights;
- **3** generations have traveled with automobiles, have used telephones and vacuum cleaners;
- **2** generations have traveled with aircraft and used radios and refrigerators;

NNNB {
- **only today's generation** has traveled in outer space, has used atomic energy, PCs and notebooks, and uses artificial satellites to transmit audio, video and other information around the globe.

90 % of the knowledge and all material values that have been arisen in the history of humanity were developed in the 20th century!

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[1] Nothing is more inventive than nature / Marcus Tullius Cicero (106-43 BC), Roman rhetorician, philosopher, statesman

[*] my favourite metaphor from book by Vikentiev I.L. and Kaikov I.K. "The stair of ideas" (in Russian), 1992

It is interesting to note that, as a biological object, the human brain has not changed in the last decades, not in many thousands of years (!). The organization and apparently the working principles of the brain are the same as they were, say, 50,000 years ago.

We can assume that the human brain is supplied with a huge "functional over-capacity" like many biological objects in nature. We can also recognize that nature uses this principle generously to maintain life on the planet, either through the distribution of seeds or through the maintenance of a bio-population of the necessary size. But, the purely biological over-capacity of the brain does not lead to **quality thinking.** This probably explains why the number of really valuable inventions does not exceed 1% of the total number of patents!

Quality thinking can change in many ways and depends on the quality of learning and the subjects learned. Modern technology and the subjects learned by individuals are not without essential faults. Along with the influence of the respective social milieu, this explains why humanity is still developing today according to "biological", stochastic laws. However, this is an unacceptable waste of potential today. It increases the probability that intellectual mediocrity will be reproduced and certainly does not support genius.

We can also see that the wealth of information, the standards, and the meaning of the problems to be solved have changed significantly. Is the human brain still capable of dealing with the continuously growing body of knowledge? Is humanity capable of dependably avoiding or successfully stopping possible catastrophes, some of which are hidden or have developed very slowly? Can humanity shape its future towards harmony and progress? Can humanity invent (or rediscover) the actual criteria for harmony and progress? Doesn't it seem that the only way that humanity can move from it current phase as ***homo sapiens technologicus*** to a phase as ***homo sapiens progressus*** (Latin: *rational, evolving, developing human*) is to create its own ideals for progress and harmony?

But, how do people find ideas for inventions? How do people find creative solutions for non-technical problems? The English philosopher Karl Popper[2] suggested that the correct question would be:

Where do good ideas come from?!

In the 20th century, someone was ready to tell the entire civilized world that it cannot think. This means that people waste their intellectual potential because of poorly organized thinking. Not only do people not learn to think, they also don't suspect that they think ineffectively!

Someone once said the following about his idea: Today, just like thousands of years ago, the method of *try and error* is the basis of thinking. This method is an unstructured guess for some kind of solution. Very few of these ideas are successful, and most of these are abandoned later. This person also said: *Wouldn't it be more logical to learn from success?!* It would be even better to condense the experience gathered from the best solutions into concrete rules and to develop a methodology with complete models or even as a practical theory.

[2] Karl Raimund Popper (1902-1994) - English philosopher

This person's name was **Genrikh Saulovich Altshuller (1926-1998).** In the middle of the 20th century, he developed the "Teorija Reschenija Izobretatel'skich Zadac" that he then called TRIZ (Russian acronym). In English this is a "Theory of Inventive Problem Solving". This is how he outlined new possibilities to learn inventive creativity and its practical application.

TRIZ has established itself more and more since the end of the 20th century. However, a complete textbook on the essential principles of classical TRIZ that everyone can understand has never been written until now. The book you are now reading is just such a textbook.

I hope that TRIZ will help you find the path to new possibilities and success!

2 Reinventing – the Key Concept for the Study of TRIZ

Among other things, this express study and self-taught study of TRIZ uses the following methodological procedure: Before you learn all of the necessary concepts and models, the practical functions of the theory will be demonstrated using simple examples as if you were already familiar with the essential principles of TRIZ.

These examples have been selected and are presented in such a way that they make a movement in thinking clear from the simple to the complex, from the external to the internal, from the concrete to the abstract, and from model to theory. In other words, this express study undertakes a kind of experiment with the objects that are essential factors in the theory. Students of TRIZ can then derive the key concepts of the theory from the experiments on their own.

The objects of classical TRIZ are inventions, technical systems, and their components. The essentials of the initial learning experiments are as follows:

1) Presentation of the key problem that was solved with a concrete invention;
2) Definition of the main procedure that was used to solve the problem with this invention.

The following methodological procedures will then be used later:

1) Generalization and classification of the models of the key problems and of the main procedures used to solve problems with inventing;
2) Presentation of laws for the creation of problems, prognosis, and the controlled and systematic solution of problems.

The process of inventing is the movement of thinking from "what already exists to what is coming*". It is the construction of an intellectual bridge between what is and what is supposed to exist.

Every "bridge" is based on a certain theory. Clearly the "reliability" of a bridge also depends heavily on the theory that provides the basis on which it is built. Classical brainstorming is an example: very few rules, essentially unlimited space to search, lots of enthusiasm and noise. Another example is classical TRIZ: systematic investigation of a task, controlled application of adequate procedures for a

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* I am interpreting a well-know expression and the title of a book by a Nobel Prize laureate, the Belgian bio-physicist Ilya Prigogine (1917-2003)

solution, and directed movement into the useful areas of especially successful solutions.

The basis of the teaching experiments in this study of TRIZ is a methodological procedure that I call "reinventing".

Reinventing – is a demonstration of the process of inventing. It works as if the users already knew the principles and procedures for a solution to the problems that their inventions then address. Reinventing then functions later as a means to strengthen skills for investigating and solving problems after the essential principles of the theory have been mastered. Finally, quick reinventing can be extremely helpful when working with the analogies that are also offered for problem solving in our software (see section 21.3).

This methodological procedure stimulates associative thinking and ensures emotional acceptance and a positive perception of the theory. The student's intuition can then connect extant knowledge, skills, and experience with the key concepts of the theory on its own.

TRIZ is a qualitative theory, not a mathematical or quantitative one. The theory's formal ideas and concepts are like categories, patterns, and metaphors. The procedural methods to solve tasks - methods that consist of several steps - are called algorithms. This is also a metaphor, although it has been shown that this is a completely correct definition in the context of modern constructive mathematics.

When my colleagues reflect on TRIZ as a theory based on the above, they might suggest that it is a conceptual, phenomenological, and finally a psychological theory. In any case, the concepts of the theory reflect its axiomatic and structural principles in a more understandable, non-formal way, even if these concepts are not specifically described in scientific articles or monograms. This mode of description is the point here. The content used for qualitative models (metaphors) is also of interest. As opposed to other procedures, the models of TRIZ are constructive and can be reproduced and taught by its users.

In this textbook, we will avoid the use of formalized constructions, although we have to create and rely on just this kind of construction in our software. It is not our goal to construct formal principles for this theory. Instead, we want to model thinking qualitatively and apply practical models from this theory to real tasks. However, we will certainly not change the terminology of the theory, although we expect you to be just as critical and suspicious of this terminology as for example of words such as *assignment, departure data, solutions, result.* In most practical cases, we also don't need to define exactly which theoretical axioms and formal associations are hidden in the background of these words. Intuitively we understand completely the qualitative essence and content of these words (that is - metaphors and images) with reference to certain concrete tasks.

But let's now examine the fundamental concepts of the theory.

According to its definition, reinventing is the following process (fig. 2.1).

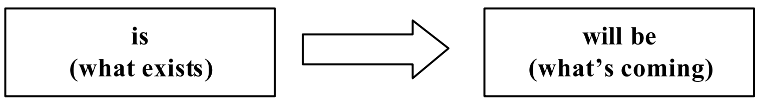

fig. 2.1. Movement of thinking from "what is" to "what's coming"

The arrow above shows thought processes - the "*flow of thought*" and the "*generation of ideas*" – in accordance with the theory's suggestions. Of course, reinventing in the sense of brainstorming reflects the process of brainstorming in solving tasks and assignments. TRIZ reinventing reflects the process of TRIZ in solving tasks and assignments.

How reliable do you think the following suggestions are from one of the versions of a "theory of brainstorming", an example of which is shown in figure 2.2?

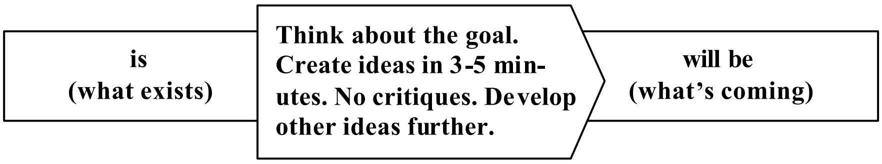

fig. 2.2. Scheme of reinventing based on brainstorming

Don't you also think that it almost seems in this scheme that the entire body of theory from military schools can be reduced to Caesar's[3] somewhat laconic method:

VENI, VIDI, VICI
I came, I saw, and I conquered.

Do you believe that this "method" teaches you to solve problems that require creativity?

What do you think about when you continue to read and see what the "stream of thought" of TRIZ is about (figure 2.3)?

fig. 2.3. An example of reinventing based on TRIZ

Don't you associatively combine these concepts into a chain like the following one:

> ***Using available or newly transformed resources, procedures, and analogies, you remove the contradictions that prevent the achievement of the ideal result.***

I certainly think that this chain looks like a more secure bridge for the movement "from what is – to what's coming"! Usually I demonstrate the principle of reinventing by using a simple example, the "tip of a feather". This is an example of the development of the *working organ* of writing instruments that work with liquids.

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[3] Gaius Julius Caesar (102 or 100 - 44 BC) - Roman statesman, military leader, and author

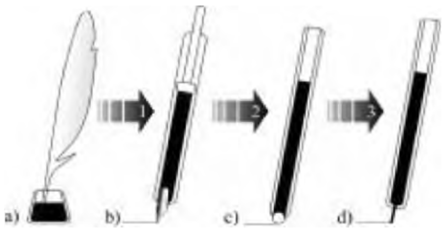

fig. 2.4. Evolution of ink writing tools: a) goose feather with ink; b) fountain pen; c) ball point pen; d) felt-tip pen

Of course, a goose feather with ink (figure 2.4a) was the most widely used means to record and transmit knowledge for ca. 2.5-3 thousand years (!) until the end of the 18th century, when the servant of the mayor of Aachen Janson devised a metal tip for the goose feather of his boss.

Then these tips called pens underwent a long construction-technical evolution.

However, the essence of writing with a pen did not change: the tip had to be dipped into ink and it could then write on paper until the ink on the pen ran out or dried out. The development of writing instruments that led to the first fountain pen (figure 2.4b) did not begin until the beginning of the 20th century (1). 50 years passed until the ball point pen spread rapidly (figure 2.4c). Then the mass use of felt-tip pens (figure 2.4d) started 25 years later. This is two times more quickly - and truly a rapid acceleration.

Let's now use TRIZ reinventing to reconstruct the evolution of writing instruments with liquid.

Example 1. 1st transition: 3000 years from goose feather - to fountain pen. Goose feathers - even when they are equipped with a metal tip - have a major problem in that they don't transmit ink evenly and smoothly onto paper. Either they dry out directly at the tip or they cause spots and puddles. The ink at the tip ran out quickly and the feather had to be accurately dipped into ink and carefully transferred to the paper in such a way that there were no drops.

The useful primary function of a pen as a work organ of the entire writing device is to leave an ink track on paper. Let's call the pen an *instrument* (or even an *actor* or *inductor*, meaning the thing that initiates action). Then the track is the *product* of the pen (or even a *reactor* or *receptor*, meaning the thing that receives or takes in the action, or is produced by the inductor). The ideal track is smooth and has the necessary width. But, what happens in the pen? When there is too little ink on the pen, the track quickly becomes too thin and the pen has to be dipped in ink often. When there is too much ink on the pen, the track can get too wide or spots can occur. This is a clear contradiction between too "little" and too "much".

Let's formulate the *ideal functional model:* there should be so much ink on the tip of the feather that it is possible to create a track of any length and there should also be no ink on the tip so that it cannot dry out or cause drops that then lead to spots.

The requirements presented in this kind of formulation are incompatible! But, this is reality!

There has to be as much ink available as possible during the creation of the track. We call this time when the feather completes its primary operation the *operational time*. At all other times until then, we don't need any ink on the tip of the pen! Doesn't it seem to you that the contradiction has disappeared somewhere?! Somehow we have *solved the contradiction in time.*

It is now time to formulate the clearest version of the ideal functional model: ink moves *by itself* to the tip of the feather when the feather is supposed to create a track. There is no room at the tip of the pen to store a large amount of ink or for a mechanism to regulate the flow of ink. In other words, there are too few *spatial resources.*

Is there an empty space near the tip of the pen? Certainly there is, for example in the hollow space in the goose feather or in a special container that can be attached to the writing instrument. Then this container can be filled with ink and connected to the tip of the feather with a tube equipped "with a small valve".

We can also say that we have *solved the contradiction in space*: it is possible that there is no ink at the tip, but there is a lot of ink nearby! This idea for a solution can also be represented as a *solution to a structural contradiction*: there is a lot of ink in the *entire* fountain pen and in the entire technical system, even though there is no ink in a small *part* of the fountain pen other than during the operational time!

But, how should we approach the requirement that the ink may move *by itself* to the tip of the pen only when a track is to be created?

Let's formulate a concrete version of the ideal functional model: the pen regulates the amount of ink that moves to the tip *by itself*! This means we need a fountain pen with a locking device.

This is how it happened in reality: the tip of the pen was formed in such a way that it consists of two parts. There is a fine canal along the pen to the point where it is connected to one or more thin tubes coupled to a container that stores ink (figure 2.5).

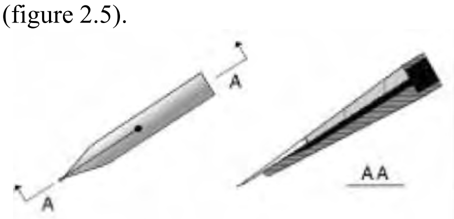

fig. 2.5. Essential construction of a pen

When the fountain pen is not in use, the canal is closed to prevent the movement of ink because both halves of the tip are very close to each other. When the pen is pressed onto paper, the parts of the tip spread and ink flows into the canal that ensues. That's it!

In short, we found an *ideal solution, an ideal final result* in the form of a tip with a locking mechanism. The energy needed for this work comes from the hand that presses on the fountain pen. When we start to write, pressure is transmitted to the tip - the locking mechanism opens. When there is no pressure, it closes!

Here we also see a *solution to a material contradiction*: *resources in construction and in the internal energy of the materials* of the pen (movable properties) and the *energy of an external source* (the resources of the hand) were used to ensure that the canal at the tip has two states (closed and open).

At first this explanation seems very long and not really clear. You are absolutely correct. There is also something else that is problematic. First, several new concepts have been introduced simultaneously. Second, there are many technical solutions to the problem of a fountain pen that can all be described with different versions of reinventing that differ in the depth of their analysis. But, you will soon be able to automatically construct similar explanations on your own for real assignments, not just for teaching examples.

Example 2. 2nd transition: the ball point pen arrives 50 years after the fountain pen. It is easy to perceive that the slightest inconsistency in production or simply with time the ink can flow spontaneously and therefore can cause spots. The ink can flow by itself when the atmospheric pressure changes, especially when there's not much ink left. Air is not completely pressed out of the reservoir when the pen is filled with ink and there is therefore always a bit of air and a bit of pressure left. When the external pressure is lower than this remaining air pressure, pressure pushes the ink out of the fountain pen. This happened often in planes. The clothes and documents of the passengers suffered.

Let's remember again the last ideal functional model that we just formulated for a fountain pen: ink moves *by itself* to the end of the pen only when it is supposed to produce a track.

We can now analyse the resources. Ink is a liquid like water that can therefore easily flow from the container to the pen. If the ink were thicker, it would not flow. But, this is a new contradiction: the ink *should be thicker* so that it doesn't flow too readily, but it should also *not be too thick* to flow easily through the work organ.

We will investigate this considerable contradiction in a *first strategic direction*: the use of "thickly flowing ink". For 50 years, there seemed to be no way to solve this problem with normal ink.

The use of "thickly flowing ink" leads specifically to the idea of the installation of some kind of valves for the movement of ink. But, we could then no longer maintain that the ink moves to the end of the work organ *by itself.*

Here it would be logical to ask about a change in the work organ. We would need an energy source that enables us to transfer "thickly flowing ink" or paste onto paper. The use of a valve would then clearly mean an interrupted operation and a partial transfer of paste. But, we need an uninterrupted and smooth transfer here.

We would need a few "tiny people" who could take the paste from the reservoir and transfer it smoothly in small portions onto the paper. These "tiny people" could then take past from the reservoir with their "shovels", pass these on to each other towards the paper, and then pass their empty shovels in this kind of chain back to the reservoir, for example. This would cause a circular movement of full shovels from the reservoir to the paper and empty shovels from the paper to the reservoir. This is similar to the functional mode of typographical machines that use a roller to bring thickly flowing ink from one side of the roller to paper. Could we not build a writing instrument that functions like a miniature pressure machine? This is a very constructive idea!

We don't know whether the inventors of the ball point pen, the Hungarian brothers Biro - the journalist Ladislas and the chemist Georg, thought this in 1938. Still they used this kind of printing ink as their first "thickly flowing ink". But, they used a ball instead of a small roller (like a miniaturized printing roller).

Clearly a roller would be too wide and we want to keep our thin lines. People could use a ball where the surface enabled the "tiny people" to do their work and transfer ink. The rotating ball puts the principle of an uninterrupted transfer of ink from reservoir to paper into praxis (figure 2.6). Friction with the surface of the paper causes the ball to rotate by itself! This means that the hand is once again the energy source that presses the tip of the pen with its ball onto the paper.

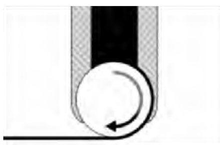

fig. 2.6. Basic construction of the work organ of a ball point pen

This is how the key idea was found by changing the *dominant resource - the material (the ink)*! This means the primary contradiction was solved *materially*. Then the inventors only needed to develop a corresponding construction (*new structure*) for the transfer of paste onto paper. The contradiction was *solved materially and structurally* in a brilliant way!

Pilots in England were the first to use these new writing devices, even though it took ca. 10 years until the ball point pen finally arrived.

Example 3. 3rd transition: 25 years from the ball point pen – to the felt-tip pen. But the ball point pen was not yet perfect. The paste dried out quickly in the pen. It was sometimes squeezed out of the reservoir when the atmospheric pressure changed. This instrument caused spots, too. The hand of the writer tired quickly because more power was required than when writing with a fountain pen.

At this point, we can turn to the *second strategic direction* that was formulated for the reinvention of the ball point pen: the ink *must not flow thickly*, so that it flows freely through the work organ. *Let's intensify the contradiction*: the ink has to flow quickly and always be available at the tip of the work organ, but it must not flow out and cause spots!

It is initially clear that the ink reservoir needs to be open on both sides to balance the effects of the atmospheric pressure. By the way, this was also done with the ball point pen. But, let's continue with our investigation.

Second, the movement of ink from the reservoir to the tip (again like a fountain pen) of the work organ has to somehow be more difficult.

Analogies! Were there any *analogies in the history of writing instruments* or of similar drawing instruments?! Obviously there were! Examinations show that ink writing devices with a copper housing were used 3,300 years ago in Ancient Egypt. There was a sharpened lead tube in this housing that had an internal, fibrous reed part soaked in ink (figure 2.7).

fig. 2.7. Basic construction of a felt-tip pen

The ink flowed slowly through the numerous fine capillaries of the read part to the sharpened tip of the lead tube. The ink flowed out when writing on papyrus and the subsequently hollow fibers closest to the tip could then be refilled with micro-doses of ink from the fiber capillaries!

Of course we can say today that the inventors of felt-tip pens in Japan in 1963 made use of the special *physical effect* of the movement of liquids in fine canals, i.e., the capillary effect!

But, we can also see that the reed writing tool in Ancient Egypt was certainly a predecessor of today's felt-tip pen!

The felt-tip pen offers another excellent solution to an extreme contradiction that we had already formulated, but it does this *in another strategic direction*! This solution was again found based on *material and structural resources* and with the use of a special *physical-technical effect*.

Finally we would like to turn to an effect that can be observed in the evolution of every technical system. When the developmental resources for a system of a certain type are finished, for example, for a writing instrument, then inventions from systems with an analogous purpose appear that either have a completely different functional principle or are systems that integrate extra functions with each other that were taken from two or more completely different systems.

Extra-example (beginning): the era of electronic writing instruments. Of course, we could start this section with an investigation of a few parallel developmental directions. We could start with those that are related to the development of typographic machines to produce books and newspapers or of machines that transfer drawings onto other materials. We could start with "writing" machines from mechanical and electrical systems to and including electro-static string and laser systems and with copying systems from copying paper and cameras to electrostatic toner copiers and laser systems.

But, we would like to investigate only one developmental direction for fixing hand-written or graphic information that is connected to the appearance of computers. Here we are concerned with entering information into a computer or with the transfer of text and drawings to certain lines of communication. For example, these markings can be initially made on paper and be transferred in real time during the writing process or using the words of a specialist. The task is to ensure that the lines of a representation are scanned, transformed into a digital format, saved, and transferred to a line of communication in a computer or other information sensor ***while*** this representation is being produced on paper.

But, this direction also includes a wealth of different principles based on surfaces with electromagnetic, resistant, hollow, acoustic, infra red, optical, laser, and combined principles to sense the local and global coordinates of the position of the writing instrument in relationship to the paper.

Fig. 2.8 shows some of the principles of scanning information that function with special electronic pens.

The electro-magnetic principle (fig. 2.8a) is based on the determination of rectangular X-Y coordinates using a system of conductors integrated into a writing tablet that sense an electromagnetic impulse from the pen at the point where pen and conductor meet. The impulses are sent at a certain frequency, for example, 100 times per second. This means that any line can be represented as a group of points (coordinates). The frequency of scanning has to be sufficient to ensure a precise representation of a line even when writing quickly. Plus factors are simplicity and reliability as well as the possibility to turn the pages of the writing tablet. Minus factor is the necessity of a special tablet where the paper cannot be moved elsewhere.

You'll find another variation of the use of electromagnetic impulses in fig. 2.8b. The information sent by the pen is received by antennas that, for example, are installed on the ceiling in the corners of a room and form a global rectangular coordinate system. A plus factor is the chance to work at any place in the room. Minus factors are the relative complexity of the system, the use of special pens, the influence of large metallic objects, and paper that cannot be moved elsewhere.

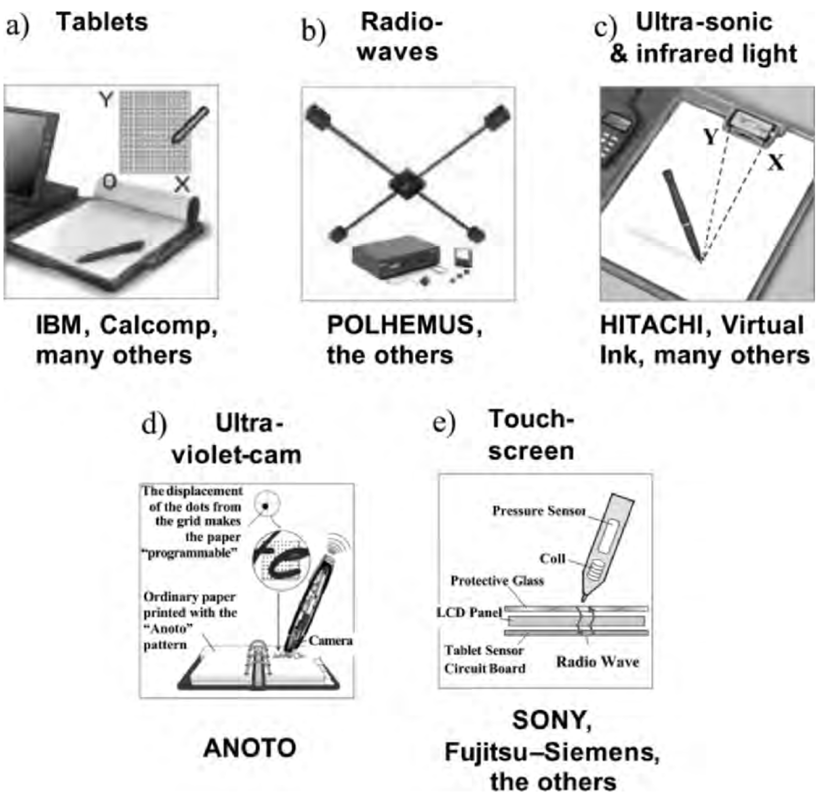

fig. 2.8. Traditional construction principles for electronic pens.

High frequency waves and/or infra red rays are used to measure the oblique-angled X-Y coordinates as the distance from the working body of the pen to two or more sensors (fig. 2.8c). Positive factors are simplicity and reliability as well as the chance to turn the pages of the writing tablet. Negative factors are the necessity of using special pens, the necessity of attaching the sensors to the page, and paper that cannot be moved elsewhere.

A totally different principle is shown in the pen in fig. 2.8d. A compact video camera installed in the pen that functions in the ultra-violet range reads special combinations of points transferred to the paper in advance that clearly show the coordinates of the position of the working body on the paper. The positive factor is that almost all components are integrated into the pen. The negative factor is the use of special paper.

Principles for scanning coordinates based on conducting, hollow, high-frequency, or electromagnetic tablets have been further developed in systems for drawing directly on the screens of televisions, computer monitors, and electronic blackboards in auditoriums (fig. 2.8e). Positive factors are simplicity and reliability. The negative side is that these devices are not meant to sense information on paper, although we could use the "thinking navigator" 11 *inverse action* (see appendix 4 ***Specialized A-Navigators***) and fix the information on paper after writing by using a printer, for example.

We see that the "old" pen has gained a new quality in the last thousand years of its development: the image can now be transferred to a computer. We have learned to enter hand-written information into a computer. This information can then be written on paper, on a blackboard, on the screen of a television, on a computer monitor, on credit cards or on the display of a mobile telephone, on special tablets that can be added to a keyboard and therefore make keyboards and mice superfluous. Dozens of principles for electronic pens were invented in the last 50 years! But, all of them had essentially the same problem: the necessity of a special pen.

To conclude this section, let me make a few essential suggestions for the following material. Simple symbolical scheme for the presentation of TRIZ (fig. 2.9) was developed to reflect a cycle in accumulating inventive experience, in studying this experience and in use it for new system development. The table of contents of this textbook also reflects this scheme. And this contents and scheme contain the roots of renovating TRIZ that will come in near future may be under the name of Modern TRIZ (M-TRIZ as at the fig. 2.9) or under another name.

fig. 2.9. Cycle of TRIZ originating, disseminating and use.

However, it seems important to me to add at this point, that the following three points make up the essentials of learning TRIZ:

1) The author has developed a general model for the solution of creative problems that is called **Meta-Algorithm of Inventing** or **Meta-ARIZ** for short (sec. 7 and **Mini-ARIZ** in sec. 9). A certain scheme for problem solving is used depending on the concrete number of steps for Meta-ARIZ that corresponds to the special “theory”: brainstorming, TRIZ, CROST, etc.
2) Key structural models for the transformation of the original description of the problem into a prepared form for the use of transformation models (sec. 6-9).
3) Transformation models for a problem in the direction of the development of a solution (sec. 10-13 and 18-19).

The strategies and tactics of TRIZ can be effectively understood and used only after the key structural models and the essential transformation models have been studied and learned. I therefore recommend that you study sections 14-17 only after you have already worked through sections 6-13.

Methods of Inventing

It pays to study the discoveries of others so that we also find a new source for inventions ...

Leibniz [4]

3 Invention

3.1 Discovery and Invention

One of the most important inventions in the history of civilization was the radio (Latin *radio* – transmit rays). In 1888, the German physicist Heinrich Hertz[5] discovered how to receive and send electromagnetic fields with the help of different kinds of long pieces made of conductible materials (today we would simply call these pieces antennas). Electricity was sent to the antenna with a specific impulse and with a specific frequency and power to generate a field. In order to receive an electromagnetic field, it was necessary to increase the electricity that was fed into the antenna and then directed by the field chosen. However, it took several years after these first experiments until ideas came and instruments were developed that offered a certain practical perspective for these physical phenomena.

By that time, technical systems such as the telegraph and telephone had already reached a certain level of technical development. The American artist and engineer Samuel Morse[6] had already developed a procedure and a device to transmit and receive signals through wires (the electrical telegraph) in 1832. The first telegraph wire between England and France was completed in 1851 and in 1858 the first wire was finished across the Atlantic between England and America. The German inventor and entrepreneur Werner von Siemens[7] finished the Indo-European telegraph line from London to Calcutta 10 years later. The telephone made its way from the first instrument invented by the German school teacher Jo-

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[4] Gottfried Wilhelm Leibniz (1646-1716) - leading German mathematician and thinker who founded the Academy of Sciences (Akademie der Wissenschaften) in Berlin in 1700

[5] Heinrich Hertz (1857-1894) - German physicist who proved the existence of electro-magnetic waves

[6] Samuel Morse (1791-1872) - American painter and engineer

[7] Werner von Siemens (1816-1892) - German inventor and entrepreneur

hann Reis[8] in 1861 to the patents of the American Alexander Graham Bell[9]. But, no one could connect wires to ships or automobiles.

The electromagnetic waves spread like a light from a single source in H. Hertz's first experiments, i.e., from a spherical surface. He therefore thought it was necessary to build antennas to send and receive waves that were shaped like optical lenses and mirrors. This proved to be very complicated but not very fruitful.

The Russian physicist Alexander Popov[10] found that the length of the antenna influenced the quality of sending and receiving in 1894. He subsequently constructed the first radio receiver. In the period 1895-1897 he demonstrated the first wireless radio-telegraph connections between ships. The first experiments with the radio-transmissions were made by famous American inventor Nikola Tesla[11] as early as 1893. The Italian inventor and entrepreneur Guglielmo Marconi[12] patented the analogous systems in 1896-97. He could improve his construction by 1899 so much that connections between England and France were made possible and by 1901 the first radio signals were transmitted across the Atlantic. Popov first discovered that ships that travel between the sender and receiver influence the radio waves between them. He though of the idea that radio waves could be used to find ships (a kind of preliminary step towards radar). At the beginning of the 20th century, Marconi further developed his radio devices. He won the Nobel Prize in physics along the German inventor and researcher Karl Braun[13] (who developed the most important components of radar) in 1909.

This is how radio technology was developed 100 years ago. Based on this technology, systems were later developed for regional, global, and cosmic communication such as radio telemechanics, radiometry and radio navigation, radio location and radio telescopics (which incidentally uses antennas shaped just like Hertz described them). Television, the Internet, and cellular phones all use radio systems. Even micro-wave devices have a primary sender element that was initially developed for radio systems.

This historical overview demonstrates clearly the difference between discoveries and inventions (figure 3.1).

Discovery	**Invention**
- Previously unknown, yet objectively extant objects or properties of objects in the material world are discovered.	- Material objects or their properties are developed that have never existed in the world and that were therefore unknown.

fig. 3.1. Definition of discovery and invention

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8 Johann Reis (1834-1874) - German school teacher

9 Alexander Graham Bell (1847-1922) – American physiologist, professor at Boston University

10 Alexander Popov (1859-1905) - Russian physicist and inventor, Navy officer

11 Nikola Tesla (1856-1943) – foremost American (Serbian) inventor and researcher

12 Guglielmo Marconi (1874-1937) – Italian inventor and entrepreneur

13 Karl Braun (1850-1918) – German inventor and researcher

Inventions that were made based on discoveries have usually led to far-reaching changes in civilization. For example, the discovery of the principles of thermodynamics and electrodynamics led to the development of electrical energy and the electrical motor, the discovery of electromagnetism led to the invention of lasers and magneto-optics, the discovery of nuclear energy led to the development of atomic power plants, solid state physics and transistors led to computer and computer-based systems. Hundreds and thousands of inventions result from attempts to turn discoveries into highly effective technical systems.

The following is yet another essential difference between discoveries and inventions: **Inventions are made with the goal in mind to create possibilities that then make them useful.** This goal then determines the **main positive function (MPF)** of the system.

For example, the MPF for radio systems can be formulated in the following way: to transmit and receive electromagnetic signals with controlled parameters in the frequency span of radio waves.

Let us now examine a phenomenon that brings discoveries and inventions closer to each other. This is the fantasy - the inventive spirit of a scientist or engineer. A discovery has no goal: it focuses totally on objective knowledge. It is often the case that the fantasy of an inventor is a requirement to imagine and visualize a goal and an idea (a hypothesis) for the practical application of new knowledge, for new technical solutions that come from a discovery. But, the activities of a scientist require just this kind of brilliant fantasy. Presumptions, hypotheses about the essence and about interaction with the phenomena observed and investigated almost always accompany discoveries. A hypothesis is therefore a technical invention, too.

Hypotheses, ideas, assumptions - these are all inventions of reason – and are therefore creative fantasy.

A creative idea is not obvious. It is an object that does not clearly exist in extant knowledge. It is an object that is created by human thinking.

It is precisely this birth of an idea, this act of enlightenment that is one of the most important secrets of human thinking. Inventing an idea is the perceivable tip of the iceberg, the high point of the process of inventing. The goal of every theory of inventing should therefore be to find practical ways to climb to this tip, to reach this creative high point - to create an effective idea.

3.2 Levels of Inventions

The steps of the developmental history of civilization - millions of inventions - are different from each other in their value. In the following table (figure 3.2) you will find a classification of inventions according to their level and with reference to various characteristic symbols. The degree of “newness”, of innovation is the general value in mind here.

Aspects of the problem	Levels of Inventions				
	1 Ration-alization	**2 Moderniza-tion**	**3 Principle**	**4 Synthesis**	**5 Discovery**
Initial condi-tions	Concrete assign-ment of task with a pa-rameter	Tasks as-signed with several pa-rameters; there are structural analogies	Badly struc-tured "pile" of tasks; only functional analogies exist	Many factors are unknown; there are no structural or functional analogies	Primary goals are unknown; there are no analogies
Resour-ces of the problem and the person who solves it	Resour-ces are obvious and eas-ily avail-able; elemen-tary pro-fessional training	Resources are not ob-vious but sill exist in the system; traditional professional training	Resources are often derived from other systems and levels; devel-opmental and combined thinking	Resources from different fields of knowledge; strong asso-ciative think-ing, broad knowledge, ability to overcome stereotypes	Resources and/or their application are previously un-known; moti-vation for se-lection, no stereotypes
Degree of diffi-culty	Tasks without conflicts	Standard problems	Non–standard problems	Extreme problems	Unique problems
Trans-forma-tion rules	Techni-cal opti-mization as a solu-tion	Technical solution based on typical analogies	Inventive solu-tion through combined methods	Inventive so-lution through the integration of technical "effects"	Scientific and technical in-ventions
Level of innova-tion	Slight changes in the pa-rameters of ele-ments	Initial func-tional and structural solutions without changes in the func-tional prin-ciple	Meaningful inventions with positive system effects - changes in the functional principal	Intense inven-tions with sys-tem super-effects that lead to an es-sential change in neighbour-ing systems	Brilliant in-ventions with system super-effects that lead to an es-sential change in civilization

fig. 3.2. Levels of Inventions

What is new is associated with the occurrence of a previously unexpected positive extra-property of an invention that is called *system super-effect*.

A system super-effect is a result that was unknown before a solution and is directly connected to the solution of a conflict in the initial system.

Meaningful inventions with system super-effect that radically changed civilization have the same value here as discoveries. This categorization is a convention. This means that the invention of the telegraph, telephone, and radio correspond to level 5 inventions. The development of radio-telephone connections was first intended for military aircraft and ships and then further developed in the course of 50 years to a system of individual communication as today's cellular phone. This development can be understood as level 4 or even level 3 in its technical content, but as level 5 in its influence on the development of civilization.

4 Inventive Creativity

4.1 Inventing Theories of Inventing

This short version of this comprehensive, yet for the most part unknown topic attempts to achieve an important goal - to help readers find their own answer to the following question: is it possible to study the experience gained in the development of civilization in such a way that **methods can be derived or invented, or a theory of inventing can be built** based on this study?

We can orient our search and our considerations on the following thoughts by Cicero:

NOSTRORUM MAJORUM INVENTA NOSCE DEBEMUS
We have to know the inventions of our ancestors

SECUNDUM NATURAM VIVERE OPORTET
We have to live in harmony with the Nature

We can split the development of humanity into two historical phases: until the beginning of the first millennium BC and from then until the present. In the first phase, we see ***Homo Faber Technologicus*** - a human well versed in the use of technical tools, who had no real scientific methodologies. In the second phase that has lasted for over 3,000 years, we can observe the development of ***Homo Sapiens Technologicus*** - a human who has developed a scientific methodology and is well versed in the use of technical tools and methods.

But, where was the *beginning of "technical civilization?"* The answer to this question will probably be lost forever in the depths of the past. Only a few names such as Pythagoras and Archimedes, Socrates and Vitruvius have survived the darkness of history until today.

What was the *organization of their thought* like? And could the civilization of Ancient Greece or China have produced inventions like television, computers, or audio and video recorders? Could the alchemists of the Middle Ages have created composites? Or could they have created a synthetic human - a homunculus?

We know today the humans had already found their first inventions a few hundred thousand years ago! It is clear that we've lost the *empirical experiences of creativity that were made in primal societies,* if we may describe these experiences in such a way. But these experiences established themselves somehow in the course of time so that the discoveries of primal cultures can be retraced to a certain degree, although they can be described as methodologically grounded only in a very limited fashion.

However, our knowledge of that time allows us to perceive through interpretation and abstraction that the following "methods of inventing" were used:

- *analogy as a direct copy*: needles, scrapers, knives, hooks, harpoons, sharpened sticks - these are all analogies of the teeth, beaks, and claws of animals;
- *analogy as a copy of an abstract image (!):* drawings, sculptures, toys, dramas, and theatre characters;
- *combination into a whole:* spears with points, axes and hammers from several parts, nets, thread braided from hair;
- *split into parts:* breaking stone to produce cutting and piercing tools;
- *changes in shape* (for example, the handles of tools) *and in parameters:* sharpen, mount, extend, etc.;
- *selection and combination of various materials:* wood, bones, stones, furs, tree bark (especially long pieces to braid into nets and to mount tools);
- *use of different energy sources:* fire - for the preparation of food and to hollow out tree trunks into boots, the power of animals, the elasticity of materials such as the sinews of animals, flexible branches, braided elastic thread and cords from hair or plant fibers.

These *empirical methods* still exist today. They are found in objects that are connected to the physical activities of humans: in the production of household implements and jewelry - vases and chairs patterned with woven pieces, clay vessels and bowls, in many tools - knives, files, axes, pitch forks, and hammers, in work in the fields or in the garden - horses or donkeys as energy sources to transport loads, in the use of water and wind power (of course, with different cause and effect principles), in sport and leisure - javelin throwing, pole vaulting, and fishing, and in boot tours and artistic activities.

The most meaningful inventions of humanity were:

- *bow and arrow,* and then the *lyre*, *pipe, and flute* (music in general!);
- *wheel* (an invention of the Sumerian state ca. 3,500 years BC);
- *levers* (to lift and throw);
- *use of high temperatures* and the production of metal implements and coatings by melting and forging, especially from bronze and gold;

- *use of rotation and revolution* in milling stones, in the transport of water with water wheels, in the potting wheel, in drilling and in the lathe since the 5th century BC;
- *invention of cloth* as a special combination of threads from different materials to a synthetic "fur"; today we would call this a method for the combination of similar objects to a reticular structure (net-like)!;
- *production of shoes and clothing, construction of synthetic living structures* from stone and sand, from wood and bone, from tree bark and fur;
- *production of complicated mechanisms,* such as gears and mechanisms with flexible connections to levers and/or wheels;
- production of the first *automatic fixtures,* such as marionettes that stretch and move with the use of cords and weights that are attached to cylinders of differing diameter.

Of course, this list is not comprehensive and we don't want to expand or structure it more closely here. We should simply ask whether there was any special experience gained in the development of new synthetic objects and whether this experience was passed on. What was learned in the search for the best solutions both in the everyday and under extreme conditions such as in conflicts, wars, catastrophes, and disease?

Unfortunately, very little about the spread and transmission of inventive creativity has survived into the present. But, there are a few examples. These can be found especially in Greek sources that incredibly enough were not lost. They returned to Europe from the Arab orient at the beginning of the 2nd millennium AD. Then they were enhanced and supplemented with sayings from Egypt, the Near East, Central Asia, and China.

Pythagoras[14] and his school created a body of thought that has had an extreme influence on Sophist, humanist, scientific, and mathematical thinking about the construction and development of the world. The Pythagoreans postulated a way of looking at the world as a harmony of conflicts. Harmony is possible only as the "unity of differences" and as the "resonance of disharmonies". It can be defined, observed, or postulated only when a concrete configuration of conflicting properties exists in 10 measurable criteria that are determined by 10 pairs of poles in the world: finite - infinite, even - odd, individual - collective, right - left, female - male, still - moving, straight - curved, light - dark, good - bad, square - linear.

Socrates[15] was one of the first teachers of creativity. He used his own method when teaching and solving problems that was called "*maievtic*" (μαιευτικη). This means literally the art of birthing aid (obstetrics), a term that characterizes his

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[14] Pythagoras (ca. 580-500 BC) - Greek mathematician, religious researcher, and politician

[15] Socrates (470-399 BC) - Greek philosopher, teacher of anthropo-centrism, one of the founders of dialectics as a method to find truth (self-knowledge)

teachings very well. Socrates' favorite saying is written on the facade of Apollo's temples at Delphi (here in Latin): NOSCE TE IPSUM *(Know yourself).*

With a help of *the ironical questions* Socrates forced the participants in a conversation to doubt generally accepted opinions, to *search for conflicts in definitions,* and *to synthesize ideas.* This was based on a strict determination of the subject of the discussion, on *the goal to accomplish something good and virtuous*, and on the attempt to make people happy. Socrates combined *harmony with the principle of usefulness*. He maintained that people can only learn from their own efforts. Knowledge cannot be ingested from the outer world in complete form.

Archimedes[16] developed a method to create ideas in his treatise "Thoughts about Mechanical Methods" *based on building mechanical models* and *on experiments* with them. This was supposed to support the hypotheses and assumptions that then had to be subjected to a mathematical test and verification. Archimedes built a *creative toy* (today we would call it a puzzle or building blocks) for his students. It consisted of 14 discs made from elephant bones that could be combined in different ways to represent various figures such as a ship, sword, helmet, temple, etc.

Archimedes, along with his pupil Ktesibius of Alexandria[17] and apparently his pupil Heron of Alexandria[18], founded the *school of inventing (ars inveniendi).* In his piece "Theatre of Automation", Heron describes *ideas about the construction* of automated machines for churches and theatres. The mathematician Pappos of Alexandria[19] noted in his description of the later statements of Heron's followers that they *became excellent inventors and builders* after they had studied those ideas and had learned their operations.

The writings of Vitruvius[20] "Ten Books about Architecture" (*De architectura*), served as a textbook for more than 1,500 years. He defined the concept of the *machine* probably for the first time in history in his tenth book: a machine is a combination of parts connected to each other that uses power to move loads.

The uses of the teachings of the technical and "free" arts can probably best be evaluated by using the best known scheme by Quintilianus[21] (figure 4.1) to make any assignment concrete with the help of 7 questions.

Pairs of combined questions are also useful when solving tasks that require inventive thinking. For example, there is 1-4 (who - with what) - who uses which means for a solution; 2-3 (object - place) - which object is supposed to be created

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16 Archimedes (287-212 BC) - mathematician, engineer, inventor of many mechanical devices, creator of teachings about movements of the body

17 Ktesibius of Alexandria (2nd century BC) - inventor of pneumatics, generally of paired cylinders and pistons, of water clocks and musical organs

18 Heron of Alexandria (2nd -1st century BC) - engineer, mechanic inventor, and optician

19 Pappos of Alexandria (3rd-4th century BC) - mathematician and mechanical inventor, author of the book "Heuristics", was influential in the Muse church (museum) in Egyptian Alexandria

20 Marcus Vitruvius Pollio (1st century BC) - Roman architect and engineer

21 Quintilianus (1st century AD) - Roman theorist of rhetorics

where; 6-7 (method - time) - with which method and when or in which time a task should be completed, etc. These questions are still successfully applied today in methods of inventing.

Who? – Quis?	**subject**	**1**	1-2	1-3	1-4	1-5	1-6	1-7
What? – Quid?	**object**	**2**	2-3	2-4	2-5	2-6	2-7	
Where? – Ubi?	**place**	**3**	3-4	3-5	3-6	3-7		
With what? – Quibus auxiliis?	**means**	**4**	4-5	4-6	4-7			
Why? – Cur?	**goal**	**5**	5-6	5-7				
How? – Quomodo?	**method**	**6**	6-7					
When? – Quando?	**time**	**7**						

fig. 4.1. Quintilianus' seven questions

Unfortunately, great researchers and inventors such as Leonardo da Vinci[22] or Galileo[23], Huygens[24] or Newton[25], Agricola[26] or Ramelli[27] and many more to and including the present did not describe the experience they collected in their works on the way to their inventions.

The beginning of a scientific investigation of the methodologies of creativity was first set into motion by the philosophers Francis Bacon and René Descartes.

F. Bacon[28] criticized the old *empirical method* of science, developed his own method, and formulated goals for the creation of ***systematic techniques of inventing*** in his book "Novum Organon Scientiarum" in 1620. He wrote: "Everyone who had anything to do with science until now was either an empiricist or simply dogmatic. Empiricists either collect things or use only those things that were already collected, just like ants. Rationalists create a spider's web from themselves, like spiders. On the other hand, bees have found a third way. They find and use everything they need from the flowers of gardens and fields and therefore have access to their own abilities.... We should hope for a closer and stable connection between experience and rationality. Our method consists of deriving reasons and axioms based on praxis and experience, and then re-deriving praxis and experience from these reasons and axioms, instead of basing our praxis on praxis and

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[22] Leonardo da Vinci (1452-1519) - great Italian artist, mechanical builder, and inventor

[23] Galileo Galilei (1564-1642) - leading Italian astronomist and physicist

[24] Christian Huygens (1629-1695) - leading Dutch astronomist, physicist, and mathematician, student of Galilei

[25] Isaac Newton (1643-1727) - leading English physicist and mathematician, discovered the laws of gravity

[26] Agricola (actually Georg Bauer, 1494-1555) - well-known German doctor, dealt with mineralogy and metallurgy

[27] Augostino Ramelli (1530-1590) - follower Leonardo da Vincis, inventor

[28] Francis Bacon (1561-1626) - English philosopher, founder of philosophical empiricism

our experience on experience (like the empiricists)". According to Bacon, this connection can be made using an ***inductive method,*** in the transition from special givens to special laws (small axioms), and then from them to more general laws (middle-sized axioms), and finally to general laws.

Descartes[29] developed the idea of the creation of a unified scientific method that he then called "universal mathematics". In his treatise "Thoughts about Methods" in 1637 - 17 years after "Organon", Descartes developed a deductive and rational method that in his view transformed knowledge into organized action in such a way that it would then be unaffected by coincidences and subjective factors such as the powers of observation, cleverness, success, or the combination of lucky circumstances. With the help of the deductive method, it was possible to arrive at an individual evaluation of every concrete problem on the basis of the perception of generally true, fixed laws.

Even today Descartes' "four rules for thinking" are astonishingly current:

rule 1: Believe nothing to be true until you've made sure that it is correct beyond the shadow of a doubt. This means don't act too quickly, avoid preconceptions and prejudice, and only use those things for your judgements that demonstrate clearly to your reason that there is no reason to doubt them.

rule 2: Reduce every difficulty to be observed to as many components as you need to solve the problem.

rule 3: Shape your thoughts from the simplest and most understandable object and then increasing step by step like a ladder to your knowledge of complex things - and, in this way, let even those things be ordered that don't belong together in nature.

rule 4: Always prepare complete hypotheses and overviews to be sure that you didn't forget anything.

G. Steinbart[30] thought that every invention is based on known and developing facts, objects, or ideas that arise through contrasts and are derived with methods that stress their analysis, synthesis, and combination. He described the discovery of the hidden qualities of objects, the determination of reasons, and the search for analogies as well as the rationalization of the usefulness of objects and phenomena for their function or change as the main sources of inventions.

The most important book by J. Beckmann[31] "History of Inventions" is clearly the first scientific investigation of procedures for inventing: *"I had a model of the art of invention made to see the effect in praxis in direct proportion to my interest in its theory".*

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[29] René Descartes (1596-1650) - leading French philosopher and mathematician

[30] See "Useful Directions of Rationality for Regular Self-Thinking", 1787, by the German researcher G. Steinbart (1738-1809)

[31] Johann Beckmann (1739-1811) - leading German "father" of science, technology, and researcher in the history of inventions and the art of inventing

One of the most important studies is Bolzano's[32] treatise "Scientific Teachings", the fourth part of which is "The Art of Inventing". For Bolzano, the main rule is the *definition of the goal and the removal of non-productive directions* while searching for insight. In addition, the main question should be examined, extant knowledge analyzed, and conclusions based on this knowledge should be defined. Then hypotheses are created and experiments are made to solve the task at hand with various methods. Finally, Bolzano foresees a c*ritical test* of one's own and other judgements by means of which the best are then later selected. Bolzano considered the finding of additional tasks, the search for analogies, the recognition and evaluation of the realism of images that appear in the subconscious, and logical thought processes to be special rules for inventing.

I believe that the ideas of two more important historical figures deserve to be examined and further developed: Leibniz and Goethe[33].

Leibniz had already developed his own method of inventing (Ars inveniendi) - primarily a method of combining (Ars combinatoria) - in his youth. His goal was to create a universal language as a system to solve creative and inventive tasks. He referred to the special role of understanding the contradictions in the structure of a problem: the first truth in the truths of rationality is the principle of contradiction (***Principum contradictionis***). Christian Wolf[34], a student of Leibniz, considered the basics of methods for inventing (art of inventing) to be knowledge that constantly develops further, to be the connection of an inventive method with supporting knowledge. He found the discovery of hidden analogies and similarities of objects very important and developed the ideas of Leibniz further: *It is useful to study the inventions of others in such a way that this opens up a new source of inventions for us.*

Goethe was responsible for the concrete development of the principle and the method of the similarities ***(morphology)*** of objects and of the abstract derivation of a special type. This is essentially the basis for every scientific classification and systematization of knowledge. "... morphology is primarily concerned with an object that is dealt with inconsistency and as a side effect in other sciences. It collects things that are widely spread and ***creates a new perspective*** that makes it easy and comfortable to observe objects of nature". Goethe wrote that "***general phenomena*** can be easily recognized, ***that are based on the transformation of types***" as "the connection of a wealth of units that in principle have similar or even the same properties" (*Italics by the author* - M.O.). These ideas as well as Leibniz' ideas about the systematization of knowledge to methods for inventive creativity have not yet been fully put to use.

Since the 1st industrial revolution of the 18th century, creativity has begun to focus more and more on *pragmatic goals* and a pragmatic orientation requires in-

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[32] See "Art of Inventing" (in: Scientific Teachings, 1837), by the famous Czech researcher B. Bolzano (1781-1848)

[33] Johann Wolfgang von Goethe (1749-1832) - leading German thinker, author, philosopher, and nature researcher

[34] Christian Wolf (1679-1754) - known mechanical researcher and inventor

creasingly practical and *instrumental methods*. Although there were more researchers who dealt with inventive creativity, such methods were not developed in the 18th and 19th centuries. Based on the following examples and on Goethe's definition, research was focused on the observation of *phenomena that accompanied the process of inventions,* not on the analysis of ideas and the essence of inventions - the change from *"what is to what's coming".*

Hermann von Helmholtz[35] often stressed that assumptions about the solution to creative problems take shape as a result of comprehensive investigation from several perspectives that makes it possible to create an intellectual overview of their entire depth and all their high points. This is usually *possible only through meticulous preparatory work.*

T. Ribot[36] described the *powers of imagination* as the primary source of inventions. He categorically refuted the possibility of the creation of a methodology of inventing even though he referred to the importance of methods of inventing such as *analysis - synthesis* and *analogies*. He agreed completely with the statement that people can invent only because they are capable of combining known ideas in new ways. According to Ribot, the most important methods for inventing were created based on the powers of imagination: a personification, an *animation* of technical objects, mystical, *symbolic* images, *metamorphosis* as well as the transfer of special properties onto another object.

Henri Poincaré[37] proposed several interesting assumptions and offered interesting evaluations. According to his definition, creativity is the development of *new useful combinations.* He was of the opinion that an inventor thinks in a strongly selective way such that "nonsensical combinations don't even occur to an inventor". He therefore considers inventors to be second-level questioners who only ask those candidates questions who have passed the first-level tests. Poincaré made further noteworthy statements about the role of aesthetic criteria in creativity. He described the creative process as an *exchange of conscious and unconscious energies* in our brains. He maintained that *harmony* does justice to our aesthetic needs and simultaneously supports rationality. Harmony watches closely that nothing "ugly" occurs in a theory or hypothesis.

At the beginning of the 20th century, efforts to create a methodology of creativity increased dramatically.

Wilhelm Ostwald[38] noted that a methodology of creativity can be learned. He expressed the hope that the art of inventing would become a general achievement and a necessary and everyday part of physical and spiritual life just like nutrition,

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[35] Hermann von Helmholtz (1821-1894) - known German physicist who studied medicine, one of the discoverers of the laws of energy reception

[36] Theodule Ribot (1838 – 1916) - known French psychologist and creativity researcher

[37] Henri Poincaré (1854-1912) - important French mathematician and astronomer

[38] Wilhelm Friedrich Ostwald (1853-1932) - known German chemist

reading, and writing. One can invent if one follows certain principles, and he used Edison[39] as an example.

Edison can be described as the creator of the first scientific institute in which experimental research was done by a large number of scientists working parallel with each other. He founded this research laboratory in Menlow Park in 1872. The laboratory received more than 600 patents in the first six years of its existence, meaning 1 patent per week. A. Bell developed a kind of production line for patents. On the average, one patent was developed every 2.5 days in the laboratories of his group from 1879 to 1900. The total number of their patents in that period was 3000.

Ostwald noticed that there were many changes in the character of creativity at the end of the 19th and beginning of the 20th century. If people had earlier searched for creative finds like hunters looking for prey in the forest and fields without knowing what they would find or whether they would find anything at all, this kind of hunt was replaced by a kind of planned collective drive (according to Edison) and the hunter needed very little luck to find prey.

Here we can recognize this image as a certain kind of answer to Joseph Priestley's[40] colorful description of creativity and a creative search like a hunter who looks for prey in the forest in which coincidence plays a large role. Priestley suggested that people should do *unexpected and illogical experiments* and was of the opinion that the most courageous and original inventors were those who let their imagination go to acknowledge the combination of thoughts that were widely separated from each other. Although many of these thoughts were unrealistic, some of them could lead to spectacular inventions.

At the beginning of the 20th century, the search for new theories intensified and theoretical methods also became more concrete. We can show these theories as a scheme that represents certain phases of the creative process.

William James'[41] scheme from 1905 looks like this:

1) Definition of the concrete subject S.
2) Investigation, whether this S is a P in any way, or how we can make a P out of S.
3) Search in the infinite wealth of the aspects of S for a special property M that leads to the desired P.

P. Behrens[42] created a scheme "of a complete synthesis" in 1907:

1) Creation of a general conception of the object.
2) Determination of the main components of the object.

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39 Thomas Alva Edison (1847-1931) - leading American inventor and entrepreneur

40 Joseph Priestley (1733-1804) – known English philosopher and nature researcher

41 William James (1842-1910) – leading American psychologist, founder of the theory of the "stream of consciousness" and the schools of "functionalism" and "pragmatism" in psychology

42 Peter Behrens (1868-1940) – German professor of architecture, consultant in 1907 and later for the AEG

3) Search for the primary procedures to fulfill every component.
4) Synthesis of all possible combinations (connections).

In 1910, Peter Engelmejer[43] wrote in his book “Theory of Creativity”: If we think of an invention to be created as an organism that is developing, we ask ourselves the question: are there not stages in an embryonic process that are repeated in all inventions regardless of external conditions and the forms of process itself? Engelmejer called his scheme “3 acted”:

first act: intuition and desire. This is the source of a thought, the development of an idea or hypothesis, the principle of invention, the goal to be worked on.

second act: knowledge and conclusions. The creation of a work plan is next. Attempts at new thought, experiments, and a logical analysis are made. What’s new is defined.

third act: objective knowledge. This is the construction of the invention and the creation of solutions for application and usage.

J. Dewey[44] created the following scheme in 1910:

1) Difficulties arise, attempts to discover elements and relationships that lead to the contradiction.
2) Definition of the search zone (localization of the problem).
3) Development of a possible solution. Movement of thought away from what is given to what is missing, construction of ideas and hypotheses.
4) Rational processing of an idea, logical further development of the primary statement.

G. Wallas[45] made the following scheme in 1926:

1) Preparation;
2) Maturity (Incubation);
3) Inspiration (Insight);
4) Testing.

Were these and other models developed haphazardly? Many scientists are of the opinion that these schemes for invention reflect similar events that are often observable in creative processes, not coincidental plans for creativity. But, a close examination of these schemes reveals their essential differences.

Let’s separate these methods into three groups[*] without going into too much detail.

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[43] Peter Engelmejer (1855-1942) - leading Russian researcher of the theory of creativity and philosophy of technology; this book was published in German in Berlin

[44] John Dewey (1859-1952) – American philosopher

[45] Graham Wallas (1858-1932) – English psychologist and political researcher; summary according to “The Art of Thought”, Harcourt Brace, New York, 1926

[*] quoted with modifications according to the work by A.Kudrjavtzev “The Methods of Intuitive Searching of the Technical Solutions”, 1992 (in Russian)

The first group describes creativity as an exclusively intuitive process and encompasses the external developmental forms of this process (P.Engelmejer, G.Wallas, and before them Priestley, Helmholtz, Poincaré and many others), generally - most of the authors.

The second group relies primarily on a logical progression that includes the construction of a generalized image of the object and the systematic discovery of all the possible variations of its development (P. Behrens and earlier many of the proponents of combinatorial analysis, of which Leibniz is the most noteworthy).

The most important characteristic of the third group is their attempt to move into the essence of the problems to be investigated, to focus on the elements and properties that lead to contradictions, and their search for methods to solve conflicts (J. Dewey, W. James and before them - Bolzano, Goethe, Leibniz, Descartes and other important scientists). This third group has not been developed further.

4.2 Traditional methods of inventing

Several methods were developed in the middle of the 20th century that have lost none of their popularity since that time.

The method of focal objects - MFO had its roots in the Ancient Greek art of thinking and was probably thought of as an answer to Lullus' combinatory method. It was formulated in its modern form by the German psychologist F. Kunze[46] in the 1920's and perfected by the American researcher C. Whiting[47] in the 1950's. The essence of MFO is to put the object to be improved into a "focus" that then becomes the center of attention. Then this object is compared and contrasted with other objects that are arbitrarily selected from the real world. A book can be used as a method for selecting objects that is opened to any page to arbitrarily find a word. Objects from the picture window of a store or from nature can also be used. The combination of properties from these two objects - the focal and the arbitrary one - can then lead to original ideas to change the focal object. The mail features are shown in figure 4.2.

Brainstorming (BS) was developed by the former Navy officer Alex Osborn[48] in the 1940's. It differs from MFO primarily in the following ways: an initial analysis of the situation with the help of a list of central questions; 2 work phases - generate an idea and than critique it. There are many different versions of BS. The essential properties of this method are shown in figure 4.3.

Synectics (SYN). SYN was worked out by W. Gordon[49] and has roots that are as long as MFO. It clearly is associated with Ribot's ideas. SYN is oriented more

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[46] Friedrich Kunze (1881-1929) – known German psychologist
[47] C.H.S. Whiting: Creative Thinking, Reinhold, New York, 1958
[48] Alex Osborn (1888-1966) - author of the method "brainstorming", company consultant and entrepreneur; s. Osborn A.F. Applied imagination, Scribener's Sons, 1963
[49] W.J.J. Gordon, Synectics: the development of creative capacity, Harper&Row, NY, 1961

towards work in a team and is less appropriate for individual use, just like BS (figure 4.4).

Method of morphological analysis (MMA). F. Zwicky[50] developed this method that represents an analogy to Behrens method of a "complete synthesis" in its central conception. It goes back methodologically (figure 4.5). This method is still very popular and useful for a search for the limitations of solutions and the systematic analysis of possible perspectives for solutions.

It is important to note that the central focus of this method is directed towards *strengthening its logical component*, towards a more solid goal-orientation in the search for solutions.

The focus on its logical component and the connection of intuitive models with the praxis of technical projecting can be followed closely in the work of many researchers in the 1970's and 1980's[51]. However this connection has changed virtually nothing in the *relationship to the object and to the number of operations for transformation.* An organizational and systematic order of the levels and stages for solutions to complicated technical tasks was introduced. As a result, the goal orientation intended is blurred and the systemic terminology can hardly hide the same "bare intuition".

Lateral Thinking (LT) was developed by the psychologist and educator Eduard de Bono. LT is a detailed strategy for the comprehensive development of the creative capabilities of individuals. The methods of searching for ideas in LT stimulate intuition and the ability to see solutions in their entirety. These methods foresee a rational tactical analysis of variations and the contemplation of possibilities when solving problems from various aspects. De Bono's works expand understanding of the possibilities for an intuitive search for ideas when compared to BS, for example. But, the same limitations exist for LT as for BS (figure 4.3).

Neuro-linguistic programming (NLP). This method can be understood as a deep psychological and physiological stimulation of a person's creative abilities.

It is possible to learn techniques with psychological training that enable us to move into a state of increased concentration and attention span. Among other things, this enhances speed reading and the learning of foreign languages. NLP supports free associative thinking and the visualization (mind mapping) and actualization of one's own experience when solving problems (sections 20-21). It supports artistic self-projection into another person's image, for example of an artist or inventor. NLP is also subject to limitations like SYN (figure 4.4).

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[50] Fritz Zwicky (1898-1974) - known American astronomer and engineer who emigrated from Switzerland

[51] see here the works of the German engineer Prof. J.Müller, "Methods have to be used" ("Methoden muss man anwenden"), 1980 and the English specialist J.C. Jones, "Design methods", 1982

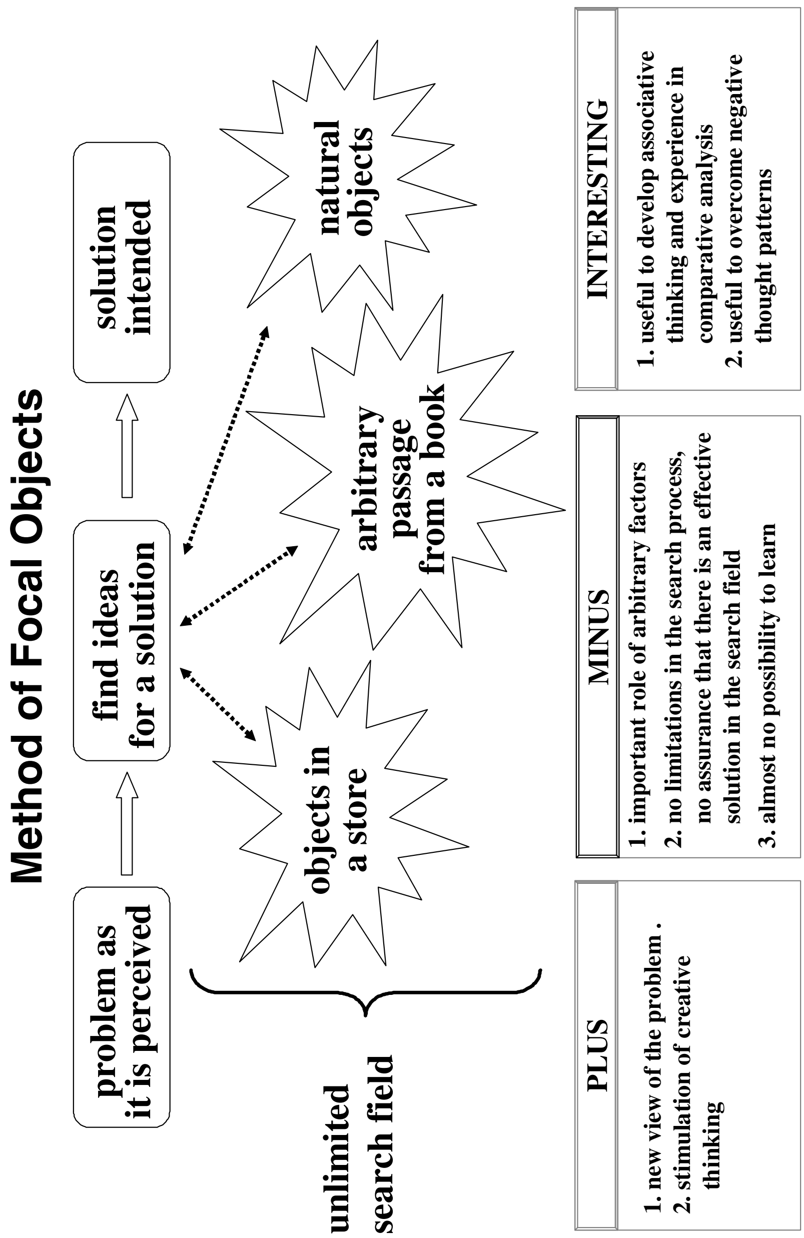

fig. 4.2. Characteristics of MFO

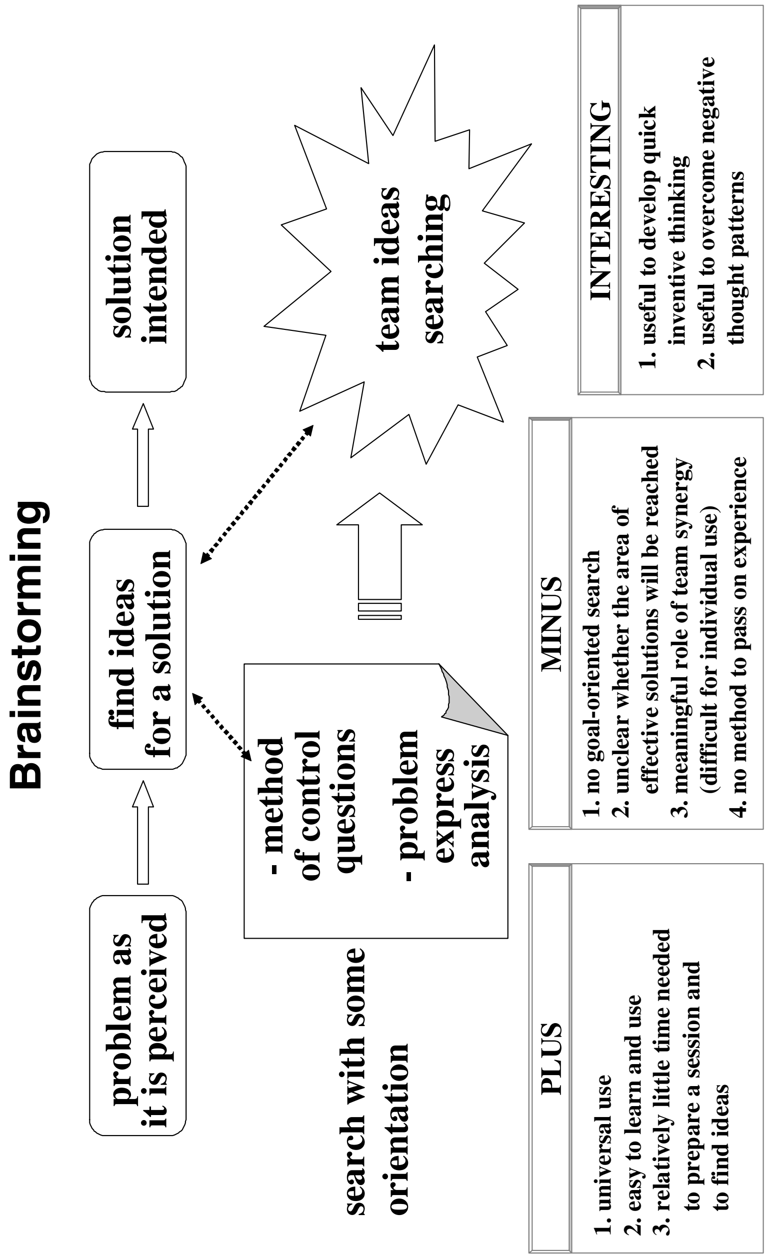

fig. 4.3. Characteristics of BS

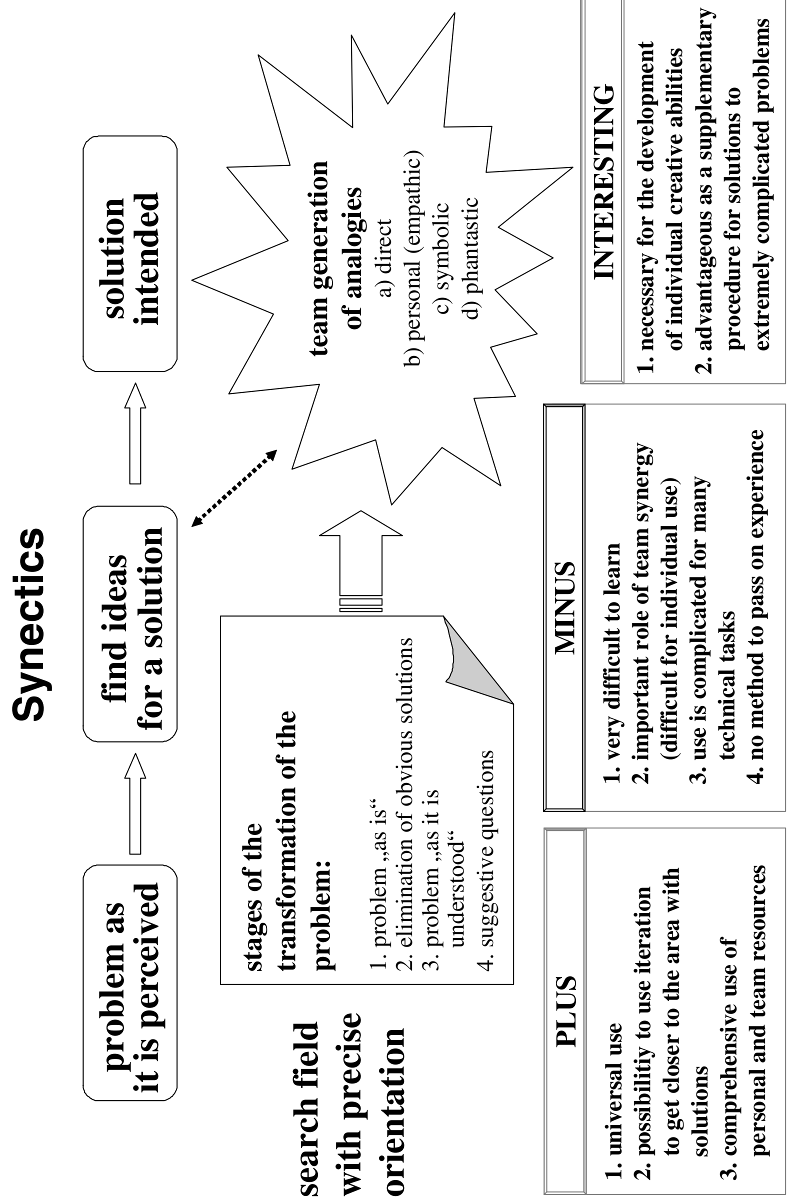

fig. 4.4. Characteristics of SYN

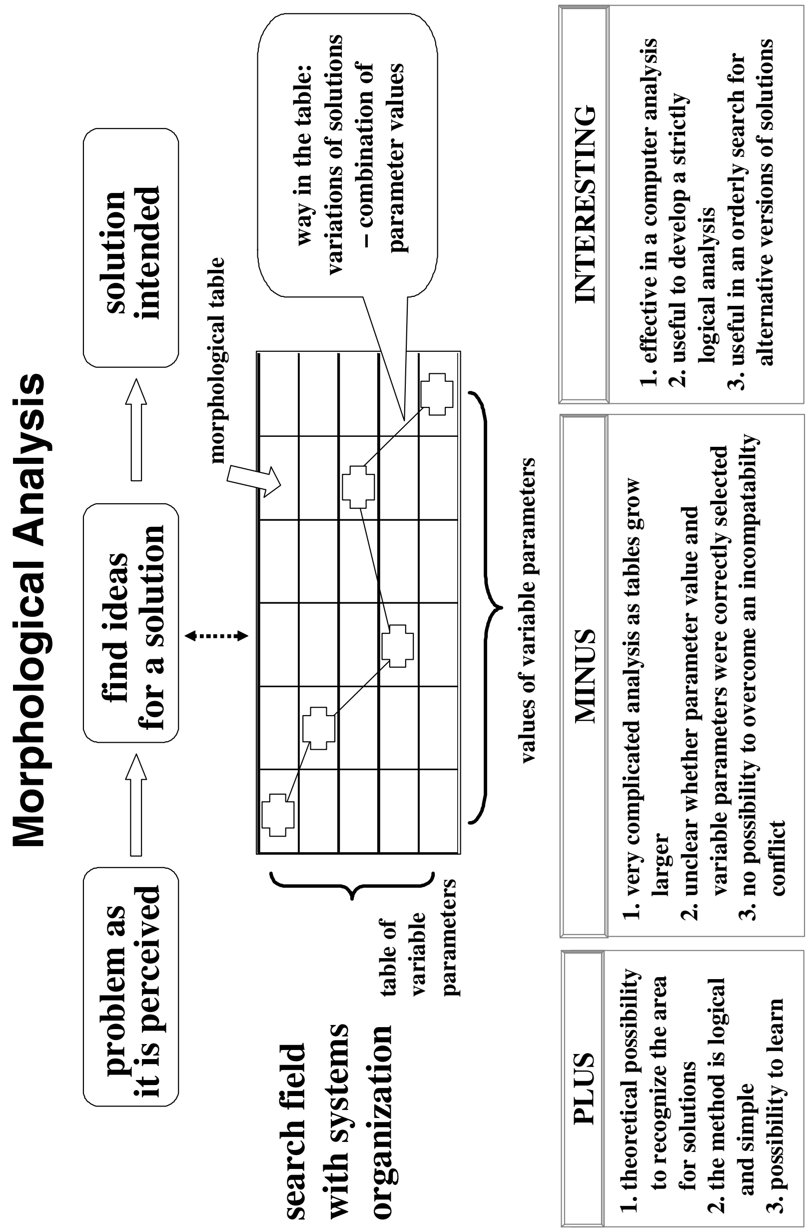

fig. 4.5. Characteristics of MMA

5 Classical TRIZ

5.1 Ideas of TRIZ

The following words by G. Altshuller [5] could be understood as a short summary of the previous section about theories of creativity:

> The speed of development of science accelerated strongly 150 years ago. The scientific revolution that started then demonstrated that the world can be perceived without limit. At the same time, a technical revolution unfolded that confirmed the idea that the world can be changed without limit. The work instrument of these incredible revolutions was creative thinking. But, it is a paradox that creative thinking itself and its technologies have not been changed in any qualitative way.

G. Altshuller worked in a patent office after graduating from a military academy. In 1945 he observed that patent applications were ineffective and weak. He also quickly recognized that bad solutions to problems ignored the key properties of problems that arose in the relevant systems. Even the most brilliant inventions were for the most part arbitrary or the result concentration on a problem to the point of exhaustion. Altshuller's investigation of known methods for inventing and psychology led to the following conclusion:

> All procedures were based on "trial and error", on intuition and fantasy. None of these methods started with an investigation of the laws of the development of the systems and physical-technical conflicts that are part of the problem at hand.

However, there were many examples of a more effective analysis of problems in the history of philosophy and in technical texts. Altshuller found the most glaring examples in the works of K. Marx[52] and F. Engels[53], who played an important role in the definition of characteristics and phases of historical changes that have occurred in the history of humanity, especially in connection with *inventions and developments* in new technologies and machines that have changed the character of work. These inventions and developments strengthened the function of technologies and machines or alienated humans totally from the means of production.

These examples are based on two essential thoughts:

1. **inventions are designed to overcome technical contradiction;**
2. **conflicts arise due to the inconsistent development of individual components in technical systems.**

This is why Engels listed numerous examples from the development of the rifle that resulted from changes in requirements as well as from internal bugs in his book "History of the Rifle" in 1860. For a long time the main problem was caused by the following conflict. On one hand, the barrel was shortened to facilitate loading and to accelerate firing speed. Loading meant putting powder and a ball directly into the barrel. On the other hand, the barrel had to be lengthened to in-

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[52] Karl Marx (1818-1883) - leading German economist and material philosopher
[53] Friedrich Engels (1820-1895) - leading German material philosopher

crease accuracy and the distance to the opponent when fighting with a bayonet. *This contradiction was resolved with a rifle* that is loaded from the back.

The examples were examined only as illustrations of dialectical and historical materialism. Therefore methodologists paid too little attention to them.

In 1956, Altshuller published his first article[54] in which he discussed the problem of the development of a theory of inventive creativity and suggested key ideas for such a development:

1. The key to the solution to problems lies in the discovery and elimination of contradictions in the system!

2. Tactics and methods for solutions to problems (procedures) can be created by analyzing important inventions.

3. The strategy of the solution of a problem must be supported by the laws of the development of technical systems.

A new draft of the first version of a technique for the development of inventive ideas is shown in the following schematic (figure 5.1).

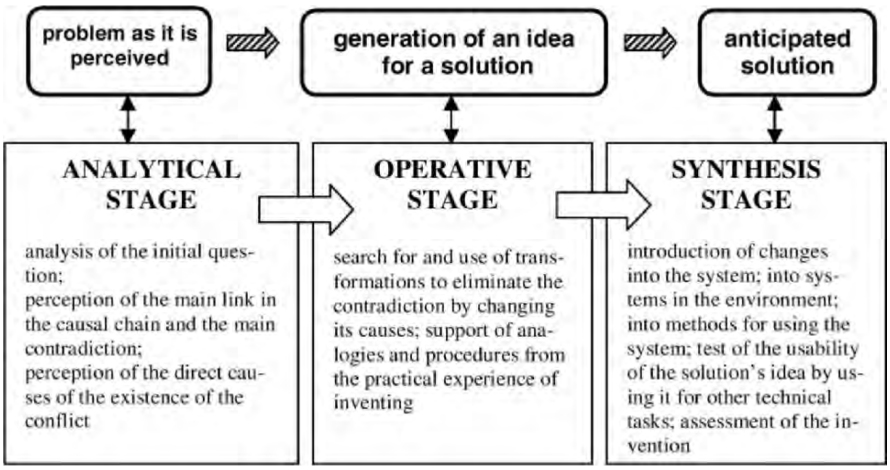

fig. 5.1. Key scheme of ARIZ for the development of solutions in inventing based on the elimination of the contradiction

By 1961, Altshuller had already analyzed ca. 10,000 inventions from 43 classes of patents! The idea to develop procedures for inventing was manifest by the following discovery:

1. **There are innumerable tasks for inventing, but there are relatively few *types of tasks*.**
2. **There are *typical system contradictions* and *typological procedures* to address them.**

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[54] G. Altshuller, R. Shapiro: *The Psychology of Inventive Creativity* - Journal "Psychological Questions", Moscow, 6'1956 (in Russian)

The author of what would be TRIZ made the following remarks: "…of course every technical task is individual in its own way. Every assignment has something unique. An analysis shows the possibilities to examine the basis ***of the conflicts in a system and their causes.*** This changes the situation completely. It is then possible to start a creative search for a specific ***rational scheme***. There is no magic formula after all, but there are ***procedures*** that are sufficient in most cases".

5.2 Development of Classical TRIZ

The development of TRIZ began with the initial version of ARIZ (fig. 5.1). Altshuller often stressed that TRIZ organizes thinking as if the experience of all or at least several talented inventors were available. Usually, even the most experienced inventor uses *experience that is based on external analogies*: this means that this task has certain similarities to an older one, i.e., the solution has to be similar, too. *An inventor who knows TRIZ can look much deeper*: there is *such a conflict* in the new assignment that the idea of a solution for an older task can be used that has no external similarities to the new one, but that *contains an analogous conflict*!

The author of TRIZ defined the difference between to concepts of *procedure, method,* and *theory* in the following way:

Procedure – this is a unique and elementary operation. A procedure can refer to the actions of a person who solves a task, as in the "usage of analogies". A procedure can refer to the technical system of the task at hand, such as "disassembly of the system", "combination of several systems". Procedures have no direction: it is not clear in which case this or that procedure is appropriate and when it will function. In one case, an analogy can lead to a solution; in another it can be misleading. Procedures cannot be further developed, although the number of procedures can increase.

Method – is a system of operations that usually contains procedures and foresees a specific order for their usage. Methods are usually based on a certain principle, on a postulate. This is why the assumption that a solution can be found by "releasing the flow of thought from the subconscious" is the basis of brainstorming. The basis of ARIZ is the *principle of the similarity* of conflict models and models for solutions to contradictions. Methods display very limited development and remain fixed in the framework of their initial principles.

Theory – is a system of several methods and procedures that foresees the goal-oriented control of the process of finding a solution to a problem based on knowledge of the laws (models) of the development of complex objects in technology and nature.

By 1985, the highpoint of the development of classical TRIZ, the theory had been shaped for almost 40 years. The author of TRIZ described the development of his theory in the following way.

Stage 1. Work on ARIZ was started in 1946. Incidentally, the concept of "ARIZ" did not yet exist then. Questions were asked differently then:

It is necessary to study experience gained in creative activities and to focus on the characteristics of good solutions that differ from bad ones. The resulting observations can then be used to solve problems in inventing.

It was immediately clear that solutions to problems in inventing are especially effective when they overcome the technical contradiction (TC) that existed in the assignment. On the other hand, solutions are ineffective when they don't address and don't overcome the TC.

But then, a totally unexpected discovery was made: it became clear that even the most experienced inventors don't understand, don't see that the correct tactics to solve problems in inventing should be to investigate the TC step by step, to examine its causes and eliminate them, thereby eliminating the TC itself. When inventors ran into an obviously screaming TC and recognized that the problem would disappear with its elimination, none of them drew the conclusion for the future that had been anticipated. *They maintained the same tactics*, worked on new tasks, sometimes wasted years on the selection of variations, and didn't attempt to formulate the conflict or contradiction that was contained in the problem.

There was therefore no hope to gain something useful for beginners from the experience of great (experienced and talented) inventors: these inventors work constantly with the same primitive method of trial and error.

Stage 2. In the second stage, the problem looked like this:

It is necessary to find a program for the planned solution of problems in inventing that can be used by all inventors. This program should be based on a successive analysis of the task in order to define, investigate, and eliminate technical conflicts. This program does not replace knowledge and abilities, but it does prevent many errors and it offers good tactics for solutions to problems in inventing.

The first programs ARIZ 1958 and 1961 had very little in common with ARIZ 1985. But they had become more precise and reliable with each modification and they took on more and more the character of an algorithmic program. Tables were created with procedures to eliminate TC's (see the latest TRIZ version in appendix 3 *A-matrix for the selection of A-navigators* and 4 *A-navigators* – in the author's notes). Patent information and descriptions of inventions became the basis for investigations. Initial seminars were held and experience was gained in the presentation of ARIZ for others.

And again an unexpected discovery was made. It became clear that knowledge was necessary for solutions to tasks at higher levels that exceeds the limits of the inventor's field. *Practical attempts lead to useless experiments in the usual direction,* the use of ARIZ and its tools (procedures, etc.) only improved the process that reached a solution.

It was clear that people are not able to effectively complete tasks of inventing at a higher level. This means that all methods are incorrect that try to activate everyone's "creative thinking" because they are only *attempts to positively organize bad thinking* (Altshuller's words). Stage 2 starts with the development of the idea to provide the inventor with a *helping tool*. It ends with the perception that it is necessary to reshape inventive creativity and thus to *change the technologies of inventing itself.* The program was now thought of as a complete system for solving problems independently from the human subject. *Thinking should follow this system and let itself be directed - then it can certainly become much more talented.* It was also clear that the operations of ARIZ should be compared and contrasted with the objective laws of the development of technical systems.

Stage 3. The formula for the third stage was as follows:

Inventions at a lower level are not creative at all. It is poor creativity to produce inventions at a higher level by trial and error. We need new technologies to solve problems in inventing that enable us to solve tasks at a higher level in a planned way. These technologies should be based on the knowledge of objective laws for the development of technical systems.

Patent information was the work basis, just like in stage 2. But, they were now no longer investigated only to create and introduce new procedures into the table for the elimination of technical contradictions. They were now also used to examine general laws for the development of technical systems.

The most important discovery was the fact that an invention is the further development of a technical system. An assignment in inventing is a form in which people uncover requirements for the development of a technical system. TRIZ teaches inventive creativity with the goal in mind to create effective methods to solve problems in inventing.

A thought is hidden in this definition that may sound very strange: are all extant methods ineffective and should they all be thrown away? People have made great inventions with these "methods"! A modern industry for inventions that produces thousands of new technical ideas every year is based on these methods. What makes them so ineffective? There are the usual, unsubstantiated viewpoints about creativity in inventing, such as: 1) "Everything is arbitrary"; 2) "Everything depends on knowledge and stamina. You have to always try different variations"; 3) "Everything comes from natural abilities".

Of course, all of these opinions contain a little bit of truth. But, this truth is external and superficial. "Trial and error" is in and of itself ineffective. However, the modern industry for inventions is organized in accordance with "Edison's method": the more difficult a problem is, the greater the number of experiments is and the more people need to take part in the search. Altshuller illustrated his critique of this method as follows: it is clear that the principle of digging remains the same even if a thousand people dig different trenches. A single inventor, a treasure hunter, can work with a good method much more effectively than a "team of mine workers"!

Without TRIZ, an inventor has to make a long and difficult choice between the usual and traditional variations that are part of his field of expertise when solving problems. It is often impossible to look beyond these variations. These ideas then often move in the direction of the psychological inertia vector (PIV). The PIV can be caused by many things. There is always the fear of leaving one's professional field behind and moving into unknown territory. There is also the fear of producing an idea that appears ludicrous. Of course, another reason can be that the inventor is not familiar with procedures to generate "wild" ideas.

Altshuller illustrated the "method of trial and error" with the following schematic (figure 5.2). The inventor starts at "task" and arrives at "solution". It is not clear where exactly this latter point is. The inventor creates a certain concept for the search and begins to “throw” ideas in the direction chosen. These directions are represented by thin arrows. And then it becomes clear that the concept is not entirely correct and that the search has moved in a totally incorrect direction. The inventor then goes back to the departure point of the task, develops a new concept for a search, and starts to “throw” again with the idea “what if ....?”

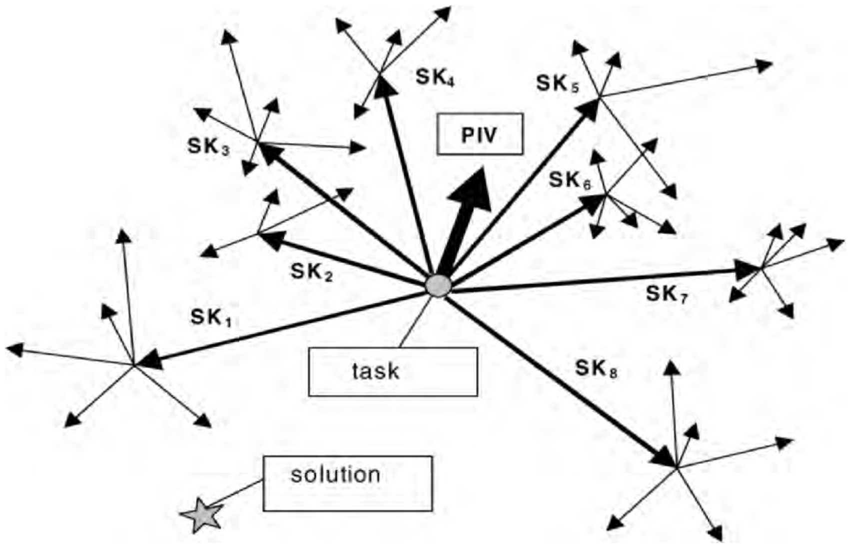

fig. 5.2. Search schematic with the method of “trial and error”

In the schematic, the arrows that move in other directions or even that prevent a solution are the thickest. This is because the attempts are not as chaotic as they initially look. They are even somewhat organized ... in the direction taken by previous experience. This is in the direction of the PIV!

Assignments on different levels differ primarily in the number of attempts that are required to find a solution. But why are 10 attempts necessary for one task, 100 for another one, and 10,000 for yet a third?! What is the *qualitative difference* between them? Altshuller came to the following conclusion (see also section 3.2 *Levels of inventions*).

1. Tasks can differ according to the *content of the knowledge required.* At the first level, assignments and the means to solve them move within the framework of a profession or a field within a profession. At the second level these means come from the framework of the entire field. For example, a task in mechanical engineering is solved using tools and experience from other areas within mechanical engineering. The limits of an entire science hold true for the third level. A mechanical task can be solved based on the laws of mechanics, for example. The fourth level includes means that go beyond the limits of the science in which the problem occurs - a mechanical task can be solved chemically. Higher levels move

beyond the limits of modern science. This is why new scientific knowledge or new discoveries can be required for use in solving problems in inventing.
2. Assignments can differ according to the *structure of the interactive factors*. This can easily be demonstrated using the "structural" differences between problems from the first and fourth levels, for example.
The following is characteristic of tasks at the first level:
1) There is a low number of interactive elements.
2) There are no unknown factors, or at least they have no meaning.
3) Uncomplicated analysis:
- *elements that must be changed can easily be separated from those that cannot be changed under the conditions that obtain in the assignment;*
- *the interaction of elements and possible changes are easy to follow.*

4) It is then somewhat disadvantageous when the task needs to be solved quickly.
The following is characteristic of tasks at the fourth level:
1) There is a large number of elements for consideration.
2) The number of unknown factors is high.
3) Complexity of the analysis:
- *it is difficult to separate elements that can be changed under the conditions that obtain in the assignment;*
- *it is difficult to construct a sufficiently complete model of the interaction of elements and of changes.*

4) It is advantageous when a lot of time is available for necessary searches.
3. Assignments can differ according to the *degree of change in an object.* An object (facilities or a procedure) is *hardly changed* in tasks at the first level. It is possible that the value of one parameter is altered, for example. At the second level, an object is changed in a relatively *unimportant way*, for example, in a few details. At the third level, an object is subjected to *meaningful changes,* for example, in its most important components. At the fourth level, it is *changed completely*, and at the fifth the *technical system is also changed* to which the object belongs. This is why a procedure for "transitions" is needed that can transform "difficult" problems into "easy" tasks, such as when quickly limiting the search parameters.
4. *Nature has not developed heuristic procedures of a high order!* In the course of human evolution, the human brain has adapted only to solutions to tasks that correspond to the first level.

Even those people who make one or two inventions at the highest level in their lives do not collect and pass on their "high-level heuristic experience". Only those heuristic experiences at a low level have been passed on by tradition: increase - decrease, combine - separate, use analogies, copy, and a few more (see section 4 *Inventive Creativity*). Others were then later added, such as "put yourself in the place of the object of investigation" (empathy), "think about psychological barriers" etc. (see also the section *Art of Inventing*).

"Heuristics" at this level can be demonstrated to young engineers continuously, but *they won't learn to use them*! Here the point is that calls to "think about psychological barriers" are doomed to failure because we don't know how to *fight against psychological barriers*. It is also useless to use analogies if it is *not clear in advance which analogies could be appropriate*. This is especially true when there are lots of analogies at hand. Empathy causes nothing but confusion and is even counter-productive when used for a complex object.

This means that our brains have only learned precise and applicable procedures in the course of evolution that can serve to solve simple tasks. Heuristic mechanisms have not yet been discovered - they simply don't exist.

But, they can and must be created!

Let's move to the third stage and to the middle of the 1970's, a time that also represents the temporal middle of the history of classical TRIZ. It was also the beginning of a comprehensive perfection of TRIZ - the discovery of the physical contradiction (PC), the formulation of laws for the development of technical systems, the compilation of the first catalogue of physical principles for the development of great inventions ("effects"), and the compilation of the first "standards" (complex procedures).

5.3 Structure of Classical TRIZ

The structure and history of classical TRIZ is shown schematically in fig. 5.3 and 5.4. TRIZ is an example of the realization of the *idea of the concentrated representation of knowledge.* An investigation of the developmental history of TRIZ reveals the following stages:

1) until 1985 - the development of ***classical TRIZ***, essential ideas with conceptual character (supplemented by instrumental aspects) that were published by Genrikh Altshuller;

2) after 1985 - the development of ***post-classical TRIZ***, essential ideas to *"expand"* the theory with detailed presentations, partial formalization, concretization, and a large collection of examples and to *combine* it with other methods, especially with methods of functional and cost analysis and with methods analogous to Quality Function Deployment (QFD) and Fault Modes and Effects Analysis (FMEA).

The most important discovery of *TRIZ* is the fact that a million registered inventions have been made based on a relatively small number of transformations of the original assignment.

TRIZ makes clear reference to the key conceptual components of the organization of every problem and the synthesis of their solutions: ***contradiction, resources, ideal result, rules,*** or rather, ***transformation models***.

In addition, both methods for the solutions to problems were formulated in steps with the help of the concretization and transformation of the original problem and *systems of procedures* were created with TRIZ. This method is described as an ***"Algorithm of Inventive Problem Solving"*** (ARIZ).

With TRIZ, a theory, methods, and models were developed to systematically investigate and solve complicated technical-technological problems ***for the first time in the history of creatively active humanity.*** These problems are characterized by considerable physical and technical conflicts and contradictions that essentially cannot be solved with traditional methods of construction.

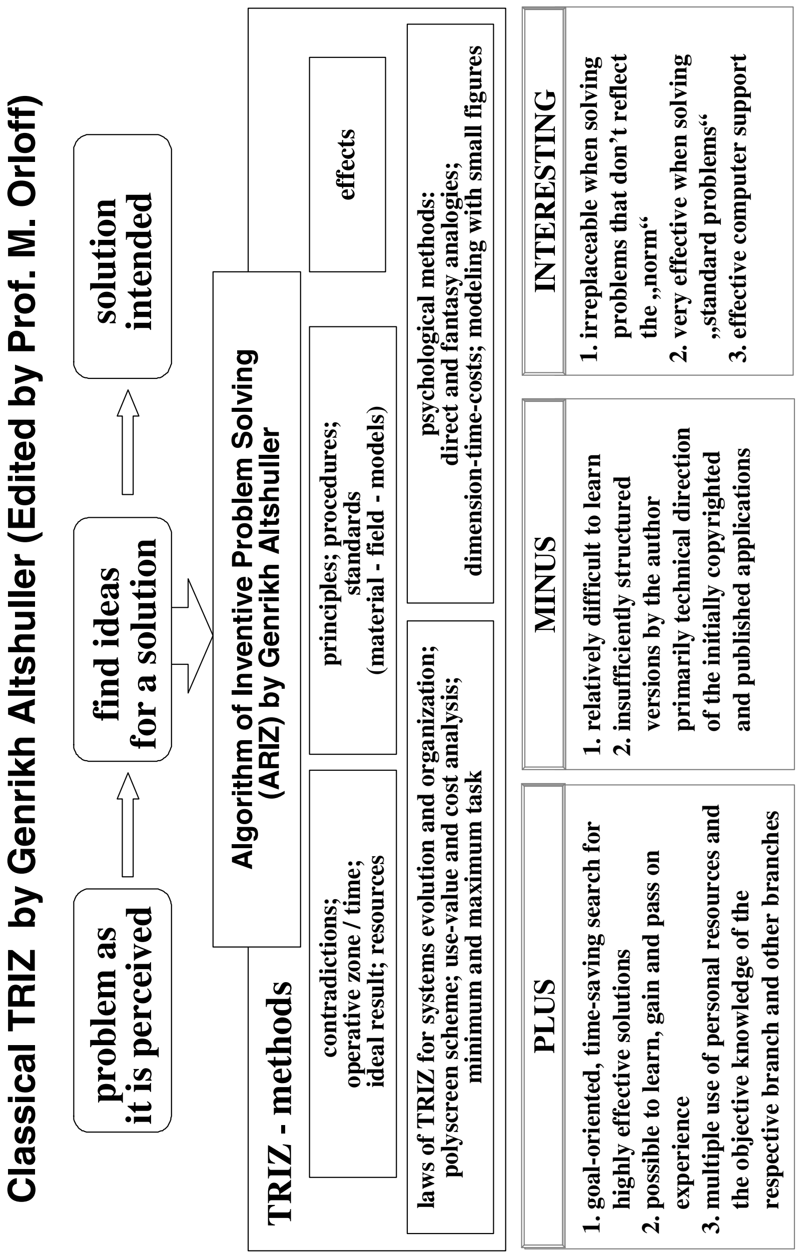

fig. 5.3. Structure of classical TRIZ

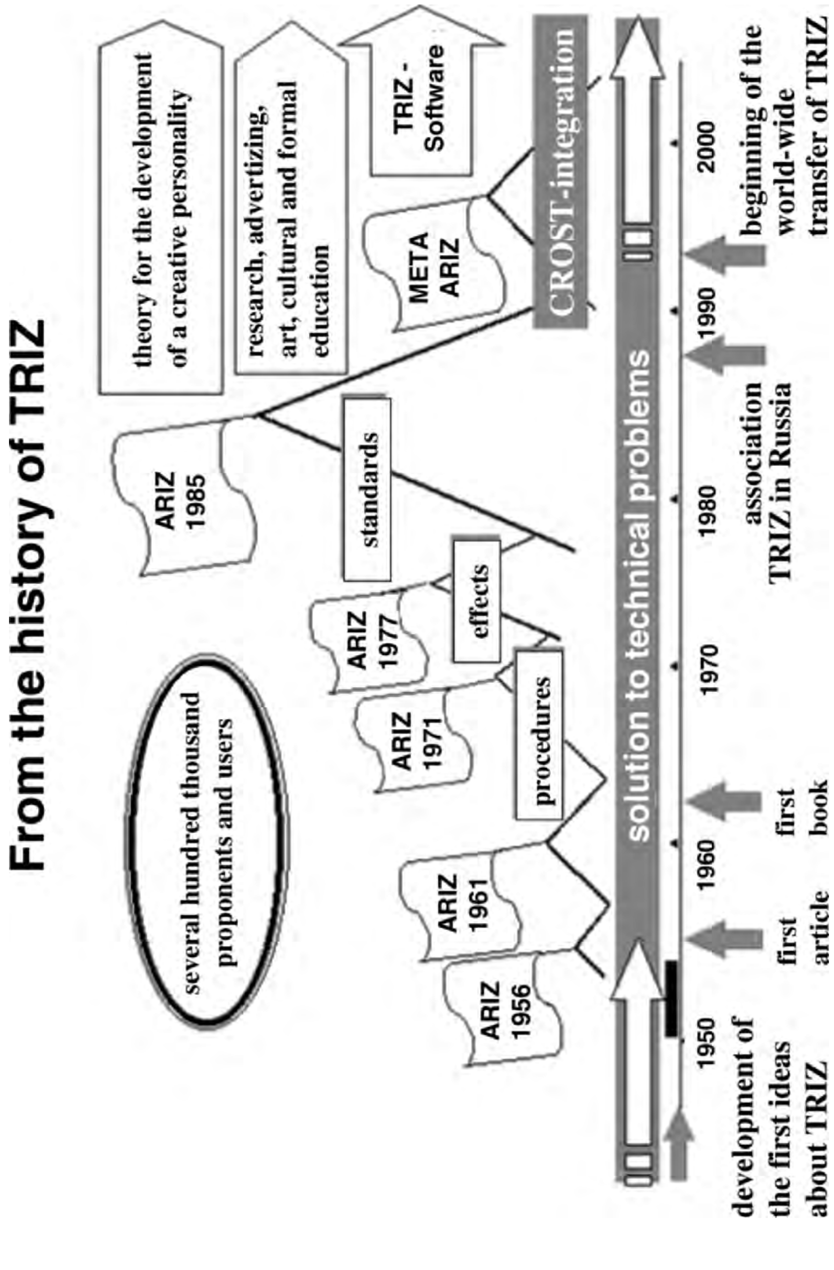

fig. 5.4. From history of classical TRIZ

According to an illustrative definition by Altshuller, ARIZ (and all of TRIZ) is supported by "three primary pillars" [4]:
1. The task is processed step by step according to a precise program that recognizes and investigates the physical conflict that has caused the problem.
2. Concise information is used to eliminate the contradiction that embodies the experience gained by several generations of inventors (tables of typical task models- procedures and standards, tables for the use of physical effects, etc.).
3. There is a kind of psychological scheme for the course of the search for a solution: ARIZ shapes the thinking of the inventor, eliminates psychological barriers, and leads inventors to unusual and courageous ideas.

Furthermore, it should be noted that most previous books and articles about TRIZ have merely repeated themselves and have shown the value of TRIZ only as a traditional system for solutions to technical problems. This has often leaded to misunderstandings about the possibilities and limits of TRIZ.

Above all else, known publications don't mention the existence of many unsolved questions about the "functions" of creative thinking. For example, this is the case with the largely comprehensive necessity of various intuitive thought acts. They also don't mention that it's not possible *to reach a solution* and constantly use terms like the "algorithm of inventing" and "transformation operator". This is why different people who use the methodologies recommended here come to widely disparate results. They don't mention the open-ended (even if drastically shortened) time for the search for a solution when using an algorithm. This is because there are *essentially non-algorithmic acts of thought.*

And finally, if the objective knowledge at hand is insufficient to solve the problem ***and a scientific investigation*** has been made, then even TRIZ has its limits. But, it should be added that TRIZ is also a useful instrument for the completion of a scientific investigation. This textbook shows the author's broad and realistic approach to a theory of inventing that attempts to integrate the highly effective models of TRIZ with traditional methods for an intuitive search as well as comparing and contrasting them.

Exercises* 3 - 5

1. Portrait of sounds. In caves with paintings of animals that were made more than 100,000 years ago, it is still possible today to simultaneously see the paintings and hear the sound of the animals or an entire herd running! How did the cave dwellers "draw" the portrait of sounds for their children? Incidentally, they could "speak" in a similar way with the representations of their ancestors and with entities from mythology.
2. Lighthouse at Alexandria. The second wonder of the world after the Egyptian pyramids was the lighthouse at Alexandria. According to legend, a ruler commanded that his own name should stand on the lighthouse, not the name of the builder. The latter would be executed if he did not comply. The builder lived, yet history has recorded his name. How did he solve this contradiction?

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* some popular TRIZ examples in Russian are prepared as the exercises here and below.

3. Puzzle of the pyramids. In the construction of the Egyptian pyramids:
a) how could the builders construct perfectly horizontal linear foundations for the pyramids, even though the surface of these foundations cover several acres?
b) how could the height of the pyramids under construction be measured?
c) how could the perfect symmetry of the pyramids be maintained?
d) how could the identical angle of 42° of the edges and also the angle of 51°-52° of the sides of the pyramids be reached?

4. Ambassador Ismenius. The Greek ambassador Ismenius arrived at the court of the Persian King Artaxerxes I. The proud ambassador did not want to bow even though this was not possible because then there would have been no negotiations. What did Ismenius do when he approached the King's throne?

5. Crowning of the emperors. Charlemagne (King Charles the Great) was crowned in the year 800 AD. According to tradition, the Pope had to put the crown on Charlemagne's head to consolidate the latter's political power. But, the ruler didn't want to submit to the Pope, as tradition also dictated that the Pope then could also remove the crown if he so desired. And now the Pope is raising the crown towards the ruler's head .... How did Charlemagne solve this conflict? The same thing happened again 1000 years later as Pope Pius VII attempted to crown Napoleon Bonaparte in the cathedral of Notre Dame in Paris in December of 1804.

6. Leaning Tower of Piza. In competitions to save the Leaning Tower of Piza in the last 60 years, more than 9,000 suggestions have been submitted from all over the world! It was noted that the tower would lean 200 years after the beginning of construction in 1173. In 1370, an eighth floor was added as a counter-weight. The height of the tower was now almost 60 meters and its weight was 14,453 metric tons. In the 600 years following this attempt, the foundation sank almost 3 meters into the ground and the deviation of the 7th floor from the vertical is now 4.47 meters (fig. 5.5). In 1990 the tower was closed to visitors.

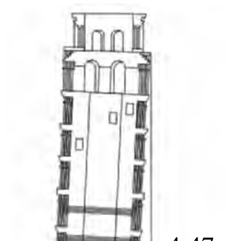

fig. 5.5. Leaning Tower of Piza

In 1993, a model of and prognosis for the future lean of the tower was made. It was not thought that the tower would stand longer than until 2050 and that it would lean farther at a speed of 1 mm per year. In 1999, the mayor of Piza, Fontanelli, opened the last exhibit of the projects *"Viva la torre!"* (Long live the tower!). By 2000 the lean of the tower had been reduced to 4.7 m, i.e., about 40 cm. This means that the tower will not reach its critical angle of lean in the next 300 years. Perhaps visitors can soon climb the 293 steps of the circular stairway to the top of the tower again.

Three questions:
1) What can you suggest that would reduce the danger that the tower of Piza will be destroyed without disturbing its historical and aesthetic value?
2) How was the critical lean of the tower reversed?
3) Why can the tower not be made completely vertical again?

A-Studio: Algorithmic Navigation of Thinking

A heuristic program is necessary for effective solutions to problems in inventing at a higher level that replaces the continuously new selection of variations with a goal-oriented movement into the domain of the solution.

Genrikh Altshuller

6 From Praxis to Theory

6.1 A-navigation of Thinking

Let's start to become familiar with the basics of TRIZ. Classical TRIZ is grounded on a stable practical foundation. This foundation is patents, millions of patents in which ***real solutions and procedures for solutions*** to problems and the ***experience of millions of inventors*** is accumulated. This was Altshuller's revolutionary discovery to directly examine the ***objective information*** that inventions contain.

The second discovery was a definition of the contents and goals of the investigations needed for the construction of a workable theory.

1. In every technical system that was improved and patented, the key problem solved has to be found, the causes and structure of this problem must be examined, and the invariable elements (constant characteristics) of real problems have to be defined.
2. The key transformation that determined the transition from the assignment of the task to the idea of a solution has to be extracted from every patent, especially from those that are very valuable. These transformations need to be classified and systematized. An assessment of their frequency and effectiveness is necessary.
3. It must also be determined how we can find the appropriate transformations in new situations in order to concretely use them for every new task as a pattern or model for the search for solutions.

So far, the investigation of more than 2.5 million patents has demonstrated that the strategy chosen by Altshuller was correct.

As a result, three practical discoveries lie at the essential foundation of TRIZ:

1. All real problems can be reduced to three different types that can then be represented by three structural models:

administrative problem with corresponding *administrative contradiction (AC)* – the situation is described using a reference to the inadequacies that should be addressed or to the goals that should be reached. There is no reference to the causes that lead to the inadequacy, to procedures for its elimination, or to the achievement of the goal in mind;

technical problem with corresponding *technical contradiction* (TC) – the situation is described using a reference to the incompatible functions or functional properties of the system of which one of these facilitates the useful primary function of the entire system (the purpose of the system) while the other hinders it;

physical problem with corresponding *physical contradiction* (PC) – the situation is described using a reference to the physical property of an element or of the entire system in which one value of this property is necessary to achieve one certain function of the system while another value is necessary to achieve another. Both values are incompatible and demonstrate mutually exclusive and opposite tendencies for their own improvement.

The author of TRIZ constructed an exact *functional structural model* shaped as *administrative, technical, and physical contradictions* for every problem that will be examined in the following sections.

The most constructive models here are those for technical and physical contradictions because their solutions are directly supported by the instruments of TRIZ. Administrative models can either be solved with methods without direct connection to TRIZ, for example, with economic methods or by means of supplementary scientific investigations, and/or they need to be transferred to one of the other two models.

2. All known solutions were found based on transformations that belong to only four classes:

- direct models for solutions to physical contradictions (in TRIZ these are "***principles***", I call them ***fundamental transformations***);
- direct models for solutions to technical contradictions (***specialized transformations*** or "***procedures***");
- recommendations for the change of physical-technical models by means of the interaction of "field-material" (***complex transformations***, or ***"standards"***);
- recommendations for the realization of the necessary function based on examples of standard or original applications of known or new physical-technical phenomena (***basic transformations***, or "***effects***").

> ***Every model represents an example of the solution to a problem using an invention of a general shape in a certain class of models and for a special situation.***

3. A progression of steps was constructed in TRIZ based on the reinvention of one hundred thousand inventions for the rational investigation of the initial situation of a problem, for the construction of a model, the selection of an appropriate

transformation model, and for a test of the effectiveness of the solutions suggested.

These schemes composed of several steps survived a long process of development and practical application. In 1985, Altshuller summarized them in a scheme with the term ***"Algorithm of Inventive Problem Solving – 1985"***, or shortened to ***ARIZ-1985***. ARIZ-1985 is a kind of condensed extract of all of TRIZ. The large number of explanations, comments, remarks, and excursus make it difficult to learn. This is precisely why the author of this textbook began to develop a more compact scheme in 1987. This version was given the name ***"Meta-Algorithm of Inventing"*** with its considerable generalizations.

Even the concept "algorithm of inventing" has been criticized to the present day. Critics argue that the most familiar definition of an algorithm as a tool to program computers of the first generation leaves no room for uncertainty. However, this definition is to narrow even for modern computer mathematics that operate with concepts of unclear, probable, iterative, recurring, or even more complicated algorithms. The use of the term "algorithm" is completely correct from the perspective of modern constructive mathematics and mathematical linguistics, both of which operate with models of *categories and functors*, with affinity and even more complex representations.

If we rely on these arguments, we can take the following step: we can define the primary goal of classical TRIZ as the achievement of an ***"algorithmic navigation of thinking"***.

It makes sense to connect this concept with the term **"A-navigation"**. Here the symbol "A" both reflects the algorithmic character of its support of solution finding processes in complicated problems even as it does the author of TRIZ Genrikh Altshuller justice. A-navigation and concepts derived from it remind us of the founder of TRIZ in this way.

The concept "thinking" that has been included here in our definition can be more precisely described as *inventive thinking* or as *thinking for solutions to problems in inventing*. This could help prevent misunderstandings and running discussions. A problem in inventing can here be understood in simple way as a *task* or *assignment that contains incompatible requirements or an "unsolvable conflict"*.

The concept "navigation" seems to be precise and extremely valuable. People think in images and metaphors and use a special transformation model so that patterns are questioned and analogues for the development of solutions are made using associations and analogies. This is how people enrich the model with concrete contents from the new task and the model directs their thinking towards the goal. Generalized transformation models and illustrated examples play the role of ***navigators of thinking or navigators of inventing,*** or as we describe them here, ***A-navigators.***

Actually "navigation" means ***both measuring the situation of a variable object and possibly a variable goal as well as shaping the path to a goal.*** This is precisely the purpose of ARIZ and its A-navigators (***A-algorithm***)! The A-algorithm plays the role of a true ***navigation system*** that foresees an analysis of the task and the application of the A-navigators (of the ***navigation instruments*** - "maps", "instructions", "rulers", "patterns", "compasses", "circle", etc.) to shape a path to the goal - the development of an effective solution. Of course, the success of an application of the A-algorithm and A-navigators also depends on the "captain", "driver", and the "navigators" who steer all movements, i.e., on concrete people who solve tasks that require creativity.

All theoretical and practical instruments of TRIZ can be divided into three levels (figure 6.1). It is clear that, in a narrow sense, ***these levels correspond to the three types of problems: administrative, technical, and physical.*** However, we will understand all A-navigators as instruments of the operative level. This is because these instruments are used only if everything has not been solved at the tactical and strategic levels. Experiments with test operations can help to better understand the properties of the assignments for tactical and strategic guidance processes.

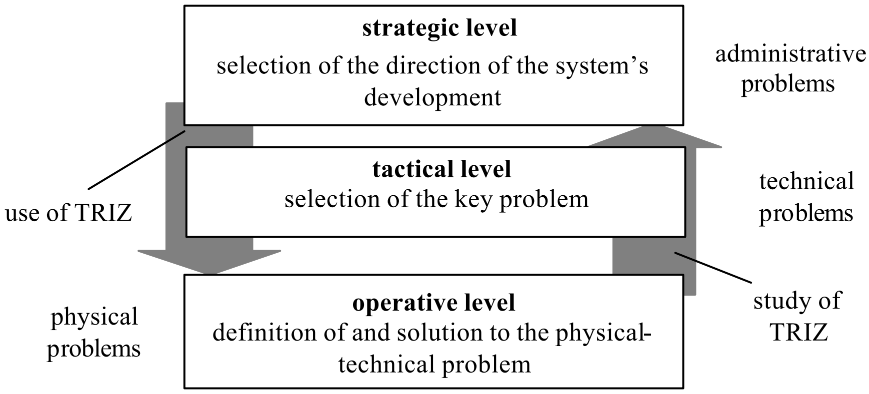

fig. 6.1. Processes of the application and study of TRIZ

The order recommended in figure 6.1. to study the instruments of classical TRIZ was created with the following advantages in mind:

1. The methods of the operative level are based to a high degree on praxis. To learn them correctly therefore makes the quick use of TRIZ instruments possible to solve practical problems (initially simple problems, of course).
2. Knowledge of the operative level functions as a basis to understand the ideas and methods of higher levels, as the study runs from simple and practical concepts more complex and abstract ones.
3. Individual capabilities to use the operative instruments are then strengthened by the subsequent study of the tactical and strategic levels using practical examples.
4. Finally, the operative level has been precisely and comprehensively developed. This makes the creativity and effectiveness of TRIZ even more convincing.

A-navigators make it possible to solve up to 80% of all tasks that arise in praxis. These models were derived by extraction from the so-called "standard assignments" that make up about 80% of all the world's patents. However, we should note that the term the "standard character" of an assignment does not mean that this problem has an obvious and easy solution. This simply means that experiments (reinventing) have revealed that the use of only one or two "classical" TRIZ procedures were sufficient to solve such tasks.

Of course these problems were solved without any knowledge of TRIZ, meaning a lot of time and energy was probably needed for the search for a solution. Only with reinventing for teaching or research purposes is it possible to perceive with which method this or that task could have been solved. The "reconstruction" of the solution process when examining "standard problems" is eased by the fact that a concrete solution can be found in a patent description and the characteristics of the transformations made are easy to recognize.

It is often difficult to tell whether the assignment in a new concrete situation can be solved with relatively simple "standard procedures". On the other hand, this is not very important because it is logical to first test the use of simpler "standard transformations" in every situation.

We will return to a definition of the degree of difficulty of a task in the following sections on the tactical and strategic models of TRIZ.

6.2 A-navigators of Inventing

In this section, you will have the opportunity to follow the entire path that TRIZ took in 45 years of development in 30 minutes. Together we will construct a few A-navigators! We will reinvent 9 examples of technical solutions and will see how the A-navigators were defined. It is important to note that those examples we have chosen could be replaced with other ones. But, the result of reinventing would be the same with the selection of a sufficient number of examples as the one achieved with TRIZ.

Attention: You should not look at the section *Classical Navigators in Inventing in the A-Studio* until you have become familiar with the following examples. This would only be confusing.

Why don't you take a short break here and think about the following questions:

Which similarities can you see in the following discoveries: aircraft with vertical take-off and landing, protection against floods for houses on a river, or the care of grape vines? How about inventions like a lifting crane for cars, a surprise for kids, and tubes to remove construction waste from upper floors when renovating houses? How are procedures to protect decorative palms against heat, natural gas in balloons, and a procedure to produce chocolate bottles filled with liquor connected?

> Could there be certain *similar ideas* in all of these groups of inventions, could an essentially *unified model* be defined, generalized, and subsequently be applied as a creative procedure?

Reinventing with TRIZ answers these questions with yes.

6.2.1 Construction of a specialized A-navigator number 7

Example 4 (task). "VTOL" - aircraft with vertical take-off and landing. These aircrafts require no take-off and landing field. The first models of this type took off and landed in a vertical position (figure 6.2).

fig. 6.2. Guidance in the first models of aircraft with vertical take-off and landing

The pilot lay on his back in his seat and could only look up. This was acceptable at take-off, but landing on the tail of the aircraft was extremely dangerous due to difficulties with visual control and guidance. There were therefore functions or properties in this situation that conflicted with each other when fulfilling the main function of the system. In concrete terms this meant that the vertical position of the aircraft corresponded with the direction of take-off and landing but that it was disadvantageous for guidance.

It is possible to describe the model of the situation by using the following contradiction:
function: vertical take-off and landing;
requirements (plus-factor): a vertical position for the fuselage;
disadvantages (minus-factor): poor visual control and guidance.

Example 5 (task). House on a river. In 1994, an idea to protect houses built close to rivers from floods was registered in the USA as a patent. In figure 6.3.b, the situation is shown where water can cause severe damage to the house. There are requirements in this example that conflict strongly with each other: the house should be close to the water (preference of the owner) under normal environmental conditions, but it should be far away from the water during floods?! The second requirement seems fantastic and like a fairytale, but certainly not very technical. But, it reflects the physical contents of the requirements for the security of the house during floods very well.

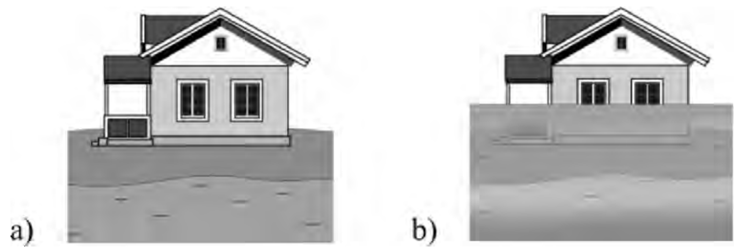

fig. 6.3. House on a river under normal conditions (a) and during floods (b)

A model of this situation can be described with the following contradiction:
object: house

desirable: close to the river under normal conditions;
undesirable: close to the river during floods.
Apparently these requirements are mutually exclusive.
Example 6 (task). Grape vine. Grape vines are removed from their wire supports, laid out on the ground, and secured with wire to minimize damage caused by frost in the winter (figure 6.4). How could the work needed for this job be reduced?

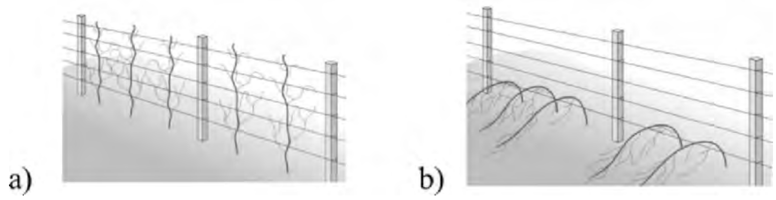

fig. 6.4. Grape vines in the summer (a) and in the winter (b)

At first, it seems that there is no contradiction here. This means that we clearly are confronted with an administrative conflict: someone wants to improve the system, even though it is not clear what motivates this person to reach the goal in mind. Let's formulate the model of the problem by using the following variation of a contradiction:
function: to lay the grape vine on the ground;
plus-factor: Losses due to frost damage are reduced (less frost damage to bark);
minus-factor: Time and effort is wasted in this operation.
We can also formulate this model in a reverse way:
function: Grape vines stay wired in place;
plus-factor: No time and effort is wasted in this operation;
minus-factor: heavy losses due to extensive frost damage to bark.
It is clear that these models shaped as conflicts offer the chance to precisely define in which direction a solution should be sought and what the search should limit. Let's now look at the known patented ideas for solutions.
Example 4 (solution). "VTOL" - Aircraft with vertical take-off and landing. There are very few patent ideas for a solution to this problem. All of the solutions reached the primary goal: to maintain a normal situation for the pilot during take-off and landing that then guarantees the required level of safety. Was there something common to all of these ideas? Yes, I think so - the ***introduction of a moveable part into the system*** – moveable wings, rotating engines, etc. For example, the engines can be directed vertically at take-off and landing like in figure 6.5, a. The wings then rotate to a horizontal position during flight (figure 6.5, b). The fuselage of the aircraft is relatively fixed in a horizontal position at take-off and landing. This means that the pilot enjoys normal conditions for observation and guidance.
Example 5 (solution). House on a river. The key idea of the patented solution (fig. 6.6) is that the *house was made moveable*! This solution creatively addresses *both parts* of the contradiction as it was formulated.

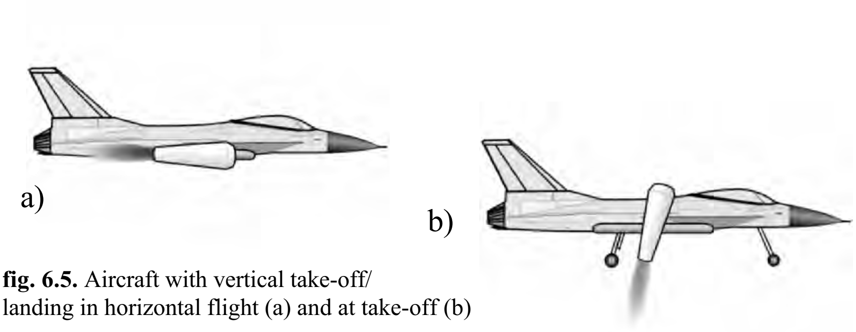

fig. 6.5. Aircraft with vertical take-off/ landing in horizontal flight (a) and at take-off (b)

The house floats during floods because its underground part was built as a hermetically sealed pontoon filled with a buoyant liquid such as foam plastic, for example. Keep in mind that the water itself moves the house and lifts it to a level where there is no more danger. The house then stands on moveable telescopic pillars. The house can be supplied with provisions - food, water, and an energy source such as Diesel fuel for a generator - to function under flood conditions in the long-term, too.

Example 6 (solution). Grape vines. I assume that the reader has already used these two examples described above to guess that a procedure can also be used here that was appropriate for the previous solutions. The grape vines are not removed from their stands before the winter. Instead, the entire fence is laid on the ground using a hinge attached at ground level (figure 6.7). This means that here too the *key to the solution to the problem is dynamization,* or the *moveable* shaping of an object.

fig. 6.6. House on pontoons and on moveable pillars

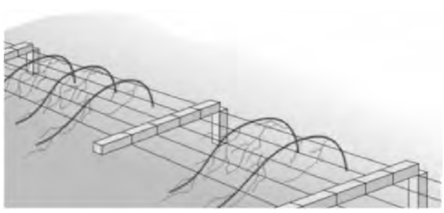

fig. 6.7. Grape vines on a hinged fence

In this way, the very same key idea was derived from completely different problems and their solutions. This method can be described as a ***specialized procedure (navigator) for inventing***. This navigator is called **"dynamization"** in TRIZ and has the number 07 in the table of specialized A-navigators (Appendix 4).

Based on the reinvention of many thousands of inventions, a generalized and shortened description of this navigator was made using the following recommendations:

a) *the characteristics of an object (or its environment) should be changed in such a way that they are optimal in every work step;*
b) *the object should be reduced to parts that are moveable with respect to each other;*
c) *if an object is fixed then it should be formed in a moveable way.*

6.2.2 Construction of a specialized A-navigator number 34

Example 7. Lifting crane for cars on the bed of trucks. We have all already seen this kind of lifting crane. But, have we all, or at least have all engineers thought about which procedure for inventing was used here as the primary construction principle?

We can formulate the main contradiction that had to be addressed in the development of this kind of crane in the following way: the moveable part of the crane has to be relatively long in its working state, but it should not be much longer than the entire car to be transported. The principle of the solution is to shape the moveable parts of the crane in a moveable way and, most importantly, to form these parts out of several segments that *fit into each other* (figure 6.8).

a)

b)

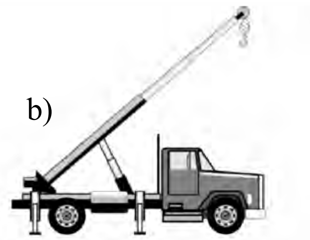

fig. 6.8. Lifting crane for cars during transport (a) and at work (b)

Example 8. Tube to remove construction waste. Cone-shaped hollow rings are used in this invention that can be *slid into each other* during transport. They can then be pulled out to their entire length even though they still fit into each other. This is how they form a "tube" of the needed length! Construction waste can then be thrown through this tube from the upper stories of a house directly into a transport container (figure 6.9).

a)

b)

fig. 6.9. Tube for construction waste removing during transport (a) and during work (b)

Example 9. Surprise toy (surprise egg). I admit that I sometimes like to be surprised by these eggs. There is really no way to know what is inside! It could be a model car or plane, a tiny bear or house, etc. There are virtually no limits placed on the fantasies of the developers of this product!

But, the real surprise is the fact that none of these toys would fit into the egg after it is put together. This is why the toys hidden in the eggs consist of several parts that are packed together ***so that the hollow space in one part (egg) is filled with other parts (parts of the toy).*** This is the main principle of this product that is used repeatedly. Keep the edible part and the aluminum packaging in mind, too (figure 6.10).

a) 

b) 

fig. 6.10. Surprise egg (a) and the toy inside (b)

To summarize the results of reinventing, we can conclude that this is the *principle of the repeated packing* of an object into another in which hollow spaces are used rationally. Space is saved and totally "incompatible" functional properties are combined with each other.

In classical TRIZ, this navigator was given the name "**Matryoschka**" after the name of a Russian toy (figure 6.11) in which several hollow figures are packed into each other according to their size (see navigator 34 in the Appendix 4 Table A-navigators).

Reinventing thousands of similar inventions led to the following laconic description of this navigator:

a) an object is placed into the inner part of another object that is inside yet another object, etc;

b) an object fits into the hollow space of another object.

a)

fig. 6.11. "Matryoschka" unpacked (a) and packed together (b)

b) 

6.2.3 Formulation of the physical and technical effect, definition of all four fundamental navigators, the complex navigators 5.3.1 (S2), and the specialized navigators 10 and 11

Example 10. How can palms in pedestrian zones be protected against heat? My youngest son told me about a TRIZ solution that he noticed in Valencia in Spain when he completed a language course there. Large pieces of ice are placed on the ground around palm trees in pedestrian zones to protect them from extreme heat. The ice melts slowly and provides these valuable trees with water. Sometimes the bark and fronds are also cooled with ice on hot days. Of course, we exchange stories in our family about such interesting examples and this is why our older son subsequently noticed the same principle at a conference in San Diego in California.

My sons have chosen professions that have very little to do with physics or chemistry. But, their school education was enough for them to recognize the principles that were used here: this can be called a ***phase transition,*** that in this case is a transition of water from a solid (ice) to a liquid state. It is precisely this physical property that was used in a "technological" procedure - continuous provision of water for trees. This is an example of the technical application of a physical property of water. The representation of this physical phenomenon with reference to its possible technical usage also provides us with the description of a certain *basic A-navigator* or ***physical-technical effect*** (in the terminology of classical TRIZ).

By the way, which structure does this problem have that was solved with the appropriate procedure for inventing?

Let's formulate the conflict in the following way:

1) water ***should be present*** at the roots of the palm so that it can survive the heat;

2) water ***should not be present*** at the roots of the palm because it evaporates too quickly in the heat.

Usually, this kind of conflict determined by physical processes that occur in physical objects can be eliminated most effectively with the help of the ***fundamental A-navigator 4***: ***separation of the conflicting properties in the material.*** In the example at hand, this kind of separation occurred using the possibility of a transition of the material into another aggregate state. Water can remain on the palm, but only as ice. More precisely, the water is present in two aggregate states in a part of the appropriate space (on the ground around the palms) for a certain period of time (as long as the ice has not melted). One part of the water is ice, the other is liquid.

A concrete and practical form of this recommendation can be found in the ***complex A-navigator 5.3.1 (S2):*** *Use of separation of material (field), application of capillary-porous structures, dynamization of fields and components,* ***use of phase transitions****, use of the coordination and de-coordination of rhythm and frequency.*

The A-navigators were developed based on reinventing many thousands of inventions that have shown that extremely important technical ideas have been developed by using precisely these transformations.

However, it seems much better to explain transformation models in this textbook without using complicated technical examples that are understandable only to a small circle of specialists. On the contrary, we should select examples here that are understood by the largest public possible.

Example 11. How can gas be injected into mine shafts safely? It is sometimes necessary to burn certain materials, for example, natural gas, in an entire series of operations in mine shafts. This can lead to the following problem: the gas should constantly be present in the zone where the technical operations occur, but there should not be too much gas at any same time. Otherwise the possibility of fire is too high. In addition, a system of tubes and pipes that is several kilometers long is truly complicated and expensive. To make the entire system more secure, gas is injected in portions in balloons instead of installing tubes and pipes. The gas is liquefied instead of reducing it so that it has less volume. The balloons are changed and stored in another shaft at a sufficient distance from the spot where the gas is then burned.

Several A-navigators were implemented in this "simple" technological invention!

First, the fundamental A-navigator 4 and the complex navigator 5.3.1 (S2) with which we are already familiar were both used.

Second, the fundamental A-navigator 1 was used: ***separation of conflicting properties in time***. The appropriate material is in a gaseous state while it burns but is stored and transported in a liquid state. These states overlap somewhat in the balloons in specific time intervals. This means that they share a common space from the moment when the particular balloon is used until the gas is burned. Note the analogy to the melting ice around the palms.

Third, the fundamental A-navigator 3 was used: ***separation of conflicting properties in structure***. A transition was made from the constant transport of the gas to a discrete and partial transport. The entire system continues to guarantee an uninterrupted supply of gas to the work zone. This means that parts of the system have one functional state while the entire system functions in the opposite way!

Example 12. How are chocolate bottles produced with a liquor filling? It is possible to make this kink of bottles in the following way: hollow bottle-shaped forms are poured from liquid chocolate that are then cooled and filled with liquor. Then the upper part is heated again until it can be pressed together into smoothly closed surface. Each bottle is constructed from two meltable parts that are reheated at their seam to press them together in a semi-liquid state. This procedure was quite complicated, expensive, and not very productive. This was caused by the complicated and expensive die for the chocolate. Low productivity was caused by the long process of filling and emptying the die, the long process of fitting the two parts of the bottle together, the long process of filling the bottle with liquor, and finally by the necessity of closing the opening of the bottle.

Here the A-navigator 4 and the physical-technical effect of a phase transition were used. But, the entire technique is not very effective. The administrative problem is: how can the whole process be improved?

An "ideal" technological process should exclude expensive dies to shape the poured chocolate, should exclude the fact that the bottles consist of two halves, and should also exclude the operation of closing the bottle's opening. But, this means that we are demanding something completely impossible! Perhaps this is only "impossible" in the framework of older technology? Why shouldn't we invent new technology, the kind we need for an "ideal" solution? What prevents us from doing this?? The fixed stereotypical image of the "unchangeable" order of operations in a familiar technological process is the problem here. We are hindered by the stereotypical image of the "unchangeable" state of the materials and the technical operations.

Well, then let's try to imagine an "ideal" technological process. Don't worry initially about how it can be put into praxis. Let's imagine the process as a ***functional ideal model***. Let's first pour the molten chocolate into an "invisible" die so that it takes the shape of a bottle as if there were yet another die inside the first one shaped like a bottle. Try to imagine this process several times! Think about how the chocolate takes on the shape of the inner die. Does it occur to you that the outer die is not really needed because the chocolate flows exactly along the lines of the inner die? Let's just forget the outer die. Not bad! But what do we do now with the inner die? How do we remove it from the cooled chocolate bottle?

We can observe again that the molten chocolate flows around something invisible or transparent like glass or ice. Incidentally, a technological process is not "ideal" until a result is achieved without the process that produces it. We can say this about a so-called "ideal" system, too: there is a function, but there is no system and the function neither uses energy nor takes up space.

Let's now use this functional "ideal" model for our problem. Let's assume that the inner die does not have to be removed. This could mean that it becomes a useful part of the final product. Do you already have an idea? If so, don't read any farther. Repeat the thought process in which the chocolate flows around some "inner" die. Think about how we could make a die from something "useful" that then would not have to be removed.

I'm sure that you have already found the solution: we can use frozen liquor as an "inner die". I have not included a figure because I'd like for you to have some fun with your own drawing of the process. Try it, it's useful and also interesting.

But, our goal is to uncover the theoretical, abstract side of this solution.

First, we have used the fundamental A-navigator 4 for the liquor filling as well as for the chocolate, although traditional technology only addressed the latter.

Second, we have used the complex A-navigator S2-4 twice in that part that is based on the physical-technical effect of the phase transition: freezing the liquor and subsequently melting it inside the finished bottle as well as melting the chocolate and cooling it on the frozen surface of the liquor die!

Third, the fundamental A-navigator 2 is at work here: ***separation of the conflicting properties in space***. Instead of searching for an impossible procedure to remove the inner metallic die from the finished chocolate bottle, the resources of the inner space were used themselves! All conflicts were eliminated by *using a hollow space* within the bottle that can be filled with a useful material!

And finally, we have used two more specialized A-navigators!

The frozen liquor shape is nothing other than a slightly smaller copy of the whole chocolate bottle (the final product). And this is a part of how the specialized A-navigator 10 *"Copy"* works:
a) a simplified and inexpensive copy is used instead of an inaccessible, expensive, inappropriate, or fragile object.

With this new technique, the liquor is no longer poured into the bottle, rather the bottle is poured around the frozen liquor! This is how the specialized A-navigator 11 *"Inversion"* can be put into praxis:
a) instead of completing an action that is given in the conditions of the task, an opposite action is taken (for example, heat an object instead of cooling it);
b) make a moveable part of an object or its environment fixed or a fixed part moveable;
c) turn an object "on its head" or turn it inside out.

We have still not considered all of the transformation models at hand even in these relatively simple problems. However, our goal is to recognize their real existence in objects that actually are around us. But you can already begin to analyze tasks that you find interesting with a better understanding of hidden relationships in systems.

Your analytical and theoretical capabilities will grow immeasurably if you closely study the navigators and A-algorithms that are presented in this textbook. But, you will note that certain assignments cannot be solved even with the help of the methods and knowledge available to you.

You could come to the conclusion that the entire system needs to be replaced or that the principles on which the system is based need to be changed so that additional scientific investigations can then be undertaken. But, even in such cases your solution will be based on the foundations of strategic thinking. It will not be a deviation from the goal or a failure.

7 Discipline of Creativity

7.1 Discipline and Inspiration

In 1996, I presented the software "*Invention Machine*" and its latest version "*TechOptimizer*" of the American firm Invention Machine Corp. at the world software&computer show CeBIT'96 in Hannover. Sometimes I left my booth in the hands of an assistant to visit other displays. I then offered our methods and software to other specialists form research and development departments. The software and methods were very well received. There was a display across from us from a large manufacturer of electric motors, from miniature motors for special devices up to motors measuring several meters for giant ocean-going ships. There was an advertising slogan on a magnetic board which constantly changed its shape and color on the glowing display:

THE QUALITY OF THINKING = THE QUALITY OF PRODUCTS

I noted this slogan so that I could use it in seminars. I soon ran into a colleague, a professor in the research and development of that firm. His first reaction to my suggestion was very laconic and reflected very clearly the attitude even of many heads of research and development departments. He said: "We're having no problems with inventing, but your *"Invention Machine" can help our sales?!*"

The end of our conversation can be found in the section *Strategies and Tactics of Inventing.*

And there were good reasons to reconsider this slogan more closely, although the desire to attain higher competitive abilities without innovation would have to be defined as *"a revolt on your knees"*, just like Genrikh Altshuller would have colorfully formulated it himself in similar situations.

In the years following that conversation there were 130 additional meetings with representatives from industry and research. As a result of these meetings, my image of *the quality of thinking* took on the following form (fig. 7.1):

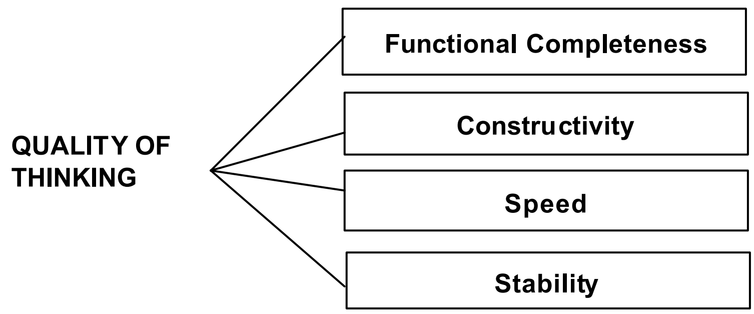

fig. 7.1. Components of the "quality of thinking"

Functional completeness means the ability and readiness to create ideas while considering the complex requirements put on the quality of a system (product). A solution that is oriented toward one aspect only is often useless due to a strong contradiction with other aspects of the quality of the system or with other systems, such as nature. *Constructivity* means to have the ability and readiness to complete a system with a purpose and goal in mind, without deviating from that goal, but also without proceeding with too much ambition or even destructively. Constructivity also means to have the ability and readiness to reach a breakthrough and become a leader in your own field. *Speed* means to have the ability and readiness to react without hesitation to challenges. It refers to the ability to free yourself and to become a challenger yourself. *Stability* in thinking means you have to successfully handle the influence of disruptive factors.

What reduces the quality of thinking? The answer to this question was formulated based on time and comprehensive experience (fig. 7.2).

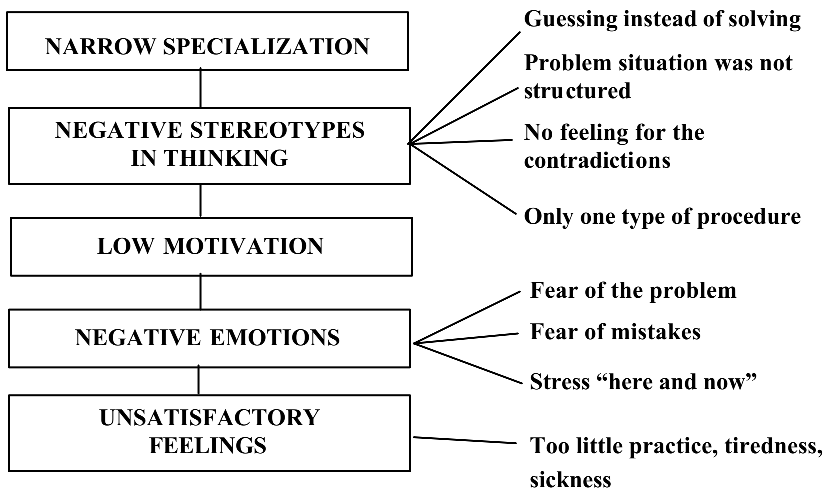

fig. 7.2. Negative factors that influence the quality of thinking

When people put the following positive factors (fig. 7.3) into practice, they compensate for all of the negative factors in fig. 7.2.

However, we cannot really expect that systems of higher education will be changed so that TRIZ/CROST could be taught everywhere. But, it is possible to learn TRIZ/CROST independently and to complete training sessions in this technique. Firms are offering this possibility more and more often.

What kinds of problems confront almost ***every specialist*** in his or her work continuously? In what way are concepts like "task" and "problem" different when they seem to have the same meaning? Answers to these questions could also shed some light onto the difference between solutions that require creativity and those that are routine or normal.

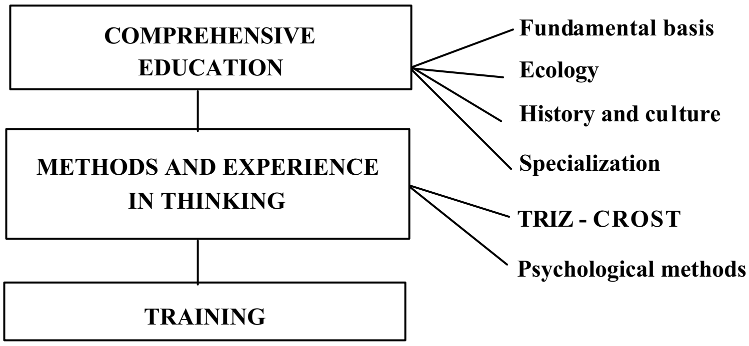

fig.7.3. Positive factors that influence the quality of thinking

Suggestions from most methodologists of creativity concentrate primarily on the stage where a solution is generated. This is the moment where previous work and strenuous thought about the problem is combined with inspiration all of which then leads to enlightenment, to an understanding of the problem, and to the development of a solution. There are many useful things for the development of such creative components like associative thinking, the concentration of the memory, and how to overcome negative stereotypes. We concentrate our efforts to develop effective techniques for solutions to problems that require creativity on exactly this point. But, as you will see, TRIZ/CROST includes all of the stages of problem solving.

In addition, the goal of TRIZ/CROST is to reduce the effort needed to prepare the problem for a solution and to create better essential conditions for the specialist. These specialists can then unfold their personal capabilities and enhance the probability that they can recognize the dependability and effectiveness of our methods. It is this reliability and effectiveness of the methods of TRIZ/CROST that causes the motivation that leads to true inspiration.

It is often the case that even tasks of the same type can be solved with different methods. Usually this is related to the *degree of difficulty* of the assignment. When a task gets complicated because of its size and context, then we can say that its high work effort makes it difficult. It is this effort that often turns an assignment into a problem.

Let's assume that you have to examine 10 factors each with 10 properties in order to find an optimal combination for the parameters of an object. Even if you only needed one second to analyze each combination, it would take more than 300 years to solve the entire task! This is the point where you need a mathematical model and a good computer. And, there are combination assignments that even the most modern computers can't solve.

But, a task becomes a problem only when there's not enough or only unreliable information available about the task or the methods for its solution (fig. 7.4). A problem arises especially when only limited resources are available for a solution.

This is most often caused by time limitations. There are situations where even simple assignments become problems due to a lack of time.

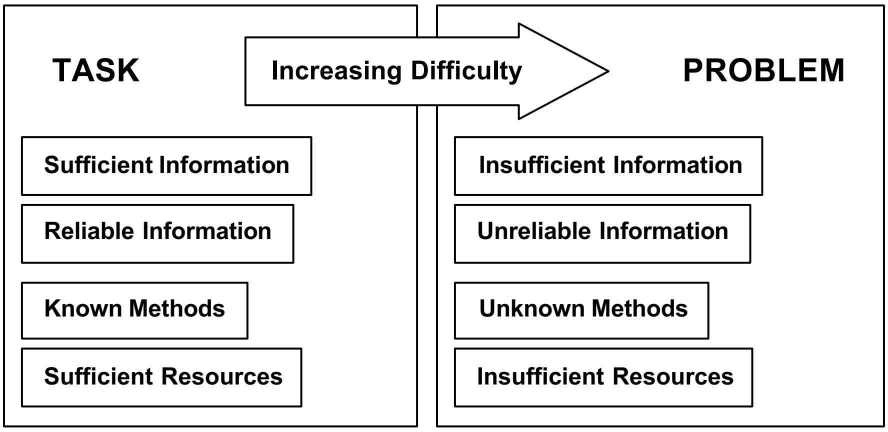

fig. 7.4. Tasks and Problems

Here are a few examples.

Ex. n^1. The multiplication of two single digits in your head such as 5 x 6 = 30 is an example of a simple task. This is especially the case because this is a standard tabular assignment where the solution is well known and is produced automatically.

Ex. n^2. To multiply 2 three digit numbers in your head such as 479 x 528 = ? let's say within 20 seconds is possible for only a very few people. This is a problem that is very difficult to solve without special training. But, there is the well known method to compute the answer with a pencil in one minute.

Ex. n^3. Two centuries ago, the solution to a quadratic formula $x^2 + ax + b = 0$ was still possible only graphically or with an approximation procedure. Today the solution can be found with the well known analytical formula $x_{1,2} = - {}^1/_2\, a \pm v(a^2 - 4ab)$. The problem was raised to the level of a computational problem.

Ex. n^4. The villain in the famous legend who wanted a beautiful young woman demanded that she pick the white stone out of a sack publicly in front of witnesses, but not the black one. He promised to forget her father's debts and free her, if she succeeded. He then secretly put two black stones in the sack. What would you suggest to the woman so that she could save herself? Assume that she knows about the villain's intentions.

Ex. n^5. Everyone knows that traffic jams occur on highways and streets because the capacity (an essential functional resource) of these roads is overwhelmed. There are regular traffic jams, especially at rush hour, even with the smallest problem such as a parked or unloading vehicle, the construction of a building on the street, or road construction. Do you have a suggestion for the modernization of extant highways and streets? Do you have a suggestion for new local and long-distance traffic systems? Are your ideas sustainable?

It is clear that a solution to the assignments in examples n^4 and n^5 requires an inventive approach and extraordinary creativity. Today entire scientific institutes and research foundations are working on the problems in example n^5 at the beginning of the 3rd millennium So far, no effective solutions have been found!

The psychologist and educator Edward de Bono explains the solution to the task in example n^4 in the following way. The girl reaches into the sack, takes out a stone, and throws it away without showing it to anyone. Then she asks the onlookers to look at the stone that's left. If it's black, then the stone she threw away has to be white and she and her father are free! The villain loses because to look for the stone that was thrown away or to refuse to take the remaining stone out of the sack would reveal his dishonest intentions.

The purpose of this example and its explanation is not only that you should not give up even in such a hopeless situation. It also means that you should examine every situation from different perspectives in order to consider the possibility of changes and to uncover resources that are often hidden, yet readily understanddable.

The actual problem is that we either don't try to find resources that are not visible at first glance or, and let's be honest, we're not able to find them.

G. Altshuller tried to analyze the degree of difficulty of the tasks described by patents. He came to the relationship of about "80:20" (fig. 7.5).

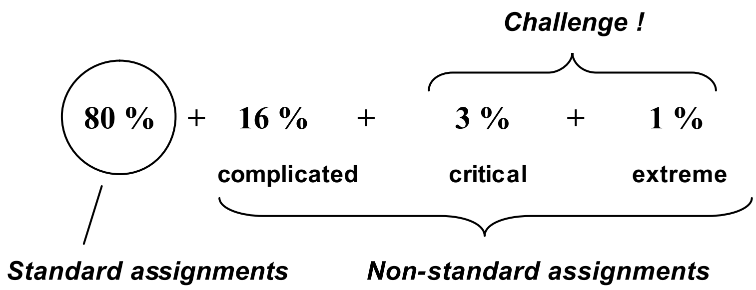

fig. 7.5. Distribution of assignments according to their degree of difficulty

Professional knowledge is the basis for solutions to all tasks. This is a ***necessary, but insufficient*** requirement.

To raise a problem to the level of a task (fig.7.4.), this problem has to fulfill at the very least the ***conditions of sufficiency.*** This means there has to be complete and reliable information about the situation, there must be sufficient resources available, and methods must be available that can be used to transform all obvious and hidden resources into a concept for a solution.

Let's consider one more time what traditional procedures such as the method of focal objects, brainstorming, synectics, and a morphological analysis recommend (fig. 4.2 – 4.5):

- look for coincidental associations;
- fantasize;
- project yourself into the role of the object;
- choose all possible combinations.

These methods are useful and can often result in solutions for certain standard problems. But, they often become less effective as soon as the degree of a problem's difficulty increases. Strictly speaking, these methods are not capable of stimulating inspiration. The results are often long and helpless searching, considerable material and intellectual effort, weak and useless ideas, and useless deviations from potentially useful goals.

> Highly effective methods are needed to help control thinking for solutions to construction-technical problems with extreme physical and technical contradictions. Concrete constructive navigators are needed for concrete problematic situations. TRIZ provides such instruments for navigation in thinking and navigation systems for standard and non-standard technical problems.

TRIZ is a system that disciplines thinking. Specialists who are well versed in TRIZ have a kind of psychological protective shield because they know that they have access to the best set of instruments for thinking in inventing that has yet been developed. This gives one hope and energy, stimulates inspiration like nothing else, and leads to daring solutions to problems.

7.2 Meta-Algorithm of Inventing

TRIZ is a *qualitative theory*. The models of this kind of theory provide recommendations, rules, instructions, suggestions, and examples. These models are all instruments for thinking, they are all navigators of thinking.

TRIZ is not the only qualitative theory. It is sufficient to refer to such "real" theories such as *qualitative physics, qualitative information theory, psychology or medicine, and also many fields of chemistry.* Qualitative models are also a basis for theories of painting and cinematography, for music and literary theory, and for all fields of knowledge and all areas of human activity such as sports, marketing, education, military strategies and tactics, etc.

TRIZ is a *constructive theory*. Other theories mentioned above are also constructive in this way.

Constructivism has two essential elements here.

The first element is the totally pragmatic interpretation of models and the purpose of each and every theory: an orientation towards applied problems, towards the achievement of practical results based on systematic and generalized experiences, based on the experimental verification of the attainability and effectiveness of the applied models of the theory. This is why psychologists often legitimize their models and theories with the following precept: *we don't know exactly how* *the brain functions, but we know in many cases exactly how to help a certain individual make the correct decisions.*

The second element is the condition, that the models of qualitative theories correspond closely to the *concepts of constructive mathematics*. Even though we have simplified these concepts here considerably, we adhere closely to them. You could say that constructive mathematics is concerned with *qualitative models* that are determined by the following constructive procedures: 1) the original *constructive objects* that are especially defined as examples and patterns are fixed; 2) *rules* are fixed (not necessarily as axioms) with which new objects can be constructed from ones that already exist; 3) *conditions* are fixed and then transmitted to the original and newly constructed objects that then determine the latter's competitiveness (attainability, advantages, and effectiveness).

The entire set of rules that determine the development of the objects to be constructed is known as an *algorithm.* Here we call generalized algorithms - on which algorithms are based that are specially oriented towards concrete applications and special classes of models or are more detailed and precise – *"meta-algorithms"*.

Let's examine a few examples that can help us understand these relationships better.

Ex. n[6]. You are organizing a party. Of course you think about how many guests you expect and what kind of cocktails you want to offer. You think about how many cocktails you want to mix in advance and which you want to make during the party according to the tastes of the guests. You think seriously about the cost of the party and about which ingredients need to be arranged for the cocktails. You check on the recipe for cocktails in a book, because you don't want to rely totally on memory. You choose the appropriate sections with the kind of cocktails, i.e., alcoholic and non-alcoholic, with and without ice. Then you choose the names of cocktails you know as well as some that you don't know, you read every recipe, and test or change the ingredients and their proportions according to your own taste. Finally, you check whether you have correctly "projected" all of the cocktails and whether you have enough of everything so that the cocktails are sufficient for the entire duration of the party.

We can think of this description as a "meta-algorithm" of the preparation of cocktails for a party. Keep in mind that this is not for a single concrete cocktail, but rather for any or several cocktails! We can describe the *recipe for the preparation of a* single cocktail as an *algorithm for the navigation of your thinking* as needed for the preparation of this cocktail.

In this "meta-algorithm", we can clearly differentiate different stages where the content is designed to solve different assignments. If we consider the organization of the party to be a problem, then you concerned yourself with an investigation of the problematic situation in the first stage. You determined the number of guests expected, thought about their tastes, made up kinds of cocktails, etc. In the second stage, you used a reference book to check whether you had correctly remembered how to make all of the cocktails or to become familiar with new cocktails. You worked with models - with the reproduction or new arrangement of recipes - in the third stage. And finally, you checked to see whether everything was ready for the party.

The entire "meta-algorithm" was divided into four stages that are completely understandable and that contain many more details for the description of practical actions. We could give these stages names, for example, as follows: *diagnostics* (problematic situation), *reduction* (refer to known models), *transformation* (find ideas based on controllable rules of transformation), and *verification* (check the potential attainability of goals).

To conclude this example, we should mention that this reference work contains *several dozen* recipe-"models". This is just like TRIZ: a certain group of models for the solution to a particular problem are combined from several dozen main models in TRIZ. This means that a goal-oriented combination of A-navigators makes a solution possible for ten or a hundred thousand different tasks.

Ex. n7. *Thousands of mathematical models and computational algorithms* were and continue to be used for solutions to assignments in production, planning, projection, control, and investigations. There is a general scheme of solutions for every class of tasks and for every task that belongs to this class. It is this general scheme that is a "meta-algorithm". For example, let's examine the simplified "meta-algorithm" for the solution to linear formula systems (fig. 7.6) in certain practical tasks. Models of linear algebra are of great practical importance for processing experimental data according to the method of the smallest quadrilaterals, for approximate computations when solving linear integral and differential equations with the method of infinite divergence (for example, for 3-D modeling with computers), etc.

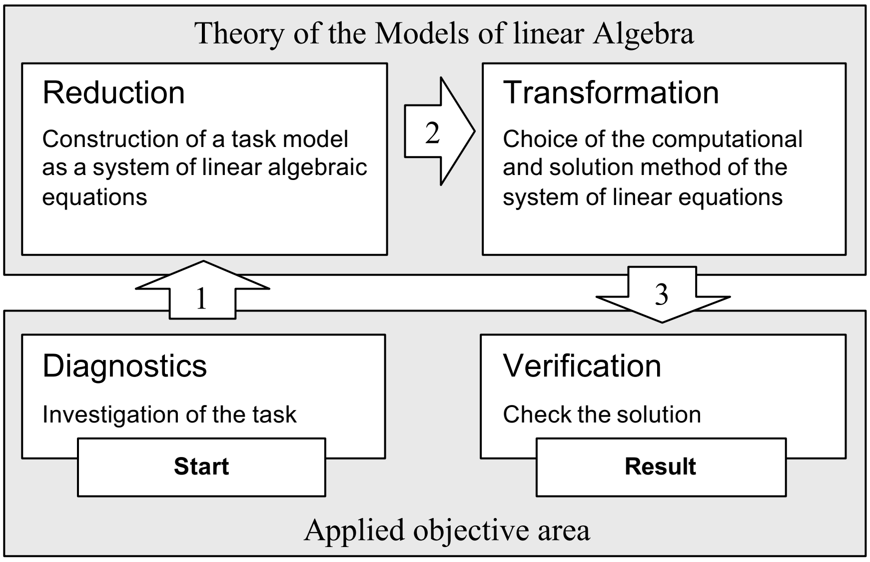

fig. 7.6. Meta-Algorithm for solutions to assignments based on the computation of systems of linear algebraic equations

The selection of a practical procedure for solutions to systems of linear algebraic equations depends on the structure of the initial data, on the context of the system (of the number of unknown variables), and even on the capacity of the computer. *Even with well constructed systems and sufficient data*, the selection of a method for a solution is in no way trivial. There is a large number of iteration methods, methods with accelerated movement, minimum disagreement, and others with different effectiveness. In addition, there is sometimes no "classically" correct solution for some data structures of an assignment *(incorrectly and poorly formulated tasks)*.

In this assignment, the "meta-algorithm" has the property of *invariance* because it is not dependent on the content of the concrete procedures of its stages. It is important here that the stages *diagnostics* and *verification* are part of the area where the assignment exists, i.e., they belong to the field of the practical application of linear equations. The stages *reduction* and *transformation* belong to the mathematical theory of linear algebra.

This is why transitions 1 and 3 require knowledge of both the models of the theory as well as of the applied fields of their use. The 2nd transition requires the capability to construct and solve models of the theory. College graduates oft don't learn all of the necessary practical abilities during their studies even for the solution to the relatively "simple" models described here. One must also be ready to accept the fact that the methods of TRIZ need to be perfected in training and praxis as much as possible.

***Ex. n*[8].** Let's look at the computational solution to **example n[7]**. Let's assume that in two sections of a firm a different number of two kinds of machines are working. In order to precisely determine the average capacity of these machines, it was decided to take measurements of the daily energy use in every section. In the *diagnostics* stage, the number of machines of every type and the figures on the use of electricity were determined. In the *reduction* stage, a system was created out of two linear equations with two unknown variables. In the *transformation* stage, the latter method was chosen from two extremely simple possibilities: elimination of variables and substitution and redirection. In the *verification* stage, it was possible to verify that the solution was correct by directly inserting the resulting values for the variables sought into the initial equation.

The following example (fig. 7.7) is an extremely simple and practical illustration of the abstract scheme in fig. 7.6. It is very important for the purpose of learning the capabilities needed for work with a "meta-algorithm", so that you can then proceed to the scheme "Meta-Algorithm of Inventing".

Now we have everything we need to examine classical TRIZ examples that reflect all of classical TRIZ in reduced form. We can now reproduce the main stages of the meta-algorithm that we just constructed for a solution of a system of linear equations and for the preparation of cocktails so that you can recognize the process of reinventing.

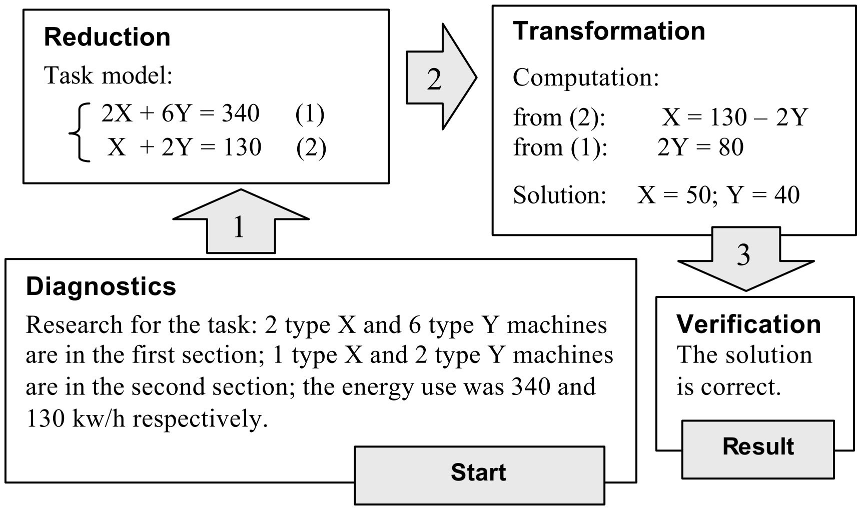

fig. 7.7. Illustration of the function of the Meta-Algorithm for the solution of a system of linear algebraic equations

Ex. 13. Shooting "flying plates". There is considerable waste from the remaining fragments of "plates" that have been hit at shooting ranges where enthusiasts train their shooting skills on flying clay plates (fig.7.8). We had to the following ideas in brainstorming sessions that I led: make the plates unbreakable; use a magnetic material so that the fragments can be quickly and easily collected with a machine, shape the plates from several parts that then don't fly so far apart when hit; attach the plates to a line so that they can be pulled to a collecting machine after when hit; cover the shooting range with a kind of carpet that can be easily cleaned; construct the plates out of clay or sand so that it's sufficient to smooth out the ground afterwards instead of collecting the fragments; etc.

fig. 7.8. At the shooting range

Here we see somewhat different effective and also successful ideas. Analyze them please and add your own ideas!

Can you formulate the main issue exactly: ***Where does the problem originate? Why is this problem so difficult to solve? And what exactly do we want to achieve?*** (It's also a good idea to note your own "models" in order to compare them afterwards with our suggestions.)

Let's try to find an answer to these questions as TRIZ teaches such a procedure. (Please remember that the following description is a teaching example and therefore has an extremely reduced form.)

Diagnostics. Let's clearly formulate the negative properties of the problem that need to be addressed: the fragments influence the ground (shooting range) negatively. We can formulate the structure of the problem as a contradiction. It requires a lot of effort to remove the fragments and the smaller pieces still clutter the ground of the shooting range. If we don't remove the fragments, we'll eventually have a huge pile of waste.

Reduction. We can try to imagine the structure of the problem in a reduced, yet clearly understandable form. The following contradictions are an example.

contradiction 1
The fragments are removed.
- **We clean the ground (shooting range).**
- **high effort**

contradiction 2
The fragments are not removed.
- **The ground (shooting range) is cluttered.**
- **no effort**

At least it is now clear that there is a concrete *model of the conflict* and that at least two *strategies* to search for a solution can be formulated. These are the following: If we tried to remove the negative properties in the first model, the goal would be to reduce the effort required. If we tried to remove the negative properties in the second model, the goal would be to prevent cluttering the ground.

The second strategy goes deeper. Its goal corresponds to the positive main result in which we are interested, i.e., not to clutter the ground at all. Therefore we'll choose the second strategy. (Please note that we would have to apply TRIZ-navigators from section 11 here, but for methodological reasons we're not including them here.)

We can now determine (we'll simply call it this) the *physical reason for the contradiction.*

contradiction 3
fragments
- *They shall be there because they come from the targets.*
- *They should not be here* so that the ground of the shooting range is not cluttered.

It seems that the problem cannot be solved when so formulated?! What do you think about another formulation of the "*physical contradiction*?"

contradiction 4
fragments
- *should not exist* - The "plate" must be whole before shooting.
- *should exist* - immediately after shooting
- *should not exist* - shortly after shooting

If we want to formulate a really fantastic "***ideal" result***, the fragments would remove ***themselves*** or, even better, they would simply disappear by themselves. Or the ground could clean them up. Or the fragments would have no effect on the ground. Or a magician named X transports all the fragments unobtrusively somewhere else. Where? Let your fantasies go!

Oh no, this has not gotten easier even with these fantasies? That could be. But doesn't it seem to you that at least something concrete has changed? Don't you now feel a tiny bit of hope?

The problem is now to transform this fantasy into a reality that really exists.

Transformation. Let's consider the first version again. Could the fragments simple disappear, fly away, meaning collect themselves and then go away? Could they dissolve in air like in a fairy tale?

The second version would be that the ground swallows the fragments and thus renders them harmless.

The third version leads us to the material of the targets. Which material is harmless?

(Are these fantasies not somehow reminiscent of synectics operations?)

And yet we can consider which of these versions sound the least fantastic. It's probably the third version, although the first one is certainly attractive, too.

So we now come to the material from which the targets are made. Every material consists of a certain number of particles that were combined into a whole. It is logical that every particle should be harmless to the ground if the material is so. What kind of material could this be? Sand? No, sand would also eventually pile up. What is left?

If we now combine all of these fantasies, we conclude that the particles of material are harmless to the ground, they sink into the ground without problem - and disappear by themselves. What kind of material is this? Water? Water can only fly as rain! Or? **Stop!** Water can also "fly" as snow or hail. And hail is ice. Of course, we can construct the "plates" out of ice.

Verification. Do you agree that we were forced by the intensification of the contradiction to develop fantasies that resembled reality? Thanks to that we recognized all of the elements of the contradiction completely and precisely. We recognized clearly what we wanted to achieve although we described everything with an illustrative language that is not exactly technical. We finally could not avoid an investigation of the material of the targets. Our selection of material was immediately limited to the only possible solution.

And precisely this is TRIZ, although in simplified form. Again we have modeled a bit to replace all of TRIZ with an example. Let's continue.

fig. 7.9

Ex. 14. Pilings. Sometimes concrete pilings with a length of several meters are hammered into the ground to help construct the foundations of bridges or buildings. This often destroys the upper part of the piling that hit by the hammer (fig. 7.9). This means that many pilings cannot be hammered far enough into the ground. Instead, they are sawed off and additional pilings are hammered into the ground, decreasing productivity and increasing costs.

Let's examine this problem a bit more closely.

Diagnostics. While achieving the **useful function** (hammering the pilings), the "**instrument**" or, to generalize, the "**inductor**" - the hammer - causes a negative effect, i.e., it creates an undesirable **negative function**, on the "product" or, to generalize, the "**receptor**" - the piling. The **primary positive function** is to quickly hammer an undamaged piling to the depth needed. Here are a few strategies that determine the direction of our search for a solution: 1) shape the entire piling harder so that it's less sensitive; 2) influence the ground in advance to make it easier to get the pilings to the depth needed; 3) develop a technique with which damaged pilings can also be hammered into the ground; 4) change the construction of the hammer so that it doesn't damage the pilings; 5) protect the upper part of the pilings from destruction.

An analysis of these strategies consists of several factors and goes beyond the limits of classical TRIZ. To simplify the description, let's assume that the first 3 strategies would lead to an extreme increase in the cost of the products and technology required. The last two strategies seem more appropriate because we can hope that **minimal changes** will be sufficient. We will therefore concentrate on them. In addition, we can formulate both of these strategies with a more general description: **ensure that the upper part of the pilings will not be destroyed by the hammering action.**

Reduction. We already seem to know how the "ideal result" can be formulated. Several strategies were developed for this purpose in TRIZ that determine the **strategy for solutions to tasks** to a great degree and thus influence the speed and quality of the search. We will examine this question later. Now we'll proceed just as simply as we did in the previous examples. The main issue here is that the pilings and the hammer don't get more expensive, meaning that only those materials (**resources**) are used that "cost nothing".

We also recognize that the part of the piling (receptor) that is subjected to the most negative influence of the hammer (inductor) is the "top of the piling", i.e., its upper end and especially the surface on top that is hit by the hammer. This is how we define the "**operative zone**" where the **conflict is concentrated,** meaning where the positive and negative function exist simultaneously. This occurs initially in the unity of receptor, inductor, and their elements where the critical surfaces meet each other when hit.

Let's consider the main forces and parameters that function in the operative zone so that we can determine them. For example, the greater the **weight** and **force** of the hammer's strike, the **quicker** the piling can be driven into the ground. But, this is what makes the internal **negative factors** greater that then lead to **damages** and to decreased **reliability**. If the pilings are driven **more slowly** into the ground, the **weight** and **power** of the strike is reduced. This can also reduce the **stability** and **reliability** of the pilings. We can already construct a few models of contradictions bases on these kinds of "physical considerations". Try to do this yourself and develop as many variations as you can. Here we'll mention only two "symmetrical" variations that refer to the useful primary function:

variation 1
increase the power of the hammer's strike
- The **speed** of the hammering increases.
- The occurrence of **negative factors** increases.

variation 2
increase the speed of the hammering
- **The power** of the strike must be increased.
- The occurrence of **negative factors** increases

Stage 3. Transformation. If we use the A-Matrix for the *first variation*, we come to the following cluster of procedures that is recommended first:

What gets better? - line 22: speed.

What gets worse? - column 14: damaging factors of the object itself.

The following procedures are recommended (here in shortened form):

05. "separation" - remove the disruptive part from the object or at least the properties needed;

18. "mediator" - use an object that passes the action on or transmits it, temporarily connect the object to another one that is easy to remove;

01. "change in the aggregate state" - fully use the transitions in the state of a material or changes in flexibility, concentration, etc.;

33. "quick jump" - increase the speed of the process.

If we use the A-Matrix for the ***second variation,*** we get a somewhat different cluster of procedures:

What gets better? - line 30: force.

What gets worse? - column 14: negative factors of the object itself.

The following procedures are recommended (here in shortened form):

11. "inverse action" - an opposite function is complete instead of the function given in the conditions of the assignment or a moveable part of an object is fixed and a fixed part is made moveable.

12. "local property" - different parts have to fulfill different functions or every part of an object should have conditions that fit best with its function;

26. "phase transitions" - use phenomena fully that occur in phase transitions, for example, thermal absorption or radiation;

18. "mediator" - use an object that passes the action on or transmits it, temporarily connect the object to another one that is easy to remove.

It is easy to recognize that procedures 05. "separation" and 18. "mediator" from the first group of procedures together with procedures 11. "inverse action", 12. "local property", and 18. "mediator" (again!) from the second group clearly indicate that an additional object in the form of a *mediator* needs to be introduced into the operative zone between the hammer and the pilings.

To save time, we will not analyze other possibilities here.

Sometimes a wooden block is attached to the upper end of a small number of pilings (fig.7.10.). The hammer strikes the block until it is destroyed.

Verification. The wooden blocks quickly fall apart and the uneven pressure caused by the material from which they are made (wood) damages the pilings before they are destroyed. The problem is by no means solved! Perhaps we should examine its essential principles again? We could also examine a new technical system that includes the mediator, too. This is how we arrive at a repetition of the cycle of Meta-ARIZ! We can now understand the mediator as a part of the piling, for example, as its "head". It is correct to understand it as a part of an instrument! But, the piling itself should not be changed, meaning that the mediator needs to be a supplementary detail of the hammer. We will later see that most of the time the inductor is changed and that this is one of the essential rules of TRIZ.

fig. 7.10

You have probably noticed during our analysis of the process of the search for a solution that it is often difficult to interpret the A-procedures, even though they are described using specially prepared constructions. You are right: you also need experience, a good understanding of physical phenomena *(technical effects),* and comprehensive professional knowledge. Sometimes a good mood (sometimes a bad one) is just as important. And ... no, that's enough for now, especially because we want to continue. But you will learn more about this "and" with time and with more experience while applying TRIZ.

Diagnostics +. Let's remember that the mediator has also become an inductor similar to the hammer in its influence on the pilings. If we don't want to repeat our previous steps from the first cycle, we should now change our strategies for a further search and direct it towards a more comprehensive analysis of the physics of the process at hand.

It is clear that the effect on the pilings will hardly change if the mediator is made of same material as the hammer. If the material of the mediator is similar to the piling (cement), then it will also be destroyed, perhaps even more quickly because of its lower mass. In addition, the speed at which the mediator is destroyed depends on how it was installed at the head of the piling. The slightest misalignment accelerates the destruction of the mediator. When the strike of the hammer and the interaction of forces on the stressed surface of the mediator with the surface of the head of the piling is not even, it occurs at certain points and along lines where the energy is then concentrated. This leads to a wealth of cracks and breaks. How can the mediator be mounted without too much play on the head of the piling? This is a complicated assignment.

Reduction +. It does not seem useful to construct variations of contradictions like in stage 2 because similar models would probably lead to a simple repetition of the previous cycle and to the same result. This is useless.

Let's formulate versions of an ideal final result:

1. The mediator distributes the energy of the strike evenly onto the entire surface of the piling (improved work method);
2. The mediator is destroyed and reproduces itself after every strike. This is really an ideal!
3. The mediator .... (Please continue by yourself.)

Now the contradiction gets extreme:

variation 3 mediator — *is necessary* to transfer the energy of the strike onto the surface of the head of the piling
— *should not be present* so that it does not fall apart

We can formulate the ideal result strictly according to TRIZ recommendations like this: the operative zone reproduces the mediator itself!

Transformation +. Let's think a little bit further. We can imagine that the mediator consists of a large number of small particles (which is true, anyway), particles that are similar to tiny figures. But these tiny figures have the capability to do everything that we need here. They can accomplish every ideal result and cost nothing, too. Their number can be easily increased or decreased. They can model every possible magnetic field, collectively take on every possible form, they can be a solid or a liquid, they can have mass or not, be visible or not, give off sound, etc. with no limits. And they still are just figures that were created by our fantasy. This is why it's possible to rough them up or subject them to difficult tests such as to strike them with a hammer.

These tiny figures could fill all the spaces on the surface of the head of a piling as well as on the work surface of the hammer and would therefore distribute the energy of the strike over a greater surface. After they've been struck once, they spread out into a single layer that smoothly covers the entire head of the piling. They also wait patently for the next strike. Can you imagine which real material has these properties?

Of course, *the mediator must be made from sand*!

Not more than one or two buckets-full of sand can be filled into a container that is then placed over the head of the piling (fig. 7.11).

The container is long enough to direct and contain the movements of the hammer. Sand costs essentially nothing and can usually be found in the ground where trenches are dug for building foundations. Finally, we don't need much of it, so it wouldn't cost much even if we had it transported to the construction site.

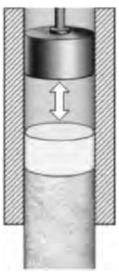

fig. 7.11

Verification +. The solution is effective because it's reliable and causes almost no additional expenses.

The principle of the solution - ***segmentation of the object*** into particles with certain properties leads to a tremendous methodological "super-effect": it can be further developed and transferred to other objects with similar or quite different contradictions!

The solution can also be further developed in the case at hand. For example, we can extend the operative zone to the entire length of the piling. We can thus formulate such an ideal result that the piling cannot be destroyed because it's not present! It could grow out the ground, like a tree that doesn't have to be driven deep.

Don't you want to become a multimillionaire with the invention of new pilings? If you believe I'm polemically exaggerating this question, believe me, that's far from the truth!

We can now put the main concepts together to build a generalized version of a "Meta-Algorithm of Inventing" (fig. 7.12).

This scheme also includes operations at a strategic level that were incorporated into the diagnostic stage and operations at a tactical level that were incorporated into the reduction stage. This reflects the combination of operations at various levels in the unified process of the development of a solution that often occurs in praxis.

To conclude we would like to note that the diagnostic and reduction stages are in essence procedures for the *analysis of the problem* while the transformations and verification stages are designed for the *synthesis of a solution*.

The Meta-Algorithm of Inventing is the primary navigation system for solutions to any problem in inventing. All of the procedures of the scheme (fig. 7.12) should be slowly learned and automatically applied in the correct order to solve new problems. Finally, all of the procedures are supported by data banks shown clearly in the form of drawings whose basis is the A-navigators. We will now address these navigators.

Meta-ARIZ is very similar to Dewey's "4-stage scheme of creativity". The actions of the *diagnostic* stage can be interpreted as a "collision with the attempt to recognize elements and connections that lead to a contradiction". One of the main goals of the actions of the *reduction* stage is the "limitation of the search zone (localization of the problem)". The actions of the *transformation* stage correspond to what Dewey describes as the "development of a possible solution: the movement of thoughts away from what's given to what's missing, the construction of an idea, a hypothesis". Finally, the *verification* stage includes "a rational processing of an ideas and the logical development of a primary thesis". Of course, the constructivism of Meta-ARIZ differs radically from the "schemes of creativity" already mentioned, including Dewey's scheme, too. But, intellectual and spiritual "Genesis" was doubtless also considered in his scheme what makes the relationship between these differing periods of time so interesting.

Meta-ARIZ was constructed as a generalization and simplification (removal of what's superfluous) of the contents of all "generations" of Altshuller's ARIZ. Still, it's clear that Meta-ARIZ is structurally very similar to the earliest and "clearest" ARIZ from 1956 and 1961 (see fig. 4.5). You could say that Meta-ARIZ embodies the first ARIZ as a new version that uses the newest levels of technical knowledge because of the half century lies between them. Certainly the construction of the stages of Meta-ARIZ differs considerably from the shaping of the "schemes of creativity" already mentioned even as it is based on the instruments of TRIZ. The origin of ARIZ and the legacy of TRIZ constructivism make Meta-ARIZ a very comfortable structure both to study the methods of TRIZ and for solutions to practical assignments.

The Meta-Algorithm of Inventing is the basis for a navigation system for solutions to any and all problems in inventing. It is necessary to learn all of the procedures of the scheme "Meta-Algorithm" (fig. 7.12) for solutions to new problems and to apply them automatically in the order shown.

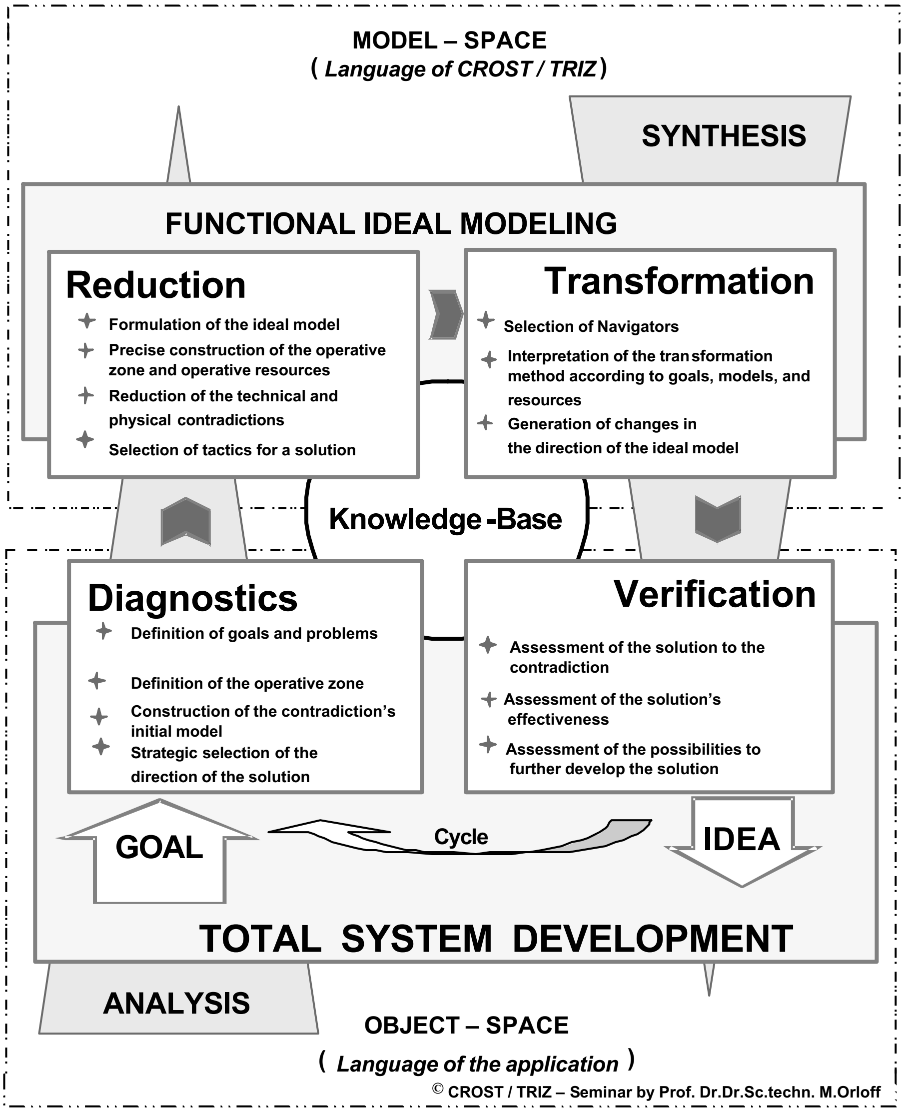

fig. 7.12. Generalized scheme of a Meta-Algorithm of Inventing

8 Operative Zone

8.1 Epicenter of the Problem

It is useful to work through the 14 previous examples of reinventing again before beginning this section. We can assume that you remember the content of those examples well. We then come to the operative zone, one of the central concepts of classical TRIZ.

The operative zone (OZ) is the entire set of components of a system and its environment that are directly related to a contradiction..

We can say that the operative zone is the *epicenter of the problem.* As with every contradiction, the influence of the problem can possibly be felt in the entire system and its environment as well as in concrete elements. It is also the case that the means to solve the problem will eventually be found in the system itself or its environment. These relationships can be clearly shown in an illustration (fig. 8.1).

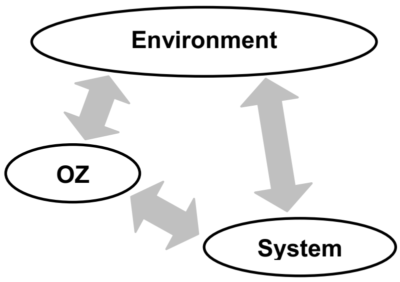

fig. 8.1. Structure of the relationship of the OZ with system and its environment

The environment of the system puts demands on it that determine the direction of its further development. These demands can conflict with the possibilities of the system or cause a conflict between parts and elements of the system. The properties that conflict with each other are connected to concrete elements of the system or even to the entire system itself. Sometimes the parts that participate in the conflict are elements of the system and its environment.

Actors are the primary elements of the OZ that interact in OZ and give rise to contradiction.

Inductor is an actor that influences another actor (receptor) with a transfer of energy, information, or material that then initiates a change or action in the receptor.

Receptor is an actor that receives the influence of the inductor and then changes itself or starts an action due to this influence.

An inductor or receptor can be present in the OZ in a form that is not obvious. There can also be two inductors or receptors. Structures occur where the inductor and receptor can exchange roles depending on the goals of the analysis or of the synthesis of a solution. The OZ should be described in such a way that a structure arises with a minimum number of elements, i.e., a model out of one inductor and one receptor. A classic example is the interaction of an instrument and a product (detail). In classical TRIZ, the primary elements of the OZ were programmatically described as instrument and product although their functional roles often didn't correspond to these terms. The terms inductor and receptor introduced here are more general and neutral in reference to the contents of the physical actions of the elements in the OZ.

We can now examine the elements of the OZ in the examples already described.

From Ex. 1. To develop the feather into an element that regulates the flow of ink out of the writing instrument, the pen would function as an inductor in its relationship to the OZ that influences the stream of ink (receptor) that flows through the groove. The atmosphere (system environment) could also be part of the OZ if we consider the influence of atmospheric pressure on the flow of ink along the groove in the feather. We could think about the speed with which the ink moves from the body of the writing instrument into the groove of the pen. The rest of the writing instrument (system) would then belong to the OZ.

Desired result is that the ink runs out of the tip of the pen. The speed of the flow is regulated by pressure on the pen.

Contradiction is that the ink should "flow freely" and easily through the groove of the pen, but it should also not "flow freely" so that it doesn't run out of the writing instrument when not desired.

Leading resources for a solution to the problem are the shape of the groove and the properties of the pen that work like a valve to regulate the function of the groove, atmospheric pressure, temperature, and humidity, hygroscopic properties of the paper or another material on which we can write, and the power of the pressure on the writing instrument.

Leading transformations are the *dynamization* of the groove of the pen with its adjustable size, materials in *several aggregate states* with the different properties of the pen, the construction of an *energy flow* form the writing instrument over its body and the pen to the paper so that the force of the pressure can open the groove in the pen. This flow of energy continues to form *fixed contours* that includes the table, the floor, the chair, and the body and hand of the person writing.

Teaching digression 1: For a more precise analysis, it could be necessary to reduce the OZ and change the groove into the pen itself. This would make sense if we want to investigate the profile and parameters of the groove, for example. Parts of the pen such as the position of installation on the body of the writing instrument, the general shape of the pen, and other components would then no longer play any special role. But, we could include the properties of the paper and therefore the paper itself as a component in the OZ for the purposes of this assignment. It would then be a second receptor on which the pen leaves an ink track. Here the entire pen is a system for the groove and all other objects then belong to the environment of the pen.

Teaching digression 2: We can consider just the task of the interaction between ink and paper. Then we can imagine that the OZ consists solely of the ink as an inductor and of the paper as a receptor along with a description of their properties and conflicting interactions.

From ex. 4. For the development of an aircraft with vertical take-off and landing, we can include the aircraft itself (system - receptor), the aircraft's engine (first inductor - part of the system), and the air (second inductor – environment). The engine has to work harder at take-off to move the aircraft vertically. The aircraft takes off and lands like a rocket that cannot support itself using the surfaces of its wings. This is why there were problems with the orientation of the fuselage in the air that led to accidents at take-off and especially during landing. The pilot could hardly see the landing pad and it was even more difficult to control the function of the engine. Pilots flew down when landing but had to look up because they were essentially lying on their backs (see fig.6.2).

Demanded result: the new function vertical take-off and landing.

Contradiction: the *orientation* of fuselage is difficult to control when *coordinated with the direction* of take-off and landing.

Leading resource for a solution to the problem are contained in the system as a change in construction.

Leading transformation is *dynamization* to make the motors or wings moveable.

From ex. 10. In accordance with the initial assignment, it is sufficient to include the water as a first inductor and part of the pouring system, the ground at the foot of the palm as a receptor and also part of the pouring system, and the air as the environment and second inductor in the OZ. Please note that the air, temperature, and other properties have direct influence on the condition of the ground at the foot of the palm, but not the sun. We also don't need to consider the palm to be a property of the system and a participant in the OZ, because it's not directly involved with the contradiction. The consequences of badly organized pouring influence the palm. The tree will be protected by a new solution, but it is *no active actor* in this situation. Look at this example closely.

Ideal result: would be that the OZ *itself ensures* a long pouring action for the palm.

Contradiction: water *should be available* at the foot of the palm to keep the tree moist but *it should also not be present* because it evaporates quickly under normal circumstances.

Leading resource for a solution to the problem is water in two aggregate states with different temperatures at the beginning and end in the system and in the OZ.

Leading transformation is a *transformation at the micro-level* of the material and the use of a *physical technical effect: a transformation of water from a solid to a liquid state.*

From ex. 12. The general assignment dictates that it is sufficient to include the liquor and bottle in the OZ and to observe their interaction when they reach the *ideal final result*! This does not happen very often when it is possible to change the product itself. Here we actually change the process of the product's manufacture by changing its components, but not the product itself. Originally, the solid chocolate bottle functioned as an inductor to influence the liquid liquor as a receptor by accepting it into its internal space through its throat. The new idea turns this around. The frozen liquor bottle as an inductor functions as a shape on which the liquid chocolate is poured as a receptor.

Ideal result is that the OZ *itself ensures* the construction of the bottle along with its contents!

Contradiction is that the liquor *should be present* in the chocolate bottle and it *should also not be present* because the entire process is too complicated.

<u>*Leading resources*</u> for the solution to the problem in the OZ are that the liquor and chocolate are in two aggregate states with different start and final temperatures. Inside the system changes are made in the arrangement of the operations and the frozen liquor replaces previous elements for the "copied" form shaped like a bottle; outside the system additional energy and forms are used to freeze the liquor and create a throat in the bottle.

<u>*Leading transformations*</u> are a *transformation to the micro-level* of the material, the use of a *physical technical effect* with the full use of the two aggregate states of the material, and the *copy principle* (see the process of reinventing in example 12).

From ex. 14. Correct TRIZ diagnostics of the original assignment require that we only include the head of the piling as a receptor in the OZ, or even more precisely, only the upper surface of the piling's head, and the hammer as an inductor. It was difficult to describe this part of the piling as a product in the traditional TRIZ description because this term referred only to the entire product. But we really don‘t need to consider the entire piling. To understand the physics of this process we only need to run our diagnostics in the area of the piling's head. The OZ is there. The receptor is quickly destroyed by the influence of the inductors due to the uneven distribution of the energy of the strike on the upper surface of the piling's head. Of course, this is primarily due to the sensitivity of the material of the piling, but the conditions of the task dictate that the piling's material (product) cannot be changed.

The following aspects participated in the first phase.

<u>*Ideas result*</u> is to completely maintain the head of the piling and use resources outside of the system.

<u>*Contradiction*</u> is that the action of the hammer is needed to drive the piling into the ground, but this action destroys the piling from above.

<u>*Leading resource*</u> for the system and the OZ is to change the instrument.

<u>*Leading transformations*</u> are *the principle of the mediator (navigator 18)* to install an insert between the hammer and the piling's head; and navigator *13 "inexpensive object with a short-life as a replacement for an expensive one with a long-life"* where the mediator, the insert is made of wood. (This is a shortened version of example 14 without more detailed explanation.)

With time it became clear that this solution was also not sufficiently effective because it costs too much. The following aspects were part of the second phase of the solution.

<u>*Expanded ideal result*</u> is that the mediator should have a long life and cost nothing more!

<u>*Contradiction*</u> is that *there should be no mediator* because it is destroyed although *there should be a piling* to fulfill the demands of the useful main function of the technological process.

<u>*Leading resource*</u> in the OZ is a change in the material of the instrument - here the mediator also became an instrument that has direct influence on the product – the piling, in the system is a change in the instrument, and outside of the system is the use of an inexpensive material (sand) at the construction site.

Leading transformation is the *intensified application of* navigator *13 "inexpensive object with a short-life as a replacement for an expensive one with a long-life",* the search for an even less expensive material for the mediator (insert), the modeling of the process using *modeling with small figures,* and the actual transition to navigator 3 *"segmentation", point c) raise the degree of segmentation (reduction).* The result is to use a layer of sand as a mediator.

The analysis of five solutions we have made here allows us to make a strong generalization. The process that finds solutions in classical TRIZ aims at a transformation of the OZ and is based on the following key concepts (fig. 8.2):

- *the functional ideal model (FIM)* is an image of how a system should function that resembles the ideal solution to a problem;
- *contradiction* is the model of a system conflict that reflects the incompatible demands on a system;
- *transformation* is a model of changes in a system that are *necessary* for the removal of the contradiction and the achievement of the FIM;
- *resources* are a model with different aspects for system properties that characterizes, among other things, the purpose of a system, its functions, the condition of its elements and the structure of the relationships between these elements, information and energy streams, materials, shape and location, the temporal parameters of the functions, effectiveness, and the special quality aspects of the functions.

These aspects have accumulated knowledge that is fundamental in classical TRIZ. They represent the most essential core of creativity: the entire instrumental and cognitive system that the author calls the A-Studio. This corresponds to the terms already introduced, for example, A-navigators and my systematization that will be explained in section 20.3 *CROST: Five Cores of Creativity*.

And precisely these aspects of the classical A-Studio will continue to be the center of our attention.

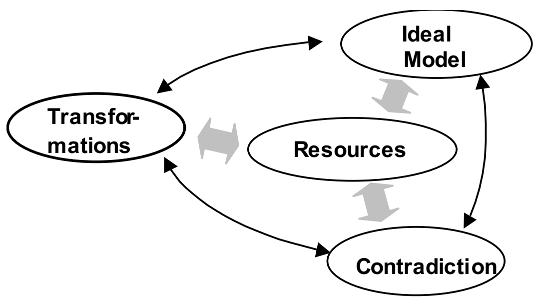

fig. 8.2. Structure of the interaction of the key concepts of TRIZ

8.2 Resources

"Resources" are in the middle of fig. 8.2. In traditional TRIZ, the concept resources essentially belonged only to a technical system and the corresponding environment. It was assumed that a problem occurs only when a resource is not available that is needed to achieve the properties desired. Generally this is true.

But, today we have to consider the process of the development of an invention in a broader and more objective way. We're moving away from the primarily technically oriented viewpoint of TRIZ to a viewpoint directed towards a people oriented, nature-scientific integration. CROST (see the section *Development of TRIZ*) is oriented in just this way. In the beginning of the development of classical TRIZ, the praxis of the theory was based on the precept that TRIZ models and ARIZ along with the integration of the laws of system development could be used to create an invention like we would solve a mathematical problem. But, with time it became clearer that people are still at the center of a "model" of the development of inventions. These people are there with their individually organized thinking, their motivation, their emotions, their character properties, and their personalities. This is why the ideas of classical TRIZ should be represented in its modern version is such a fashion that they also consider the possibility, and the necessity of including general theories of which TRIZ can then become an essential component.

The scheme in fig. 8.3 differs from the one in fig. 8.1 primarily in the fact that here "source" of the problem, i.e., people, play a central role. We can definitely say that success in solving problems depends on two types of resources: from those of the system and its environment and those of the source of the problem. It is clear that it is difficult and useless to separate one from the other. Together these resources serve the same purpose: to increase effectiveness and to shorten the time needed for people to solve a problem.

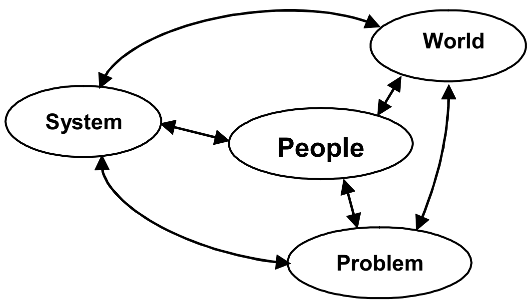

fig. 8.3. System relationships of people as "problem solver"

TRIZ offers constructive models for solutions to problems that originate in a technical system. In addition, TRIZ developed active support procedures for sources of problems with positive and negative thought stereotypes. But, there are still no real theories for solutions to problems with constructive models "from the perspective of the problem source". The position taken in this textbook is motivated by the attempt to not limit itself to a one-sided conception. Instead, I hope that in the future the essentials of TRIZ will be learned together with the basics of mathematics, spelling, and computer skills and will be seen as just as useful.

Bur first, we need to investigate the resource models of TRIZ. Above all else, TRIZ suggests that while solving problems you remember that in every system all the parts are directly or indirectly connected to each other. In addition, every system, subsystem, and even every element can be represented as an abstract machine (fig. 8.4). Every technical system has a general structure to which an energy source (ES), a transmission (TR), a working organ (WO), a control system (CS), and a configurator (CF) belong shaped as a construction that connects all the parts with each other.

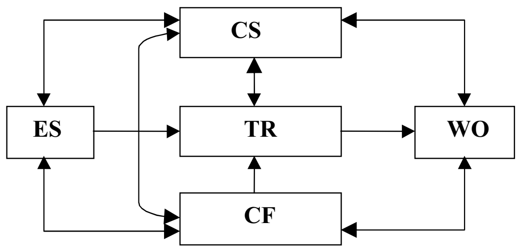

fig. 8.4. Abstract machine

TRIZ postulates the following properties for developmental systems:

1) a technical system is minimally complete if all the components of an abstract machine are present in its concrete form;
2) a technical system is minimally functioning, if all the components of an abstract machine partially or together are minimally functioning;
3) the development of every technical system begins with the minimal functioning core;
4) problems in the development of a technical system are related to the uneven development of its components and can be removed *in time and locally* by perfectioning components and their relationships with each other, or by *permanently and totally* replacing the system with another one with the same functions.

TRIZ postulates the following principles for the development of minimal functioning core:

1) all of the components should be combined with each other into a unified body that has system properties that the individual parts do not possess;
2) all of the streams of energy, material, and information from the related components of the system must be uninterrupted and build a complete shape either inside the system or outside using the environment.

This is how the first automobile was constructed. A gasoline engine (energy source) was installed in a wagon (configurator) with a device to transmit the torque (transmission) to the wheels (drive - working organs) and a device to turn the wheels (directional control for the direction of movement).

A pencil is definitely a technical system because an external energy source (a hand) and a control system (a person) are necessary for its use. But, it has a working organ in the cartridge that is integrated into its body that simultaneously represents the configurator for the pencil and the transmission for the movement of energy from the working organ of the person writing.

Many mistakes in the development of inventions come from the fact that inventors disregard the postulates described above or it is simply not possible to put them into praxis. For example, the first aircraft could not climb into the air because the capacity of their energy source was too weak to provide sufficient lift to overcome the drag of their wings. There was no unified construct of energy between aircraft and air that could compensate for the aircraft's weight. Then aircraft underwent a complicated process of development in aircraft control systems. This included the development of rudders, stabilizers, and elevators as well as the choice of the number of wings and their shape. This process can be cyclically repeated (see section 15 *Classical TRIZ-Models for Innovative Development*). There were continuously difficulties with the perfection of all the components, for example, with the thickness of the leading surface of the wings and the rounding of the wings on the upper side to ensure that the air flowed at different speeds over and under the wings, etc.

The basis for the development of a system is the search for resources and their application that are both necessary and sufficient for solutions to concrete problems. *The combination of extant and new (or transformed) resources that create a new and positive technical effect is an invention.* And turned around, the lack - often only an apparent lack! - of necessary and sufficient resources to achieve the necessary properties for a system causes the problem at hand.

Let's examine a few examples.

Ex. 15. Navigation systems for automobiles. The useful primary function of this system is the preparation of the information needed to optimally plan travel within one's own city or in other places. The integration of a large number of other systems into a unified navigation system made the preparation of this information possible. The function that assesses traffic and road conditions was transferred to a regional observation and control system. The function that determines the coordination of traffic resources in certain locations is provided by a global system of navigation satellites that are orbiting the planet. Data is transmitted by radio communication systems. A board computer displays a representation of the situation and the driver takes care of the assessment of this situation and the selection of the appropriate stretch. What is the most important aspect from the perspective of an invention? We could say that this is about information. This is true, but here information is only the "main product" to be processed. But, who processes this product? The answer is an essentially new organization of the unity of all interacting systems that then develop a new functional property that none of the components of the systems have individually. Or we can say that the functional property came from the *integration of resources from different systems* with the invention of a procedure and a scheme for their interaction. This means for each component that its resource is applied, i.e., what every component adds to the unified system.

Ex. 16. Invention ... of interest. Innumerable packages increasingly display lottery numbers, jokes, funny drawings, comics series, calendars, short stories, biographies of famous persons, games, and recipes for special dishes using the product at hand. Of course, there are also instructions and examples for the use of the product. Which resource is used here? We could say that technically speaking this is the resource of the free space on the package or of color, etc. But the decisive component is the creativity and here it is an *information resource*!

Ex. 17. On the way to the DVD. The first magnetic devices to permanently save data in computers were developed after they had undergone a somewhat long developmental process as mechanisms to record sound. This means that the magnetic recording process was changed so that it was appropriate for saving dual information. However, a revolutionary turn around of this process occurred when devices to save information on laser (optical) and Compact Discs (CD) reached such high recording density that it became possible to save 600-700 MB of information or 40-60 minutes of uninterrupted music of the highest sound quality. Finally, the DVD (Digital Video Disc) with an information density of up to 20 gigabytes was developed towards the end of the 20th century with the possibility to replay video films that last several hours. This means that recording and reading dual information was the continuously developing resource for CDs that lead to revolutionary changes in the further development of computer, audio, and video technology. These are examples of the development of different inventions with the use of different physical phenomena that are all still based on one and the same *functional resource.* Here we can also note the important role of the *information resource* with new systems for data compression. Today MPEG-2 (Motion Pictures Experts Group) plays a decisive role for the transfer of video representations and a series of audio formats such as Dolby Digital Format, Digital Cinema Sound, etc.

Ex. 18. Systems with several processors. More than just a few patents have been awarded for special computer systems. Such systems, usually with several processors, have a theoretically maximum productivity for a certain class of tasks or even for just one kind of assignment. There are also many patents for concrete structures for universal systems with several processors. The high productivity of such systems stems from the fact that a dynamic distribution of available processors occurs to process the various assignments or even just the individual task at hand depending on just these assignments. This means that the structure of the data flow changes constantly while the continuous physical interaction of the processors remains constant. The process of inventing is dominated in this case by a *structural resource*. We should also note the important meaning of the *temporal resource* because the processors address their tasks in a schedule of time allotments (synchronically or asychronically, dynamically).

Ex. 19. What is common to the cinema, an electric light, and a display? It took quite a while from the discovery of the possibility to fix picture representations on photographic plates to cinematography. This was possible only after it was determined that our lazy eyes need a recording and replay of images with a frequency of at least 16 picture sequences per second (16 Hertz) to perceive the images as uninterrupted movement. This is how cinema developed. Incidentally, electric lights go on and off at a frequency of ca. 50 Hz so that we don't even notice. This is due to the fact that the element cannot cool quickly enough with alternating current. The frequency of the alternation of representation on computer screens is today already 100 Hz which leads to high picture quality and low stress for the user. This is obviously the full use of a *temporal resource*.

Ex. 20. Corridors for aircraft and satellites. In areas with large airports, air traffic controllers set up standard or situational air corridors for certain aircraft that are preparing for landing or take-off. These corridors are determined by the altitude of the flight over the area, the height and width of the corridor itself, and by the course of the aircraft, i.e., by the orientation of the corridor and the direction of the flight. This gets more difficult with take-off and landing corridors. The work of the controller is similar when new space probes take off and then move into a certain orbit with new parameters. These operations are run so that trajectories in outer space don't overlap which then prevents collisions. Clearly a *spatial resource* dominates here.

Ex. 21. Sun glasses. Recently sun glasses were patented with opacity that can be regulated by the person who wears them. There are two lenses for each eye from which one can be rotated. This means that the lenses are so-called polarization filters. The polarization vectors are equal at certain positions of the lenses and the glasses have maximum transparency. When one of the lenses rotates, the polarization vectors change and the transparency is reduced. Sun glasses had already been developed earlier that had phototropic lenses that could automatically change their opacity in accordance with the intensity of the light. Clearly a *material resource* was used here. **Ex. 22. Power plant in an "exhaust shaft".** In the 1920's, the French engineer Bernard Dubot developed the concept of a power plant where a turbine spins in a shaft driven by the warm stream of rising air.

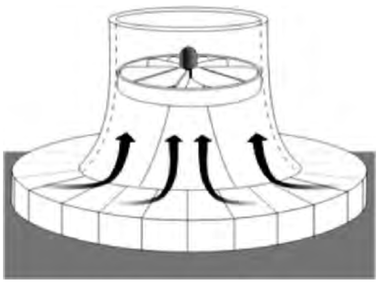

fig. 8.5. Dubot-Schleich's power plant

50 years later, the German engineer Jörg Schleich from Stuttgart (designer of a series of original bridges, cooling towers, and the roof of the Olympic stadium in Munich) developed this idea further and verified its usability with the 10 year service of this kind of plant in Spain. The basis for this power plant are two well-known effects: the green-house and chimney effects (fig. 8.5). A large "green-house" with a large glass roof, for example, with a surface of a square kilometer, is warmed by the sun. The hot air from the "green-house" rises into a pipe in its center that is several hundred meters high. This air then drives the turbine of the electrical generator that is installed in this "exhaust shaft". An enclosed thermal accumulator made of pipes filled with water is installed in the "green-house" so that the power plant can also function at night. Warm air from this accumulator can also drive the generator at night.

This idea incorporates all different types of resources as all great technical ideas do. However, the most important of the resources used is the *energy resource* of the system. The essence of the idea is clearly the use of solar rays that fall to the earth and then the energy of the warm, rising air. And finally, the transformation of the mechanical energy of the rotations of the turbine into the electric energy is used.

All of the resources mentioned in these examples can be divided into two groups (fig. 8.6). *System-technical resources* are abstract in their own way and can be understood as a model. *Physical-technical resources* are easier to perceive in a system as the temporal parameters of their influence, as geometric shapes, concrete materials, and as the types of energy used. Regardless of what was invented with the dominance of these or those system technical resources, the practical use of an idea has always happened on the basis of a change in physical technical resources. An idea can only become reality materially.

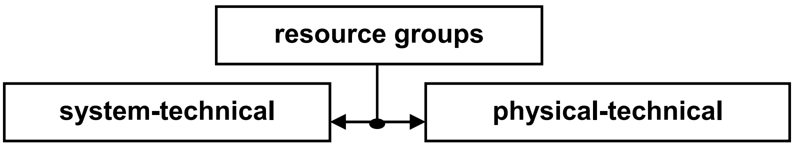

fig. 8.6. Resource types

Regardless of the slightly arbitrary division of resources into types and groups, this is a highly useful definition process that can help to determine the dominant aspects of a problem and its solution. This is why we should attempt to understand which resource is the cause of the conflict or, if possible, which resource is insufficient in the system and why. Perhaps the resource is used up, but it could also be that it is simply being used poorly or ineffectively. The resource types mentioned above are shown in the classification table 8.7.

If it's necessary to introduce new resources for a solution to a problem, we should be careful and pragmatic. *The best solution for extant systems is always achieved with minimal changes.* This is why practical recommendations were worked out in TRIZ that you can find in fig. 8.8.

To conclude this section, we can again look at a few practical teaching examples of the direct application of resources from the archives of classical TRIZ.

Ex. 23. How can we visualize a strong draft in buildings? There is often a strong draft in large buildings that are being or were just built (storage or factory buildings). This comes from the relationships of air streams that originate in still unfinished openings in walls or insufficiently insulated ventilation systems, pipe systems, or in other open locations.

The use of soap bubbles created by a special and simple device was recommended to uncover the source and path of drafts precisely and quickly. Thousands of flying bubbles visualize the streams of drafts. Here a material resource was used. The soap film functions like a fixed cover for the air it contains. The energy source is the warmer air in the soap bubbles that creates a driving force.

SYSTEM-TECHNICAL RESOURCES			
SYSTEM RESOURCES	**INFORMATION RESOURCES**	**FUNCTIONAL RESOURCES**	**STRUCTURE RESOURCES**
Belong to general system properties	Belong to the transmission of signals and messages	Belong to the creation of functions	Belong to the condition of the object
Effectiveness, productivity, reliability, security, durability, and others	Reliability, stability, precision, completeness, methods and effectiveness of codification, procedures and parameters of data compression, etc.	Purpose (useful primary function), auxiliary functions, negative functions, description of the functional principle (functional model)	Components and connections between components, structural types (linear, linked, parallel, closed, etc.)
PHYSICAL-TECHNICAL RESOURCES			
TEMPORAL RESOURCES	**SPATIAL RESOURCES**	**MATERIAL RESOURCES**	**ENERGY RESOURCES**
Belong to the assessment of time	Belong to geometric properties	Belong to material properties	Belong to energy properties and their phenomena
Frequency of events, duration of time intervals, order of events in time, value of later or earlier action	Shape of an object, size - length, width, height, diameter, etc., special aspects of the shape - presence of protrusions, hollow spaces, etc.	Chemical combinations, physical properties, special engineering technical properties	Types of energy used and considered including mechanical forces, gravitational, thermal, electromagnetic forces, etc.

fig. 8.7. Classification of resources

Properties of resources	**Value:** free → inexpensive → expensive
	Quality: damaging → neutral → useful
	Quantity: unlimited → sufficient → insufficient
	Readiness for use: ready → changeable → to be developed

fig. 8.8. Recommendations for the selection of resources

Ex. 24. Coconut palms. You truly need suppleness and experience to climb to the top of a 20 meter high or even higher palm tree. It would be great if every palm had its *own* steps that then resembled a ladder. In many areas where coconuts are harvested, cuts are made in the bark of young palms that don't harm the tree. After the palm is full-grown, there is already a ladder in its bark. Here a *temporal re-*

source is used cleverly in advance - the ladder grew itself during the growth phase of the tree - and of course a *spatial resource* - the step-like shape on the tree's trunk.

Ex. 25. Lights for the "Lunochod". It has been reported that it was very difficult to develop head lights for the so-called "Lunochod", the first vehicle that moved on the moon. The construction office in Moscow searched for a long time for a sufficiently hard material for the glass outer surface of the head lights. The engineers knew that in essence an ideal vacuum exists on the moon. When the air was pumped out the head light, it couldn't stand the atmospheric pressure and it imploded. When an inert gas was pumped into the head light, it exploded in a vacuum. This continued until someone realized that the filament of the head light didn't need protection on the moon. There the very vacuum exists that is need for the filament to light normally. A glass cover is needed to protect the filament from mechanical damage and to focus the light. This inventive colleague used the extant *material resource* of the vacuum on the moon, a material that doesn't exist!

Ex. 26. Water in water. In many countries in Africa and the Arab peninsula, water gaining and drink water conservation and storage including rain water is really a problem. The storage facilities needed would have to be huge constructions that would also have to be cooled. The Swedish engineer had the idea to store water in the ocean! Floating storage tanks shaped like cylinders without a floor or a top could be built for this purpose in the ocean and would then be made buoyant with pontoons. Rain falls into the pontoons where it is stored until it is pumped out onto land. These storage tanks could be transported over thousands of kilometers because potable water is less dense than salt water so that it floats on the ocean and doesn't mix with it. We could add as a further development that these storage tanks could be moved, for example, to the Antarctic and back if they had a "top". In the Antarctic a storage tank could catch a small iceberg out of potable water and transport it into warmer zones. The iceberg would function as this top and slowly melt until the storage tank is completely filled with potable water. A *material resource* and to a large part also an *energy resource* dominate in this idea. It applies Archimedes' law in which the potable water floats *by itself* on the surface of the ocean instead of mixing with the salt water.

It is characteristic for the ideas in examples 15–26 that these or those dominating resources were used. For this reason, we can say that it is often sufficient to correctly determine the resource that is in conflict and is insufficient in order to strengthen it and to find an original solution with its help. But, more complicated problems need a more thorough investigation and transformations that immediately concern several resources. The contradictions need to be investigated and modes for transformations need to be used. Knowledge of physical technical effects is absolutely necessary here.

9 From What exists to What's coming

9.1 Contradictions

9.1.1 The concept contradiction

Goethe once noted cleverly that truth lies between extremes ... no, that *the problem lies between extremes.*

Many philosophers and researchers of methods of creativity have recognized that *the contradiction represents the essence of the problem.* But, before Genrikh Altshuller, no one transformed this concept into a universal key to uncover and solve the problem in itself. Contradiction began to work as a fundamental model for the first time with TRIZ in 1956 in a way that opened up the entire process for solutions. TRIZ first turned contradiction into a constructive model equipped with instruments for the transformation of this model to remove this contradiction.

Inventing means - remove a contradiction!

There are many possibilities to define and represent models of contradictions. Here we would like to consider only those definitions that best correspond to the basis of classical TRIZ. However, in other courses we investigate yet other derivations and original models.

Contradiction is the model of a system conflict that puts incompatible requirements on functional properties of components that are in conflict.

*Binary model of a contradiction (*or simply, *binary model)* or *binary contradiction* (fig. 9.1*) – models a contradiction in the incompatibility of only two factors (properties).*

Composition of binary models is the totality of related binary contradictions that is created to describe a conflict with several factors.

Any and all multi-layered conflicts with different factors can be represented with a composition of binary models. But then you need to find the most important factor, the key binary conflict where a solution is absolutely necessary to solve a model with several factors.

There are two primary cases for incompatibility:

1. One of the factors corresponds to and supports the useful mail function of the system (*positive factor* or *plus-factor*), the other one does not correspond to this function and even hinders it (*negative factor* or *minus-factor*);

2. Both factors are positive. They work against each other because they are in conflict over a certain resource that they both need but that they cannot use simultaneously or to the degree needed.

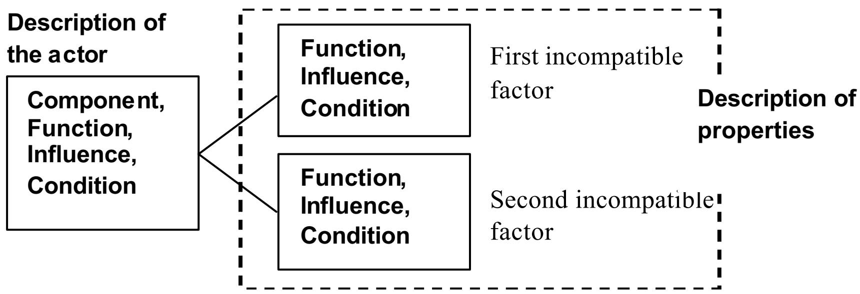

fig. 9.1. Generalized graphic form for a representation of binary contradictions

***To solve the contradiction** means to remove the incompatibilities at hand.*

The apparent or real (physically determined) *incompatibility* that reduces the effectiveness of the system or makes it completely impossible to achieve the useful main function is reflected in the contradiction.

When an extant incompatibility cannot be resolved using obvious procedures then the situation becomes a problem that is difficult to solve (see fig. 7.4 and 7.5). In such situations a solution to the problem requires transformations that are anything but trivial with ideas that are often unexpected and often with unbelievable effects.

Is it really so easy to come up with ideas such as a house that simply swims away during floods? Or how about the idea of a frozen liquor bottle that is surrounded by hot chocolate, or ice at the foot of a palm tree?

Aircraft that take-off vertically had to suffer hundreds of accidents before it was clear that a vertical orientation of the fuselage is unacceptable - it's not needed at all! Material, financial, and intellectual resources were wasted, not to speak of the lives of test pilots! The original administrative and strategic image of the necessity of the vertical direction of the fuselage turned out to be a *primitive mistake!* It was technically simpler and more effective to use aircraft with a normal horizontal fuselage arrangement. But, dynamization was required first. *Dynamization resolved the initial contradiction.* This was important from the initial conception of the aircraft to its *projection* to the strategical level of the development of a new technical function! This means that a new administrative-strategic solution was used based on transferring the problem to a tactical-technical and operative-physical level.

This is how we come to a large number of types of contradictions, for example technical-economic (*technical property - cost*), technical-technological (*technical property – complexity of production*), technical (*incompatibility of functions*), physical (*incompatibility in the conditions of the property*), and others or even combinations of these mentioned here. The first two types are usually administrative contradictions. These contradictions need to be transferred to the technical of physical level where the instruments of classical TRIZ are optimally oriented.

Let's look at some of the special characteristics of the development of contradictions (fig. 9.2). This is how we can construct *inverse models* or *alternative variations* for every contradiction that in their meaning more or less resemble the factors of the initial *direct* contradiction. Constructive alternative variations occur when several properties of an object are in conflict. This phenomenon can be used with the combination of procedures that are directed towards solving certain alternative contradictions (see for example section 11.4. *Integration of alternative contradictions – the CICO method*). Alternative variations often arise due to different descriptions of one and the same conflicting property by different specialists. This often leads to misunderstandings and discussions within teams that are solving the same problem. Use of the A-matrix and the table of fundamental contradictions help to limit the variations of models.

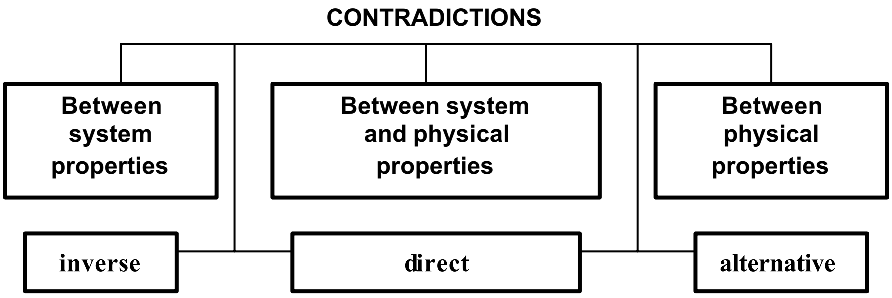

fig. 9.2. Types of contradiction models

Contradiction models can include properties from different system levels. For example, they can place both properties on one level or one property can be physical-technical while the other is system-technical. You can orient yourself on the table of resource types (fig. 8.7). We can now consider these contradictions more closely with the following two comments in mind:

1. The exact formulation of the contradiction is not an easy operation and it requires experience and of course professional knowledge. How the contradiction is formulated and what it reflects determines further attempts to solve the problem;
2. Different kinds of contradictions can be represented in hierarchical form like a "matryoshka of contradictions" where in every administrative contradiction a technical one is shown and in every technical one a *physical contradiction.*

9.1.2 Technical contradiction

You have already seen clearly formulated models of technical contradictions in the examples of reinventing 4, 6, 13, and 14. It makes sense to examine them at this point again so that you can understand and accept the following definitions better.

Technical contradiction is a binary model that reflects incompatible demands placed on different functional properties of a component or several components that interact in conflict with each other.

Ex. 4 (Continuation). This is the initial contradiction (fig. 9.3):

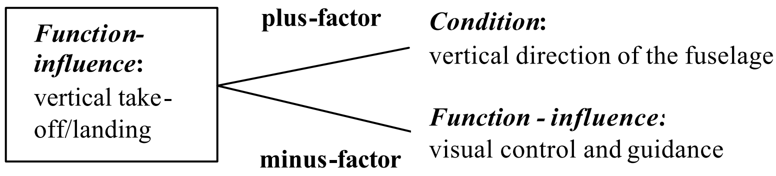

fig. 9.3. Graphic model of the binary contradiction for example 4

Initially, there were strong psychological barriers in the development of a solution that prevented a dynamization of the construction of the aircraft. It was assumed that only the orientation of the plane at take-off and landing would change, not the plane itself. People thought that a jet with vertical take-off and landing had to move with the tip flying forward and land on its rear. Years later the developers realized that effective observation and control as well as the horizontal orientation of the fuselage is very important! Let's go further with our teaching reinventing and determine that the plus-factor has to be the easy guidance of the plane (system-technical resource) while the orientation of the fuselage (physical-technical resource) becomes a problematic minus-factor. This means we want to move to an *inverse contradiction* (fig. 9.4):

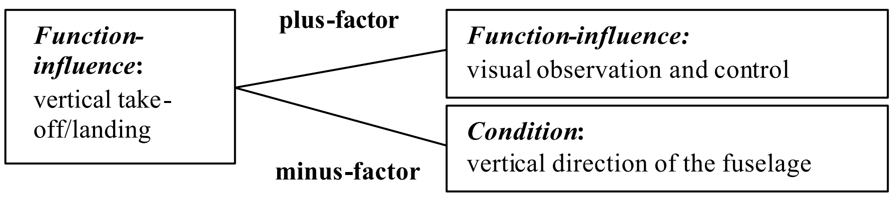

fig. 9.4. Inverse model of a binary contradiction for example 4

The reduction of the inverse initial model on the basis of the A-matrix leads to the following contradiction model (fig. 9.5):

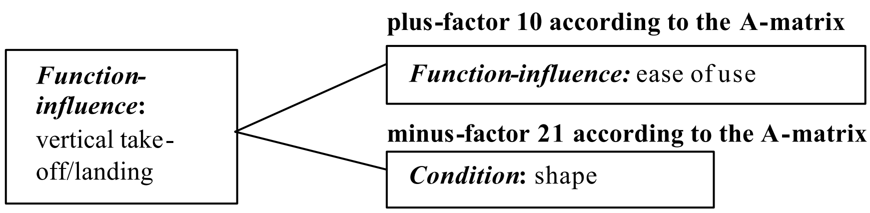

fig. 9.5. Simplified model of the inverse contradiction for example 4

The A-matrix shows the following procedures: 04 *replacement of mechanical matter*; 07 *dynamization*; 14 *use of pneumatic or hydraulic constructions* and 15 *discard and renewal of parts.*

As you already know, the procedure 07 *dynamization* finally led to a solution for this problem. We should also note that an attempt was made to apply procedure 15 *discard and renewal of parts* by installing disposable boosters for take-off.

Ex. 27. Training stations at a fitness center (first step). *Diagnostics* show that different special training devices were set up at a fitness club. Every device takes up space, especially those designed for training in a lying position. Devices for training while standing take up less space. Space should be saved so that more guests can work out on the stations. We can think of a single station as a main element of the operative zone where a solution can be applied to other devices, too, if at all possible. We can formulate the initial technical contradiction like this: *the construction of the station has to ensure training by several guests (plus-factor)*, even though this takes up *more space (minus-factor)*.

Ex. 28. Driving pilings with vibrations (first step). *Diagnostics* show that driving pilings with strikes (example 14 continued) creates a large amount of waste and no more opportunities to increase productivity. We would like to suggest that we expand the operative zone to include the entire piling and investigate other procedures for the piling's movements. There is a conflict here between system-physical properties that can be shown as a technical contradiction: *the movement of the pilings* should be *accelerated,* but this increases the influence of destructive *damaging factors* and it reduces the *reliability* of the operations.

Ex. 29. Put satellite groups into precise orbits (first step). *Diagnostics* discovered that groups of satellites are very difficult to bring into precise orbits or into the same orbit at a specified distance from each other with a rocket. This is reflected in the following technical contradiction: orbiting a satellite group *with a rocket* with exact *precision* requires the development of *extremely complex* systems for take-off and guidance.

Ex. 30. Blackboards (first step). *Diagnostics* of the process of "holding lectures" using traditional blackboards with chalk show that this process allows the creation of *spontaneous illustrations* and that it is easy to use. But, this method does not demonstrate *high productivity*, especially when it is necessary to show complex finished illustrations from textbooks or CAD data banks. Such a procedure is also *not easy* when information is to be transferred from the board to a computer, for example, during Internet lectures. Cameras have to be used that can transmit the information from the board. Then *the participants receive images on TV or computer screens.* The image is recorded and transmitted in an analogous form, meaning that the image of the entire board is transmitted as analogous picture images.

If we consider the multiple possibilities in this task, we can formulate several alternative technical contradictions that support each other. This means that drawing on the board has the following positive properties: *simplicity of construction* and *possibility to represent any drawing.* Its negative properties are: *low productivity when drawing,* especially with complex drawings, *lack of automation* when drawing, *comprehensive transmission and complicated recording* of video information, that are transmitted using TV technology, and *uncomfortable usage.* It requires the use of chalk or felt-tip markers that dirty one's hands, complicated corrections, and the drawings can only be reproduced as an entire board or flip-chart.

Don't you also think that it's too early to try to perfect the blackboard after this kind of diagnostics? First, there are too many contradictions and they are not in order. Second, there is no goal formulated as a useful main function and no ideal functional model expected. Third, it is not clear which resources are available or permitted.

However, the contradictions exist and this means that there is work for creative spirits.

Ex. 31. Dome of the Reichstag (first step). You can now put yourself into the role of the head architect Sir Norman Foster for a while who had the idea for the reconstruction of the Reichstag (Parliament building) in Berlin that was then carried out (fig. 9.6). The *number one* idea both architecturally-technically as well as in its symbolic character is to see the glass dome as an element in the system of the natural illumination of the main chamber and as a sight worth seeing in Berlin, just like the Eiffel tower in Paris or Big Ben and Westminster Abbey in London. By the way, I'll return to the deep symbolic meaning of the dome at the end of this book.

Let's examine the first assignment with the dome. There is a ramp on the inner side of the dome that allows visitors to reach the upper platform. How could the ramp be built so that the streams of visitors from above and below don't meet?? If the ramp were built like in fig. 9.7, the visitors would get in each other's way. In such a project, there are always strong technical contradictions: the *ramp* has a certain *shape* that causes the visitors to run into each other when ascending and descending. This leads to loss of time and to difficulties. A more optimal shape is needed for the ramp.

fig. 9.6. Germany's Parliament building in Berlin

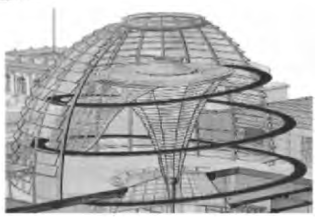

fig. 9.7. Possible variation of the ramp in the dome

Now we would like to conclude the orientation examples where initial models for technical contradictions were developed like this is normally done in the *diagnostic* stage. Directed solving of problems begins with making the models precise and concrete in the *reduction* stage. This continues with the resolution of contradictions in the *transformation* stage and it ends with the *verification* stage. Try to find a solution yourself and compare your ideas with the answers that you will find later in section 9.3 *Reduction and Transformation*.

9.1.3 *Physical contradiction*

You have already seen clearly formulated models of physical contradictions in reinventing in the examples 1, 2, 3, 5, 7, 10, 11, 13, and 14. Let's examine the following definition:

A *physical contradiction is binary model that places incompatible demands on one and the same functional property*.

A solution to this kind of contradiction is so complicated because both conditions in conflict are needed for the initiation of the useful main function of the system.

We can again consider the formulation and solution of the physical contradiction in reinventing the fountain pen in example 1. In its sharpest form, the physical contradiction for the goose feather looks like this: there *should be a lot of ink and no ink at the tip of the feather!* It is clear that this assignment cannot be quickly solved without additional analysis and an "anatomic investigation" of the contradiction. But, our investigation has to closely follow these four physical aspects: space, time, structure, and material. This is essentially what happened with the story about the pen. These experiences had not been investigated, accumulated, and generalized prior to TRIZ. The solution to the contradictions happened in accordance with one or more of the following aspects (fig. 9.8).

Aspects	Distribution of incompatible properties	
	Initially	**Development**
Space	Ink is ready for writing on the feather. Spots are therefore possible initially. Soon the ink is dry and it needs to be replenished. The ink source is separated from the writing instrument.	Ink used to write does not change and is in the pen. The ink needed is in a special hollow space in the writing instrument from which it moves to the pen as needed.
Time	The time in which ink is on the feather determines (limits) the time for writing to a few minutes, and these intervals function simultaneously.	The time in which ink is in the writing instrument is a hundred times longer than the time in which the ink is on the goose feather. This time can exceed the time of writing considerably. The ink lasts even by continuous writing for several hours. ***Ink reaches the pen only when someone writes and does not flow to the pen when there's no pressure.***
Structure	The amount of ink in the writing instrument corresponds exactly with the amount on the feather.	There is very little ink in a part of the system (pen) even though there is a lot in the entire system.
Material	The tip of the feather is solid and fixed. Ink flows freely on the surface of the feather.	The tip of the pen is divided into two parts that make a groove through which the ink flows. The groove is dynamic and spreads with pressure on the pen.

fig. 9.8. Solution to the physical contradiction

The phenomenon of the unequalled usability of a binary physical contradiction looks like this:

1. the physical contradiction has a *practical navigation* function to the degree in which all solutions can be run with the aid of the real physical transformations of real physical objects, i.e., by changing their materials, shape, processes, etc. This contradiction is *oriented* towards the realization of this kind of transformations on the object where *attention is primarily focused on the useful factors desired*;
2. the physical contradiction has an effective *limiting function* when constructing ideas for a solution and *prevents an irrational search beyond the fundamental transformations* to the degree in which the fundamental procedures for solving physical contradictions are well known (see section 12 *Navigators for Solutions to Physical Contradictions*).

a)

b)

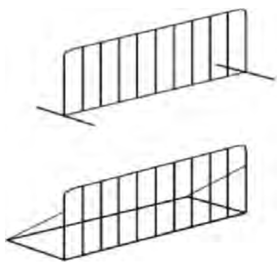

fig. 9.9. Initial construction of a crowd fence

Ex. 32. Crowd fence (first step). In fig. 9.9a you see a fence that determines the direction and width of streams of people walking by. This kind of fence is used for exhibitions, for example. Their construction is not stable and they can tip over when guests lean against them. This is why the lower end is made wider and the fence itself is secured with diagonals (fig. 9.9b). But, this construction is also unacceptable because it can be easily pushed to the side, especially on stone or asphalt.

It is a physical contradiction that the fence is supposed to be *wide* at the bottom so that it cannot be moved easily while it needs to be *narrow* for ease of transport and set up.

Ex. 33. Reaction time of car drivers (first step). We know that alcohol reduces the speed with which car drivers react to new road conditions. Many drivers think this does not effect them. They make the same mistakes made by others and often with tragic and costly results. How can we convince drivers of the real danger that awaits them when they drink and drive? This is a strong physical and incidentally also an ethical contradiction: the driver *has to be drunk* so that changes occur while driving that make the danger clear, but the driver *should not be drunk* so that no danger actually arises. How do we resolve this contradiction?

Ex. 34. Pilings (first step in the last example of pilings). Driving pilings still creates an unsolved problem that is the direct consequence of the hammering principle used. In addition, an important part of the energy is used to destroy the piling itself. This is a considerable physical contradiction: the piling *has to be driven* deep into the ground, but it *may not be driven* because it is then destroyed. Perhaps you have new ideas for a technique to drive pilings in a non-destructive way?

Ex. 35. Repair of pipes (first step). A water pipe is broken! It has to be repaired quickly, but water is flowing at high pressure out of the pipe and it is not possible to weld the break. To stop the flow of water in the entire system is often neither possible nor sensible. This is a dangerous break down situation: the water *has to be stopped* to carry out the repairs, but external reasons dictate that the water *cannot be stopped*.

Ex. 36. Blackboard (Intensified problem described in example 30). We can generalize the technical contradictions in example 30 as a physical contradiction. The board *has to be present* to draw illustrations for class, but the board *should not be present* so that illustrations are not drawn on it. Do you already see a solution or have you lost all hope of the possibility of a solution? There's no hurry, just project yourself into the incompatible alternatives of this model!

Ex. 37. Dome of the Reichstag (Intensified problem described in example 31). The physical contradiction in the construction in fig. 9.7 could be described like this: visitors *have to go back down* after they leave the viewing platform, but they *should not go back down* in order not to get into the way of those on their way up. Of course, there's some irony in this formulation, although the task to project a construction for the transport of guests up to and down from the dome is certainly reasonable. I also wanted to demonstrate that sometimes this kind of not-so serious formulation appears. This does not mean that we should be afraid of such tasks nor that we should avoid them. Sometimes it helps to solve a problem without the "savage seriousness", like Nils Bohr[55] once noted. We will see this again later in section 9.3 *Reduction and Transformation*.

If you knew nothing about TRIZ previously, we can now assume that you could gain some experience with the concentration and modeling of problems as technical and physical contradictions. I hope that these examples have also served to make the considerable difference between technical and physical contradictions when modeling one and the same problem understandable.

To test this, you should try to solve the assignments in *exercises 6–9* by yourself.

9.2 Functional-Ideal Modeling

Psychologists and neurophysiologists together have discovered in investigations at different levels a few secrets about the organization and functions of the human brain. However, so far no one has discovered the source of genius thinking, the sources of motivation while creating, the dominants and imperatives of belief, love, hope, and the good. Luckily they exist by themselves in resonance with the even more powerful principles of the construction of the universe. This is why we want to use an extremely simplified and superficial scheme here that shows the components that support the process of thinking in TRIZ, but does not reflect the entire process of inventing a new idea (fig. 9.10). This scheme differs from fig. 2.3 by considering the absolutely necessary individual aspects of thinking.

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[55] Nils Bohr (1885-1962) – leading Danish physicist, creator of quantum theory, Nobel prize winner 1922

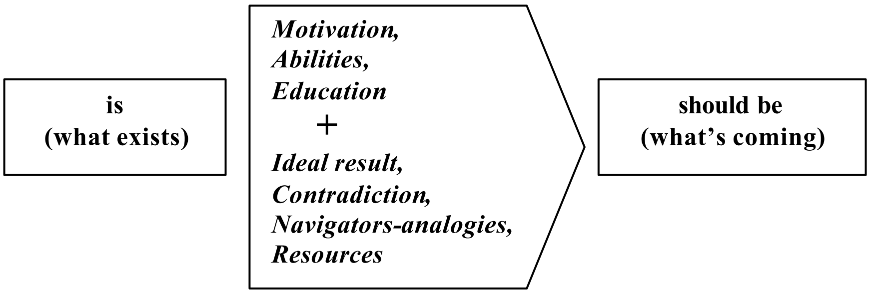


fig. 9.10. Most important aspects of TRIZ solutions to problems

Necessary conditions for a successful solution to problems are:
- strong positive motivation, resolution, stamina (will) to reach the goal;
- certain capabilities for associative thinking, memory, powers of imagination, powers of observation, objectivity, flexibility, the ability to overcome slow and lazy thinking;
- professional knowledge and command of TRIZ/CROST techniques.

In this world, we all strive for an ideal in the way that everyone imagines such a thing. But, the path to this goal is often not immediately recognizable and almost never easy. In addition, the search for and selection of a goal that seems to be worth our efforts and attention is certainly not a simple task for almost all of us. As soon as we realize this, we can begin with our discussion of the topic "ideal modeling". This is perhaps the most difficult topic of TRIZ even in simple and straightforward examples. Let us first take a look at three following examples.

Ex. 38. Vase in a museum. Valuable objects are often exhibited in museums in glass containers or in niches integrated into the wall. This means that it's not possible to examine the objects from behind or below, i.e., they cannot be examined in their full value. What's really important here? It's the possibility to see a vase from all sides and even from below without going around it or bending down to see under the glass. Most of the time it's not possible to go around the vase because it is standing in a case on the wall that's not transparent from behind. Why don't you (initially) demand something not real: *the wall and the case should show us the vase from all sides*! Exactly this kind of statement should be learned with TRIZ! This is precisely the formulation of a *goal-oriented metaphor* as a *"functional ideal model" - FIM.* And this metaphor is precisely an image of what we want to achieve. It is a functional image that contains the concrete result expected. In classical TRIZ, it is also known as an *"ideal final result" – IFR*. I'm sure that you've already found the well-known solution to reach the FIM or IFR for this task: mirrors are installed behind and under the vase! If this assignment seems to be too simple for you and the solution to obvious, I ask you to please go easier with this example. It's good for teaching purposes. Incidentally, there's a slight complication in the installation of mirrors under the vase. Take care of this yourself. It's good practice to apply the Meta-ARIZ. If you believe that you've already dealt with the complication, then put a vase on a mirror at home and try to see its underside. You'll notice the complication immediately.

Ex. 39. Keel of a sailing yacht. Sailing yachts are stable when they move using their sales because they have a keel, a course stabilizer under their floor. When the yacht comes to port and docks in shallow water, the keel gets in the way because it hits the harbor floor. Again, what's important for us here? It's the possibility to move smoothly in shallow water without striking the floor with the keel. Let's formulate the "administrative" FIM: the yacht travels unproblematically in shallow water that's somewhat deeper than its draft, i.e., than the distance from the surface to the deepest point of its bottom. Let's formulate the "technical" FIM: the yacht has no keel in shallow water. We cannot demand that shallow water suddenly gets deep, although in other cases such metaphors should certainly not be excluded! But, the keel is in place in deep water and when we want to sail at high speed. This is a clear physical contradiction. We already know procedures to resolve it. We also perceive the clear *incompatibility in space* (little depth – large depth) *and in structure* (the keel is in place – it's not in place). *Logically, these resources are critical in this task and they will dominate in the solution.* Surely you've already found the essential idea: the keel has to be dynamized - we must be able to raise and lower it. This is not easy to do technically. A special port has to be built into the middle of the yacht that is sometimes open (fig. 9.11). This is not compatible with the general stability of the hull because the lower keel beam is the actual "backbone" of the yacht. We need to make a longitudinal cut in it here. In another variation, two lifting stabilizers are installed as a keel on the walls of the yacht. But this makes steering difficult and it influences speed negatively. Although yachts have already been developed for centuries there are many topics here for inventing.

Ex. 40. Electrical connectors for street cars. Electrical connectors are often shaped like a bow. The upper part runs perpendicular to power lines that supply the street car with electricity. The bow is equipped with springs that maintain constant pressure on the power lines. The bow shape ensures reliable contact in curves although the lines wear ruts in the bow on straight stretches. This sometimes causes the lines to break. How could this wear be reduced or even removed completely?

What's important here? We should keep in mind that direct contact between the power line and the bow is essential. We can expect to put the IER into effect: the line doesn't wear on the same place on the bow. We don't yet know how to achieve this IER, but we have an idea how it should work. It is totally logical to reformulate the initial metaphor like this: the line is in contact with the bow at several places, just like this happens in curves anyway. Now we can take an important step towards a solution: the contact wires have to run in a zig-zag on straight stretches where the size of the zigs corresponds to the length of the contact element of the bow (fig. 9.12). This makes the construction of the lines more expensive but it extends the life of the bows and reduces the possibility that a line is broken by a damaged bow like in the older version.

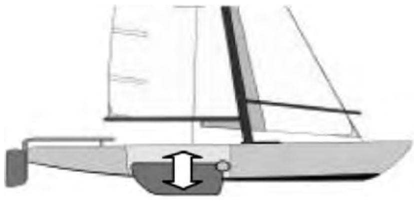


fig. 9.11. Yacht with a central keel stabilizer

fig. 9.12. Zig-zag contact wire

In all of these cases, we came to a solution almost on the basis of a precise formulation of the functional ideal model or the ideal final solution alone. Of course, it is *sometimes sufficient to formulate the goal of the solution to a problem because the goal itself points towards a solution*. It was sufficient to focus our attention on the FIM or IFR in the examples we've examined and the resources needed appeared essentially by themselves. As opposed to these examples, real problems are often anything but simple. But, the formulation of ideal functional model plays an extremely important role in the solution of all problems. The *FIM and IFR motivate creative thinking and direct it towards the areas where effective solutions exist.*

Essential system-technical principals to formulate the FIM and IFR will be discussed in section *12. Guiding system development.* Here we would like to rely initially on an intuitive formulation of the "ideal" function of an object in solutions to problems.

Let's now look at the main definitions in their current version.

Ideal final result IFR is the required or desired condition of an object. Functional ideal model FIM is an image, hypothesis, or metaphor that contains an idea of how an object should function in order to achieve the IFR.

In most cases the FIM is formulated because it provides more information about how the object should function after its changes. In addition, the IFR is often somehow hidden in the FIM but is not explicitly named as such.

Depending on where the IFR is directed, we can differentiate two types of FIM:

FIM-minus: Description (goal, demand, condition, process) of the function desired ***minus*** negative phenomena that caused the contradiction;

FIM-plus: Description (goal, demand, condition, process) of the function desired ***plus*** effects or resources that lead to the *"resolution"* of the contradiction by itself.

The model FIM-minus is usually constructed in the first discussions about the problem. The model FIM-plus is more constructive and includes a hidden version of the FIM-minus. Classical formulations should be used for the construction of the FIM-plus. But, they all assume that the solution can only be found based on changes in extant resources or by introducing supplementary resources.

The closer the description of the FIM is to reality, the better. However, we are not able to precisely describe how to reach the FIM or IFR. This is why there are often formulations with the properties that are not without psychological limitations. In the course of several decades, two rules were established in TRIZ to reduce psychological difficulties while formulating the FIM that have proven to be effective:

1) Don't think immediately how precisely and by what means a solution can be found;

2) Unknown resources or influences that are needed to achieve a result can be temporarily replaced with metaphoric symbols, such as an ***X-resource.***

TRIZ clearly uses here a procedure to solve open and strong "physical" contradictions that arise in our conscious: we need resources to solve the problem and resources can also be available that we simply don't recognize as such. TRIZ recommends that you temporarily replace an unknown resource with your image (solution of incompatibilities in time), i.e., with a copy itself if it is not clear (solution of incompatibilities in space-material-energy)!

This is where we also find the solution to a contradiction in structure. The impossible is hidden in "X". It already looks like the FIM is in the realm of the possible. A part of the FIM includes something unknown although the entire FIM is known. Our conscious makes the impossible possible and this is helped by the fact that it really doesn't seem impossible. And now we can examine practical models, or more precisely, prepared forms for the construction of **FIM-plus** models:

1. Macro-FIM:

An X-resource ensures a solution together with other extant resources without complicating the system and without creating negative effects

[*the function required*]

2. Micro-FIM:

An X-resource as *material or energy particles* is in the operative zone and ensures a solution together with other resources

[*the function required*].

3. Maxi-FIM:

The operative zone ***itself*** ensures a solution

[*the function required*].

At this point I would like to refer to two statements by the author of TRIZ Genrikh Altshuller about the role of functional ideal modeling in solutions to problems.

The first idea first appeared in Russian in 1979 [3]: "The ideal final result can be compared to a line that a mountain climber securely grasps while climbing a steep mountainside. The line doesn't pull the climber up, but it does provide a hold and prevents falls. If you release the line, you definitely crash to the earth".

The following is [2]: "Imagine that someone is stuck in a dead-end street. Someone suggests that you should go farther in the dead-end (to find the exit – M.O.). This certainly seems to be a useless suggestion! We have to proceed differently: first go back to the entrance and then proceed in the correct direction. Unfortunately, assignments are usually formulated in such a fashion that they lead to a dead-end in a way that we don't notice".

The IFR and FIM help inventors out of dead-ends where psychological difficulties bring them and provide them with a sure orientation towards successful solutions regardless of how impossible these may initially seem.

Here are more examples.

Ex. 41. All-terrain vehicles. All-terrain vehicles that transport large construction pieces in impassable regions need large wheels and a large space between the lowest point of their wheels and their floor. But then the center of balance is relatively high, meaning that the vehicle can tip over on uneven surfaces. To prevent this, the vehicle's center of balance needs to be as low as possible. This is a considerable physical contradiction! This is the **macro-FIM:**

An X-resource ensures *as low a center of gravity as possible in the vehicle* together with other extant resources without complicating the system and without negative effects.

The maximum stability is achieved with the center of balance on the ground! How can we construct the center of gravity as close to the ground as possible? We need an X-change in the system that brings as much of the system's weight as far down as possible. But this kind of all-terrain truck is a construction that can only be modified with difficulty. Its lightest part is the driver's seat and controls at the very top. Parts like the engine and transport components can't be moved lower than the lowest part of the vehicle. Only the lowest parts of the wheels are lower. The wheels themselves are very large and wide, but they have no influence on the space between the wheels and floor of the vehicle. What can we do here?

If you still have no idea, let's first define the operative zone. We can understand the OZ as the surface of the wheels that comes into contact with the ground. The vehicle starts to tip when the wheels are no longer in contact with the ground on one side. In effect, a low center of gravity presses this surface against the ground. It would be helpful if the front part of this surface were somehow "pressed" against the ground. The pressure on the rear part of the surface would have to be reduced so that this part could start to roll up. And this would all have to happen without interruption while the wheels are rolling.

Let's formulate the **micro-FIM:**

An X-resource in the shape of *material or energy particles* is in the operative zone and ensures together with other extant resources *maximum pressure of the wheels against the ground*.

It is difficult to imagine how we could do this outside of wheels. We could also examine the resource of the operative zone - the contact surface - from the inside of the wheels. We could install X-particles that press on the front part of the contact surface but not on the rear part! An idea like this was patented in the USA. A Japanese inventor suggested that a large number of small steel balls could be installed in the wheels. While driving, the balls roll steadily along the inner surface of the wheel and bring the center of gravity of the vehicle much lower (fig. 9.13).

This is similar to a well-known toy, a stand-up man (fig. 9.14). A piece of metal is installed in the rounded lower part that balances the entire doll. This is why it always stands upright of flat surfaces.

Verify the solution and check to see to what degree the FIM was put into effect. Perhaps we should move a bit away from the "ideal" without extra costs or negative super effects and pay for the achievement of the effect desired in any shape or form?

Ex. 42. Winter shoes. Under icy conditions it helps very little to reshape the profile of the sole or heel of winter shoes. You can't walk around in rooms with shoes equipped with spikes. Special spike underlays can be attached to the soles like people do this in many northern areas. This doesn't make the shoes prettier and in cities it's neither usual nor useful. What can we do?

fig. 9.13. Wheel construction of an all-terrain truck

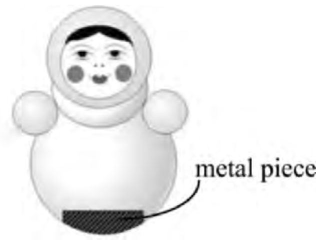


fig. 9.14. Stand-up man

Let's first define what we want to achieve in the operative zone (sole and heel) and try to define the FIM for this situation. We have learned to formulate physical contradictions quickly. This is usually more difficult that the definition of technical contradiction. We can introduce the physical contradiction into the following **maxi-FIM**: the operative zone itself ensures *the presence of spikes under icy conditions and the removal of the spikes at higher temperatures.*

What could be more ideal than the use of a material resource like in the following solution: vertical metal pins are installed in the sole of the shoe that have a shape memory according to thermal conditions. At temperatures under 0°, the metal pins stick out of the sole and function like spikes, while they recede back into the shoe at temperatures above 0°. The spikes disappear by themselves.

Ex. 43. Work or dinner table for a bed. A normal tray or another flat surface, for example out of plastic, is uncomfortable while eating or working in bed. A small table slides around at the smallest movement. Special moveable trays or tables are often used in hospitals that are mounted at a comfortable height over the bed. We need something simpler for home. The technical source of the problem is that the flat lower surface of a table is not compatible with the complicated shape of the lower part of a human body sitting or lying in bed.

Let's note the following **micro-FIM:** ***an X-resource*** as *material particles* in the operative zone ensures *the maximum coordination of the shape of the underside of the table and the shape of the human body.*

It's clear that the lower part of the table needs at the very least a dynamic outer surface that easily adjusts to uneven changes. The solution is to mount a cover on the entire lower surface of the table that is filled with light plastic balls. When this table is placed on a patient's legs, the cover adjusts closely and remains stable.

Ex. 44. Steps at a memorial site. The architecture of memorial sites is always designed to have an emotional effect on visitors. Many sites are shaped as sculpture compositions that are built on natural heights or synthetic hills. How can we ensure that the behavior of visitors, especially young visitors on the way to the hill is commensurate with the dignity of the site? Surely you've already noticed that this is a clear administrative contradiction, isn't it? We need a new function, or concretely, the *memorial site should promote dignified behavior itself.* It's not clear how this can be done.

As a technical contradiction, this can be formulated like this: the stream of visitors *should not move quickly*, but smoothly, although faster visitors sometimes cause *disturbances.* The OZ is the steps. **Maxi-FIM:** the *steps themselves limit* the movements of the visitors. This FIM targets a solution using internal resources of the OZ in the construction of the steps themselves. We need special stairs that *reduce the speed of the visitors*!

An initial solution would be that the steps have several different sizes. Visitors have to look at their feet often and their speed remains slow and dignified.

Ex. 45. Bottles with dangerous materials. How can we store strong medicine so that it is protected from children but easily accessible to adults, even when a quick swallow is often necessary and sometimes in the dark? In our first approach to the problem, we define the operative zone as the entire bottle. Then we can describe the **maxi-FIM** as the following physical contradiction**:** the bottle *itself ensures protection* against children and is *recognizable for adults*.

Let's not forget that in the initial requirements the recognizability of the bottle in the dark was important. This means that the bottle has to be recognizable by touch. The maxi-FIM dictates that the shape of the bottle is critical here. This shape needs to simultaneously prove positive information for adults and negative information for children.

The initial solution came from a "barbed bottle" that won a contest in England. The entire surface of the bottle is covered with barbs that don't cause injury but that make the bottle uninteresting for children who are used to playing with round and/or soft toys.

To conclude this section about the FIM, we can note that inventive tasks always have several paths to a solution. This is why it's important to solve them with different methods and resources, meaning to use different "chess figures" in this complex game. The FIM is oriented here towards the uncompromising achievement of the desired result.

9.3 Reduction and Transformation

We can resolve or remove extant incompatibilities with 5 main navigators:

1) *removal of the negative factor or neutralization of the consequences of its influence;*
2) *construction of an inverse contradiction (transformation of the negative factor into a positive one, the target factor) and transition to the first navigators;*
3) *integration of inverse contradictions while excluding negative properties;*
4) *segmentation of equally valuable positive influences that are in conflict with each other according to time, space, or other resources that are causing the conflict;*
5) *replace the task by removing/ resolving the conflict entirely.*

In any case, the process of transformation occurs in TRIZ according to a scheme that I call a *Mini-Algorithm of Inventing* or *Mini-ARIZ* (fig. 9.15). Both main steps in Mini-ARIZ as numbers 1 and 3 belong just to the stages *reduction* and *transformation* and are directly related to a solution to the concrete contradiction and to the generation of a solution. Step 2 reflects the transition between the stages *reduction* and *transformation.* Arrow 4 shows a possible return to *reduction*, for example, possibility to make the models more concrete or to search for new resources.

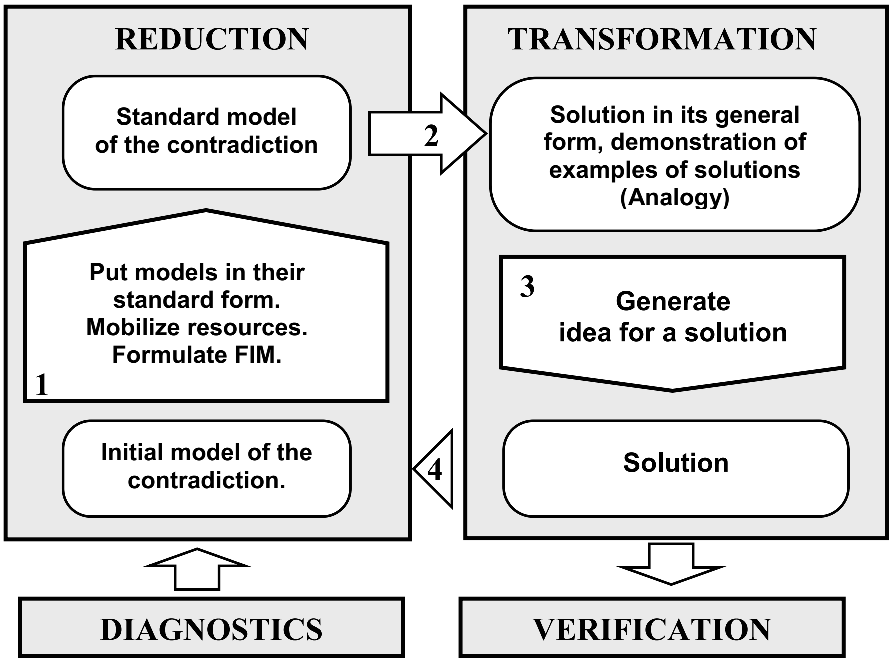


fig. 9.15. Mini-Algorithm of Inventing (Mini-ARIZ)

Surely you've already noticed that in many of our examples a shortened version of the solution process was given that included only the steps of the Mini-ARIZ. We would also like to continue this approach in this section, at least in the first examples.

Reduction is a connecting stage between *diagnostics* and *transformation*. In this stage, we examine *one concrete assignment* only that is concentrated in *one operative zone*. The reduction of the problem includes the selection of navigators and standard TRIZ models for which solutions are known in a general form, the formulation of the functional ideal model and the ideal final result, and a search for potentially useful operative resources.

Transformation is in the truest sense of the word the decisive stage in Meta-ARIZ. In this stage, we encounter the disciplines of thinking and inspiration, logic and intuition, experience and motivation, and determination in the search for new ideas. This is where all the preparatory work done according to TRIZ can unfold its great effect. It's also where the diagnosis of the problem situation occurs that ends with the construction of the operative zone, the definition of the initial models of contradictions, and the reduction of the original descriptions down to standardized descriptions. Here is also where you are directly confronted with the last desperate resistance of the problem and the uncertain future of your invention or your series of inventions. I wish you lots of success!

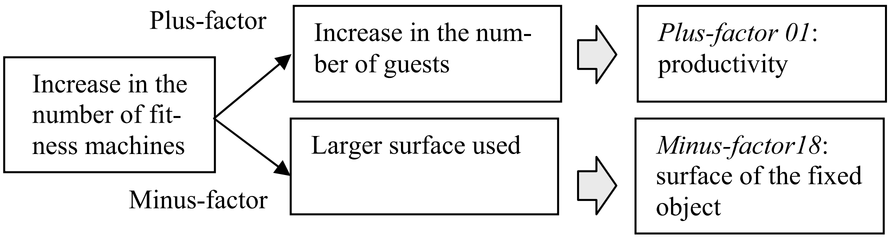
The models TRIZ/CROST are *instruments for thinking* in the transformation stage. The examples in the following section are set up so that you can understand how to use these TRIZ instruments. This includes how long it's possible to move securely on the basis of analogies in the process of problem solving and from what point your own creative efforts are needed. We don't have prefabricated answers to all problems. But, there are models and recommendations in TRIZ that describe *how the correct answers can be found in the shortest time.* Does this lower the value of TRIZ? Or do you now no longer want to use TRIZ to solve a concrete problem?

We need to answer these questions for all reflective people. Let's now think about a few questions while considering the capabilities we have developed during reinventing, especially our capabilities to accumulate and generalize examples:

- Do you know a chess player who never learned any theories of chess and didn't study hundreds and thousands of chess games and the moves of other talented players from the past and present?
- Do you know a brilliant pianist who didn't study music theory, who didn't play thousands of scales, etudes, and the difficult passages of new pieces?
- Do you know a famous mathematician who didn't first study arithmetics, then geometry and algebra, and then who didn't practice on thousands of mathematical problems?
- Do you know a painter who didn't first learn the elements of painting, composition, and drawing, didn't make any drawings, and didn't study the works of past and present masters?
- Finally, do you know a famous boxing or karate champion who became so good using a couple of textbooks without years of training and practice, who didn't learn the most complicated movements through the simplest movements, and who didn't work long and hard on stability and concentration?

I'm sure that you've already reached your own conclusions about how these questions can be evaluated in relationship to the conception of ideal modeling in TRIZ. TRIZ has theoretical principles and models, study examples with different levels of difficulty, strategies and tactics, and even ideas about the "beauty" of a solution! We'll come to that later, but first let's look at the "exercises" of the A-Studio. Here are some assignments from the exercises for the section *Algorithmic Navigation of Thinking.*

Ex. 27. Training stations in a fitness center (conclusion). *Reduction shows,* that the *resource of the available surface* are extremely limited. We need to search for a solution in the direction of the following *ideal result*: new fitness machines require no extra space! A selection of the appropriate factors from the A-matrix leads to the following concrete models of the technical contradiction:



Transformation. The A-Matrix recommend the following navigators from the table of A-navigators: 01 *change in the aggregate state*, 02 *preliminary action*, 19 *transition into another dimension,* and 34 *matryoshka*.

A common interpretation of navigators 19 and 34 seems very constructive. According to navigator 19, we can use the resource height of the room and either raise the machine onto an additional level or place it vertically. Navigator 34 is oriented towards the use either of constructions that can be moved in and out or towards the combination of several training machines into one construction.

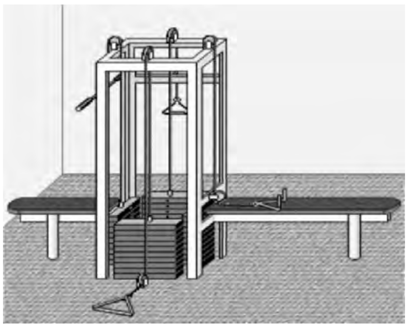
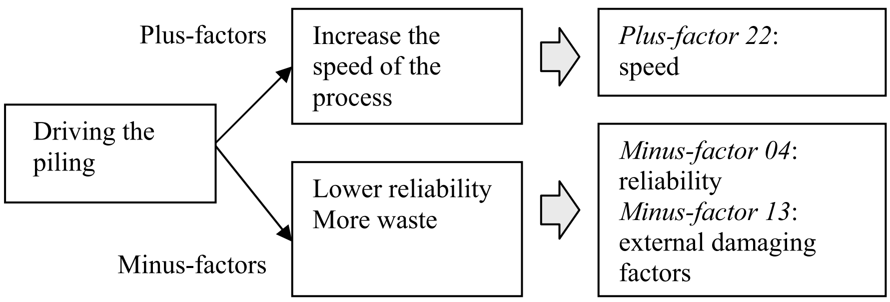


fig. 9.16. Training station with four functional sides

The example of a well know solution is shown in fig. 9.16: the machine allows guests to do different exercises from all four sides.

The moveable weights are mounted on all four sides of the station and cables with rollers are threaded through consoles that are installed at different levels according to the type of exercise done.

Ex. 28. Driving pilings with vibrations (conclusion). Our analysis shows that we have to turn to the resource of the piling's material. Let's formulate the micro-FIM: an X-resource in the shape of material particles in the operative zone ensures the movement of the undamaged piling. The reduced model of two alternative technical contradictions looks like this:



Transformation. We get the following navigators from two boxes in the A-Matrix: 01 *change in the aggregate state* (twice), 03 *segmentation*, 04 *replacement of mechanical matter* (twice), 13 *inexpensive short-life object as a replacement for expensive long-life one*, 28 *previously installed cushions*, 36 *feedback.* Essentially, all of the navigators have interesting interpretations. Examine these navigators yourself and compare them with the solution of example 34.

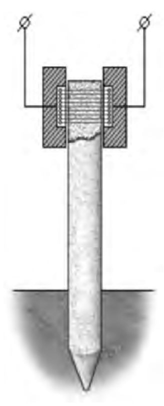


fig. 9.17. Piling with electrodynamic movement

For teaching purposes we can concentrate on a known solution (fig. 9.17) with navigator 04 that recommends specifically: b) use of electrical, magnetic and electromagnetic fields for interaction with the object; d) use of fields in relationship to ferro-magnetic particles.

A ferro-magnetic powder is added to the material of the piling. A steel armature is also installed in the piling. The piling is placed in a heavy cylinder that contains a ring-shaped electromagnetic inductor that generates electrical impulses. The magnetic field that is generated interacts with the ferro-magnetic and metallic components of the piling to develop mechanical force that moves the piling down.

The selection of the type of impulses and the strength of the electricity allows several kinds of movement for the piling that create striking and vibration effects.

If we examine the series of transformations from the first problem to the solution found, we can see that the character of the influences and effects have changed in the operative zone: *local* influence (initial driving navigator) – *surface* influence (using a mediator) – *spatial* influence (using ferro-magnetic particles). This is the implementation of the *principle of the dynamization of the operative zone*, although the changes can also run in the opposite direction in relationship to the context of the assignment.

Ex. 29. Placement of satellite groups in exact orbits (conclusion). In the *reduction* stage, we can establish the following model of the technical contradiction:

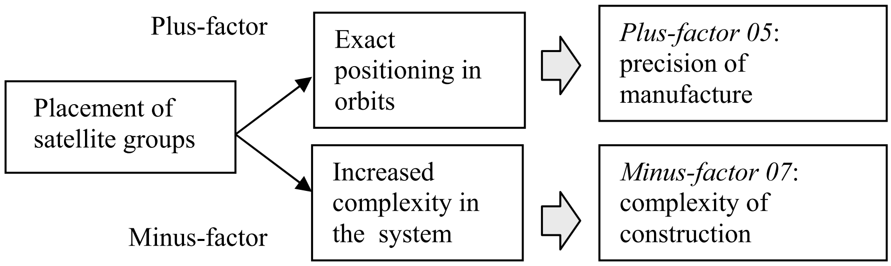
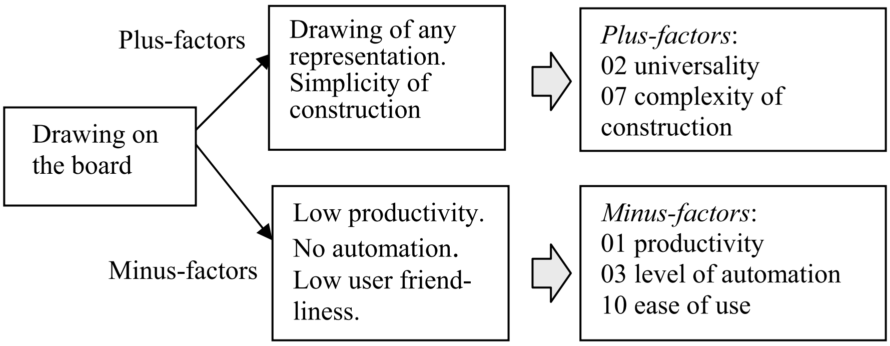


fig. 9.18. A shuttle places satellites into precise orbits

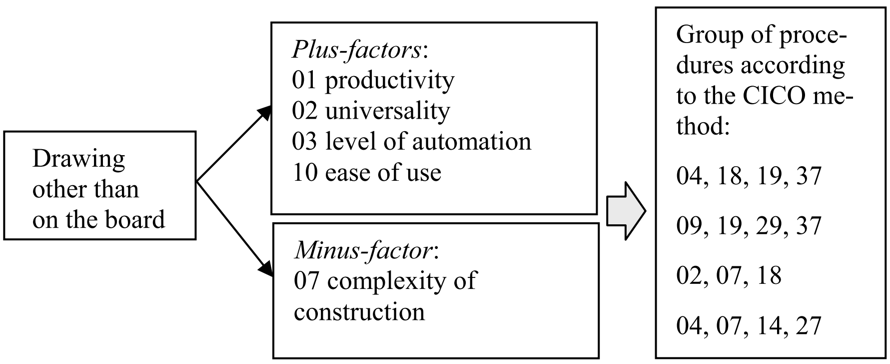
These are the recommended navigators: 05 *separation*, 06 *use of mechanical vibrations*, 10 *Copying*. One of the best known solutions based on the *navigator of the separation* of parts means *"separate the only part needed (property needed)"*:

A group of satellites is brought into outer space with a vehicle like the shuttle (fig. 9.18). Then a robot takes the satellites out of the cargo area of the shuttle with an arm and places them in specific orbits with the parameters required.

Ex. 30. Blackboard (conclusion). The reduction of the initial contradictions in this problem turns out to be anything but simple. Let's examine the development of this process. First, we can reduce the initial contradictions to the following form.



Here the number of negative factors exceeds the positive factors. It therefore seems sensible to move to inverse models and add factor 02 universality.



Ranking the navigators leads to the following order: 04 (2 twice), 07 (2), 18 (2), 19 (2), 37 (2), 02, 09, 14, 27, 29.

We can now note the key recommendations from the first four navigators in order:

- replace the mechanical system with an **optical**, acoustic, or "olfactory" one;
- the **characteristics of the object** or the environment should be changed so that they are optimized **in every step**;
- use a **mediating object** that transmits or transfers the effect;
- possibly improve the system by moving from a surface to a 3-D space; **use optical beams** that shine on a neighboring surface.

The following solution was developed in Germany (fig. 9.19). The lecturer holds a pen 2 on the board 1 with a normal size of 3 x 1.5 meters as if he or she wanted to draw or write. A sensor network 3 in the board reads the position of the tip of the pen. The "X" and "Y" coordinates of the position of the pen are passed on by a processor 4 into the computer 5.

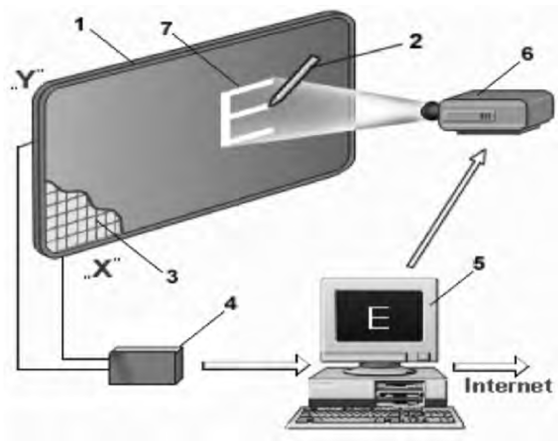


fig. 9.19. Construction principle of an electronic-optical board

The computer sends everything to the projector 6 that was previously drawn or written on the board (7). The projector projects the end of a newly drawn line at the position where the pen is. The "board" (white light) plays the role of a screen with an system installed to read the position of the pen. This means that the *universality* of drawing on the board doesn't change and the *level of automation* increases using the possibility to save the representation in every computer that is connected via Internet to the transmitting computer 5. *Productivity, ease of use, and the level of automation* are increased because now all of the complicated drawings and texts that were previously prepared can be shown on the board.

Ex. 31 and 37. Dome of the Reichstag (conclusion). Are you now ready to reconstruct the thought processes of the architect Sir Norman Foster? If so, let's try it. If not, read this textbook again from the beginning!

Here we'll combine solutions based on technical and physical contradictions, especially because we want to move to an investigation of transformations on the basis of physical contradictions after this example:

Ideal result: Streams of visitors do not encounter each other!

Technical contradiction: Plus factor 21 *shape* and minus factor 25 *loss of time*.

Physical contradiction: There *have to be* streams of visitors moving in opposite directions because they go to and from the platform, and there *cannot be* streams of visitors moving in opposite directions so that they don't disturb each other.

Leading resource: space

The A-matrix recommend navigators 02 *preliminary action*, 15 *discard and renewal of parts*, 19 *transition to another dimension,* and 22 *spherical-shape*.

The table of "Fundamental Transformations and A-Navigators" (Appendix 7) recommends that these navigators seem extremely promising: 05 *separation*, 10 *copying*, 19 *transition into another dimension*, 22 *spherical-shape*, 34 *matryoshka*.

Now we have all the recommendations and their interpretations.

- navigator 05: remove the disruptive part (for example, the visitors leaving), and separate the part needed (analogy);
- navigator 10: use copies (install a second ramp!);
- navigator 19: shape a construction with several floors (somehow place a ramp over the other one);
- navigator 22: use spirals (they already are in use here!);
- navigator 34: put objects into each other, let an object move through the hollow space of another (the ramps need to be installed in each other!?).

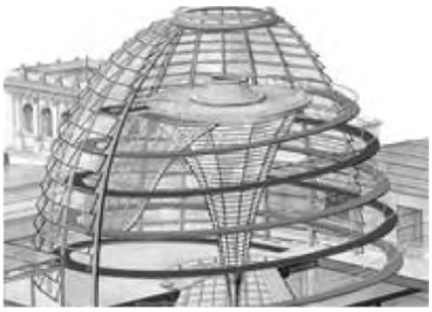


fig. 9.20. Ramps to the visitor's platform in the dome of Reichstag (Germany's Parliament building) in Berlin

Fig. 9.20 shows a simple and effective solution: the second ramp is turned 180º in its installation and its curves spiral between the curves of the first ramp. The ramps are identical, meaning they are copies of each other.

Ex. 32. Crowd fence (conclusion). We can formulate the maxi-FIM like this: the operative zone itself holds the fence. See example 30, too! Let's try to formulate another version of the physical contradiction: the fence needs to be heavy so that it cannot be easily moved, but it needs to be light so that it can be transported.

Above all else, we want to consider a *solution to the contradiction in time* because the fence needs to be heavy (wide) in one time interval but light (narrow) in another. These intervals don't overlap. It's clear that certain changes in construction need to be made. We need to investigate *all available resources*! For example, what moves the fence? It's the pressure and weight of the crowd that presses against the fence.

fig. 9.21. Stabile fence

This is certainly a real resource, this mass of people that appears precisely in the interval of conflict. Damages need to be changed into advantages here. A very effective solution is shown in (fig. 9.21): the supports for the fence on the crowd side are shaped like a grid that is so wide that the crowd has to stand on it when people press up against the fence. The operative zone itself uses the weight of the crowd to prevent this same crowd from moving the fence!

Ex. 33. Drivers' reactions (conclusion). I know of a few driving schools where this contradiction was solved in a completely natural way. Parties were thrown where sparkling wine and highly alcoholic drinks were served. Afterwards the somewhat tipsy drivers complete normal exercises at training sites in specially equipped cars together with driving instructors. A video recording is made and the time required for these exercises is measured. At the next class, the participants are shown these recordings. They're usually really astonished! This exercise has a considerable effect.

The second solution corresponds closer to TRIZ. The negative influence has to be transferred to the environment by using an external resource. A computer training machine gets "drunk". The contradiction was solved in structure and time: the entire system functions *normally* but a part of the system functions *abnormally*. Concretely, this means that the training machine functions with delays.

Ex. 34. Pilings (conclusion of this example). Even if you already know the control solution or you have your own idea, please study this example very closely. It only appears to be simple. In reality, there are very important details in the *reduction* stage that were discovered by TRIZ. We can construct the functional structural model of the conflict in the operative zone (fig. 9.22). Have you noticed that this is a *simplified variation*? If so, that's very good! If not, then read the following text very closely.

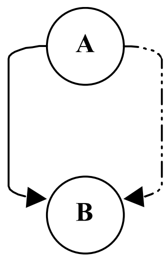


fig. 9.22. Simplified model of the conflict when driving a piling

First, we can see that this analysis should already have been made in the *diagnostics* stage. But, let's assume that we were distracted and we thought that there was only one operative zone in this situation and that correspondingly there was only one "obvious" conflicting pair, the hammer A and the piling B. At that moment, when we defined the initial model in this way, our entire search was limited to this operative zone!

This is what happens to people who are not familiar with TRIZ!

A TRIZ specialist does a more complete analysis in the *diagnostics* stage. Let's continue where we left off.

Let's construct a more complete functional structural model in the operative zone (fig. 9.23). Everyone who doesn't know the details of TRIZ modeling describes this model like this: the hammer A influences the piling B and transfers its energy to move it into the ground C. But, this damages the piling B. The piling influences the ground C that also influences the piling negatively.

This is where TRIZ dictates that the zones and also the actors need to be defined more closely, even if not in a traditional way.

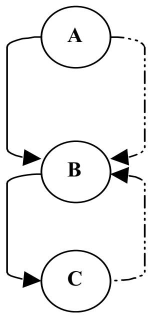


fig. 9.23. Complete model of the conflict when driving a piling

First, we clearly see two operative zones here. The first one is obvious and it contains the hammer A and the piling B. We have considered this zone just like hundreds and thousands of "piling specialists" without noticing that there are other zones and resources present in this system.

The second operative zone contains the piling B and the ground C. We ignored this zone completely because we thought the entire system conflict was only the conflict between A and B. This mistake prevented a systematic investigation of the entire system and therefore the possibility to search for alternative solutions on purpose.

But, we now come to an even less perceivable and more detailed mistake that we also made in our description of the complete model. As opposed to unprepared problem solvers, TRIZ specialists would have said that the *hole in the ground* influences the piling, not the ground itself. They would have said that the piling doesn't just influence the ground, it creates a hole for itself! If this hole already had the form of a piling, then the piling would not need to be driven in at all.

We can move away from the actual topic at this point and ask ourselves whether we believe that on the basis of this really simple discussion an alternative idea has already appeared? Of course we could make a hole for the piling in advance and then drive it in with much less force. If the hole were large enough, we could even place it in the hole without driving it.

Well, let's continue. In the previous section, you saw that the formulation of the functional ideal model somehow points to the decisive idea as well as playing a role in preparing to generate an idea. The ideal result is that the piling should find its place as one piece without damage. We need a new definition of what "as one piece without damage" means. For example, the hole in the ground should have the same shape that the piling received during its manufacture.

We can also look for a more precise definition of the operative zone! It's completely correct to define the walls of the hole and the outer surface of the piling where it contacts the hole as the operative zone. We can test the veracity of this model by using a few questions and answers. The navigator to formulate them will be totally clear to you. How does the ground interact with the piling? This happens only at the walls of the hole. How does the piling interact with the walls of the hole? This happens only at its outer surface.

Let's take the functional ideal model to the extreme: the operative zone itself ensures the implementation of an entire piling! This can only mean in order that the walls of the hole themselves make sure that an entire piling is driven. Can we interpret this image constructively? If so, then write down your idea so that you can soon compare it to the control solution. If not, then read the following very closely.

The *operative time* should now concern us instead of the final result. Somehow the piling gets into the ground, and this is the conflict time. The piling is brought to the construction site after it's been manufactured by a company. Sand and cement were mixed with water and a metal armature was manufactured. The armature was placed in a die and then the cement mix was poured in. After the mix cools in the die, the finished piling is removed.

Have your seen a way to interpret the functional ideal model? Check your idea by using the control key at the back of the book.

Ex. 35. Repairing pipes (conclusion). The result of the *reduction* stage is a strong physical contradiction: the water *has to be stopped* but it *may not be stopped*! This is where we should start to make all TRIZ aspects of a problematic situation more concrete. Let's first deal with the operative zone. It includes the break in the pipe and the section of the pipe with a break and water. The ideal result would be that the water has stopped and there is no more water around the break. There seem to be no resources available. Let's turn to the table of *fundamental transformations and compact A-standards*. Our general interpretation of the system transition 1-c (position 5) is that water moves in the entire system but not in the operative zone (?). Our interpretation of position 7 is to apply phase transition 1 to replace the state of part of the system! The control solution is to freeze the water locally around the break. The technology needed to do this is manufactured by the German firm Rothenberger.

Ex. 46. Blackboard (really the last conclusion!). We should now think about the special properties of the solution that we found in example 30 (conclusion). It's an extremely interesting and important solution because it shows how one of the most stubborn stereotypes could be removed that prevented innovations in teaching. This was the idea that it's not possible to write on the board with anything other than chalk or a felt-tip.

But why don't we ask ourselves the question why the lecturer has to write anything in the scale of the board on the board? Isn't this a stereotype that we all hold dear?

Express diagnostics of this situation are also possible. We need a large auditorium with a large number of students for drawings on a large board. But this board is totally unnecessary to pass on lecture material that is also in the Internet! It is sufficient to pass on drawings, text, and formulas. And the lecturer doesn't have to do this! Do we really need a lecturer in a large and traditional auditorium who stands at the board, *imitates* the process of drawing, which is precisely what happens in the conclusion to example 30, and enhances the drawings with verbal explanations?

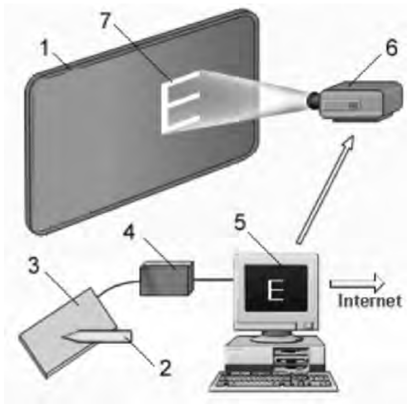


fig. 9.24. Principle of a device for a virtual electronic-optic board

Our new requirements look like this: the lecturer has to stand at the board even though he or she should not stand there and the representation should be on the board but it doesn't need to be drawn there! These contradictions are clearly related to a spatial resource and the solution will probably be based on the *Principle of Transformations in Space*! I assume that you've already looked at the scheme in fig. 9.19 and have come to the control solution in (fig. 9.24).

The lecturer draws or writes a text with a pen 2 on a surface 3 (digital table) with precise sensors that then read the position of the pen's tip. The pen also leaves a track, for example, ink on a sheet of paper that is attached to the surface 3. The representation can then be projected onto the screen 1 *in any size*. Of course, this data is stored in the computer 5 and can then be transmitted via Internet. This increases the *user friendliness* again.

Ex. 47. Ship on underwater foils. Our *express diagnostics* show the following: the ship, as a technical system *TS*, has a useful primary function *MPF* "transport loads on the water" and a negative primary function *MNF* "displace the water during movement". As a component of the TS, the hull of the ship has a positive function *PF* "keep the load above water" that is a part of the MPF and a negative function *NF* that is in agreement with the MNF of the ship. The operative time is determined by the time of the ship's movement. This is a conflict time because the ship is forced to use energy while moving to overcome the resistance of the water. The increase in speed from increased engine power is slowed considerably by the increased resistance of the water. How can speed be increased with only slightly increased engine power?

We can now use our *reduction* to examine primarily the operative zone and all contradictions. The operative zone *OZ* includes everything that slows the movements of the ship. Above all else, this is the water and the main part of the OZ, the part of the ship under water, or more precisely, the cross section of the part of the hull that is under water. Here the hull is the inductor that *influences* the receptor water to create movement. In addition to its positive influence - displacement in accordance with Archimedes' law to hold the ship above water, the receptor also has a strong negative influence on the inductor by slowing its movement.

Administrative contradiction (AC): the speed of the ship has to be raised in such a way that the engine power only increases to an acceptable degree. The goal is set but the means are not yet clear.

Technical contradiction (TC): increased engine power increases the speed of the ship, but the resistance of the water increases more quickly and it soon makes increased engine power impossible.

Physical contradiction (PC): the hull of the ship needs to be broad to ensure its stability but it needs to be narrow so that the resistance of the water is decreased during movement.

Make a graphic representation of these contradictions.

Let's formulate functional ideal models:

1. Macro-FIM: ***An X-resource*** ensures little or no increase in the resistance of the water while increasing speed without complicating the system or causing negative effects.

2. Micro-FIM: ***An X-resource*** from *material or energy particles* is in the operative zone and ensures little or no resistance from particles of water during movement.

3. Maxi-FIM: The operative zone ***itself*** increases speed to the same degree as it decreases the resistance of the water.

In *transformation* stage, we can examine the physical contradiction more closely and replace special terms with simpler words. The ship holds itself on the surface of the water, meaning in floats because its part under water displaces water that corresponds to its own weight (Archimedes' law). This means that the ship interacts positively with the water *when it doesn't move. While moving,* the part under water displaces water particles in order to create an empty space that facilitates its forward movement. Think about this - an empty space without water! This space could be filled with water, which is exactly what happens. We can note that an ice breaker displaces ice to create an open space for itself in water. A ship that moves quickly displaces water and creates an open space ... in air.

We can now apply modeling using the coordinates "size – time – cost" from section 18.2 *Model "Fantogram" and "Was-Became"*. Here we can shorten the description and consider only the result of modeling: a "narrow" hull means no hull or a lacking hull! In other words, the part of the hull under water where the resistance of the water has its influence needs to have no depth, i.e., it should not be in the water! You find the physical contradiction in this kind of extreme form in fig. 9.25b.

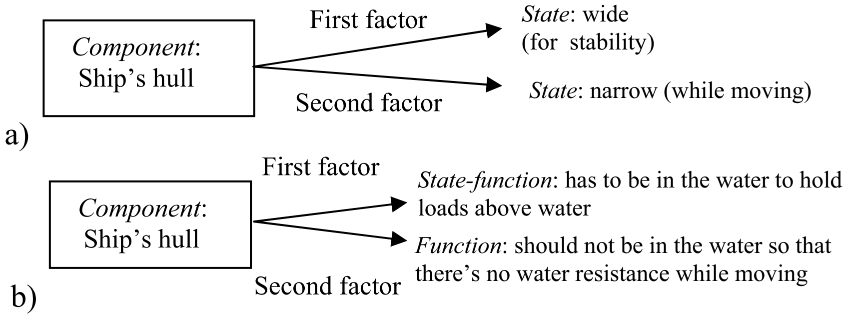


fig. 9.25. Original (a) and generalized (b) physical contradiction

The question is how to construct a ship so that its hull is not in the water while it moves. Why should we not build a kind of aircraft ship? The hull has to be lifted out of the water and maintained there. Think for a moment about what kind of stone skips better across the surface of the water when it is thrown parallel to this surface. Of course, a flat stone is better. The stone skips across the water without sinking as long as its speed holds. This means that something other than Archimedes' law is at work here. On one hand, there's the repelling force caused when the stone strikes the water and on the other hand a flat stone has *aerodynamic lift* like the wings of a bird or aircraft. Why should we not add "wings" to the ship's hull? Another question is how to install them. If they were installed on the ship above water, lift would only come from the support of the air and the ship would have to reach the speed of an aircraft. But, a ship is heavier than a plane and it needs much more lift.

What would happen if we mounted the "wings" under water? Then the support of the water would develop much *more lift and hydrodynamic power*, and it would push the hull up. The higher the speed, the higher the ship rises out of the water and the smaller the part of the hull is that is still under water. The resistance of the water decreases and it gets correspondingly easier to accelerate the ship. It will move higher and higher until the entire hull is above water. Only the "wings" and the propeller are still in the water!

This is exactly the idea of the Russian inventor Rostislav Alexeyev who started the development of high-speed ships with hydro-foils at the beginning of the 1950's (fig. 9.26).

fig. 9.26. High-speed ship with hydrofoils

Here we would like to offer an important explanation in the *verification* stage. We can say that we have found an ideal functional solution because the foils are an element of the hull. The OZ *itself* causes an increase in the ship's speed regardless of the width of the hull. We can now complete our investigation by examining the technical contradictions and the possibility of a solution with the help of the A-navigator.

In accordance with the technical contradiction, we can read the plus factor "speed increases" (line 22) and the minus factor "performance (power) decreases" (column 36) from the A-matrix. The matrix recommends the following navigators: 01 *change in the aggregate state of an object,* 05 *separation,* 08 *periodic action,* and 30 *use of strong oxidants.*

The A-navigator 05 seems most appropriate for a constructive interpretation:

Separate the "disruptive" part (disruptive property) from the object or, turned around, the necessary part (property).

The "disruptive" hull of the ship was separated *from the water* using "necessary" elements separated *from the ship's hull* – the hydro-foils.

Ex. 48. Sunny house. Usually country houses are built so that as much sun as possible shines into the living room. But, it's possible that the other sides of the house get no sun. Try to invent a solution where every room in the house gets sun. Preliminary *diagnostics* show the following. As a technical system *TS,* the house has the useful primary function *MPF* "protect the internal space from external influences" and the negative primary function *MNF* (in this case) "lack of sunshine in some rooms". A requirement is that sunlight shines through windows into the house. If the house has only one room, then this room always has sun, even when no sunlight shines through the other windows. This already leads to a few obvious ideas from our *diagnostics* (fig. 9.27): we can build a house where all of the windows are on the sunny side (a), the rooms on the second floor have windows over the roof of the first floor (b), or the house is shaped like a ring of single-room sections around an inner courtyard (c). More complicated solutions area also obvious: reflectors are installed on the side away from the sun (d), installed mirror light projectors (e).

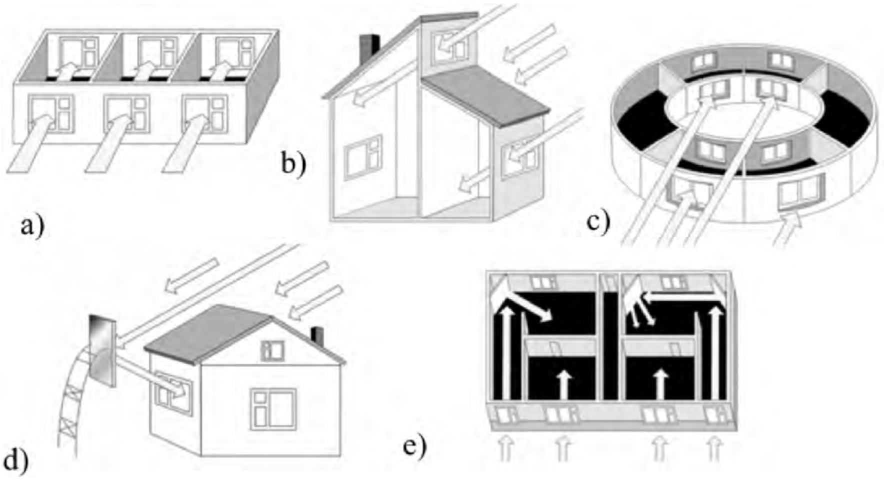


fig. 9.27. Construction principles for a sun house

We can use these projects as prototypes for a search for new ideas. Let's start with solution "a". The problem here is the difficult planning of a single-row house.

Reduction. We first need to determine the actors and the OZ of this system (put the book away and try to determine these components yourself).

The necessary auxiliary function of the house is to light the rooms (with sunlight). It is clear that the rooms are the receptors here and that the house is the inductor system. The sunlight can be understood as the system environment. Then we can consider the OZ to be the entire group of rooms. TRIZ dictates that when similar objects are present, a solution can be developed for one object and then transferred to all of the objects (of course, only when all of the objects together have no new system properties). This is why we can define the OZ as a room on the side away from the sun.

This is a strong physical contradiction:

The house lights the rooms on the sunny side well using windows but lights the house poorly on the side away from the sun!

We see that the operative time (conflict time) in this OZ starts *immediately after the position of the house is set* at the construction site. Let's look more closely at the OT. "Before" the final position of the house is set in the plans of the construction site, the house, i.e., its projection can be turned to select the optimal direction. This can then ensure the best sunlight for the rooms. The problem in the middle of our investigation comes "after" the final position of the house has been set.

Attention: again, before the position is set, the problem does not exist. It appears after the construction plans have been drawn! This is already an answer in very general form: the position of the house should not be fixed. In other words, the house needs to be built so that it is dynamic and can turn with the movement of the sun.

There are still several difficult problems in the *transformation* stage. The largest and most important problem is the development of a rotation mechanism for the house. Could this be a giant ball bearing or rollers? Or perhaps the house should float and then it would be relatively light to "turn" it? Should it turn like a carrousel in any direction or would it be sufficient if it turned in a smaller sector, such as from 60° to 90°?

We don't need to develop this idea any further here because there is already an entire series of patents for this concept. Our goal was to demonstrate that a solution can be developed in different stages of Meta-ARIZ. This is why it's so important to go through the stages so carefully and in the correct order.

Verification. A wealth of new problems arise, such as the construction of the foundations, energy and water systems, sewage system, a special TV antenna, and the relationship of the house to its garage. But, I'll let your fantasies address these problems. It's your project! Perhaps totally unexpected ideas will occur to you.

Ex. 49. Wall. A firm at the Hannover industrial exhibition built an extremely interesting wall around its booth. You could say that this wall wore clothes but also wore nothing, just like the well-known fairy tale figure. The wall was there, but it was also not there. Precise advertizing and informative films were projected onto the wall, Take your time and think about this task! Use Meta-ARIZ. If you've already guessed my suggestion, try reinventing and work carefully through all of the stages of Meta-ARIZ.

This is really a problem: the wall is standing, but it also is not there. The clothes are worn, but the clothes are not worn. It is clear that compared to a pessimist, an optimist examines this problem from a totally different perspective, like the bottle that is 50% full. As we know, the optimist says that the bottle is half full while the pessimist considers it to be half empty, or perhaps even almost empty! Let's get closer to this problem: the fairy tale figure wore a dress from fish net but at the booth another solution was found. Was it a glass wall? No, that would still be a fixed and extremely traditional construction like a glass case in a store. We would now like to try to construct a wall that is not present!

Diagnostics. Let's formulate the useful primary function of the wall for the booth: separate the internal space from the external. The traditional auxiliary functions are a structural wall for the ceiling or roof, an optically transparent wall out of glass, or an opaque wall out of live or synthetic plants, etc. These are the usual ideas from brainstorming. The ideas you are about to read about could certainly originate in brainstorming. We want to try to find it by reinventing. Let's consider a *variable* wall as an auxiliary function that sometimes is present and sometimes not. People should be able to go through it just like a thin thicket of live plants. However, this could be rather uncomfortable, especially if you are at a business show and you're wearing a suit.

Reduction. Let's construct the physical contradiction by using „incompatible„ ideal functional properties: *the wall stands* so that visitors can only get through a special entrance to the booth and *the wall should not stand* so that everything at the booth can be seen, advertizing spots can be projected, and so that they can then quickly appear and just as quickly disappear.

Transformation. In section 12 *Navigators for Solutions to Physical Contradictions,* there are 4 fundamental navigators: separation of incompatible properties in space, time, structure, and material. Clearly all 4 aspects are at hand in our task - spatially the wall is present, then it's not there, temporally the wall appears only during working time, structurally the wall has a variable structure so that it doesn't negate both of the first aspects, and materially the wall consists of elements that are neither expensive nor complicated. In section 8.2. *Resources,* we find the recommendation that we should use primarily easily accessible and inexpensive resources. This is especially important for the selection of materials that should be readily available and not cost too much. Air and water are readily available at exhibits like at many other locations. Could we construct an inflatable wall? It wouldn't be completely transparent and the construction doesn't exactly seem easy. Water is still possible. At least two ideas seem immediately interesting: fountains and water falls that correspond to the contours of the booth. Here the idea of a water fall was aesthetically developed in an excellent way: thousands of thin water rays flowed along the contours of the booth with the exception of the entrance. They flowed without spraying and almost silently into a narrow groove in the floor. The advertisements on this moving wall were not very clear, but they were very effective because of their contrast as static images to the dynamic of the "projection" wall.

Verification. You could ask about the costs of the wall and about the particulars of the technical implementation. Inventive thinking was certainly needed here. Good ideas are worth the initial expense because they often then help to save a lot of money. Here is an example of this.

Ex. 50. Cooling tower. The thermal efficiency of modern steam cooling towers is between 25-40%. An increase in the efficiency of a cooling tower increases the effectiveness of the *entire power plant and reduces the environmental damage of emissions.* Towers were previously relatively inefficient because they developed internal whirl-pool zones that disrupted efficient flow. These zones have a diameter of up to 30% of the entire diameter of the tower and therefore disrupt the flow of the air to be cooled. This air is drawn into the tower by a compact strip of openings along the entire circle of the tower's base. Strong winds cause even greater jams in the tower when they blow strongly into the base, in opposition to what we would expect. How can we improve the function of the cooling tower? In the labs of the Institute for Thermal-Mass-Exchange at the Academy of Science in Minsk (Belarus), different aspects of the efficiency, security, and environmental impact of nuclear and thermal power plants were investigated. We would now like to examine the relatively recent solution from 1995 that led to a noticeable increase in the effectiveness of thermal power plants. A change in the processes of the cooling towers in which a new system was introduced that focuses on enhanced cooling of the turbine water lead to this increase.

Diagnostics. In traditional construction, whirl-pool zones inside the tower hinder the movement of cooling air that enters the tower though a compact strip of openings along the entire circle of its base (fig. 9.28). Strong winds cause even greater whirl-pools!

fig. 9.28. Normal cooling tower

Reduction. The *FIM* was formulated like this: the air in the tower *itself* creates a stabile, optimal cooling stream without turbulence in the entire space of the tower. Notice again that the focus of the *FIM* is on the *instrument, on the working organ of the tower – on the stream of air inside the tower!* TRIZ requires that this organ is defined precisely: the inductor-air moving in the tower cools the water and carries out the *MPF*, not the cooling tower.

Transformation. This time we'll look carefully at the entire A-table (appendix 4). It's relatively easy to do this. The following navigators could be associated with the goals set: 01, 04, 05, 07, 12, 14, 19, 21, 22, 24, 29, 34, 39, 40! Even though this seems to be a lot, it's possible that there are yet more related navigators. We continued to interpret and arrange the navigators according to the "proximity" to the *FIM*. Or course, experience is needed here. We found the following results:

1) We began in our ordering of the navigators with number 21: *transform damage into use*. The environment with strong winds and warm air that cools the water poorly has a negative influence on the tower's functions, but *this disadvantage could take care of "itself"*! It would be advantageous to use any *"low-cost, readily available" environmental resources that create their own stream of cooling air;*

2) Number 29 was selected as the second navigator - *self-servicing*: the stream of air should remove the "jams" itself, or even better, prevent them from occurring! It's not yet clear how we can do this, but we should not deviate from our *FIM;*

3) The next navigator that fits is number 04 *replacement the mechanical matter*: move from fixed to moveable fields, from temporally fixed to flexible ones, from unstructured fields to ones with a certain structure. *The field of the air needs to be made stronger so that it can prevent "jams";*

4) The next navigator is number 19 *transition into another dimension*: move from a linear movement to one along a surface or to a three dimensional one. If the linear stream of air from the bottom to the top cannot prevent whirl-pools, why don't we try to turn it into *a spiral* like a fan or a tornado? This is the key idea! A whirlpool is extremely stable in nature because it's twisted. *We need to create a twisted stream - a tornado - inside the tower!* But there's a minus factor in that we don't know what kind of giant fan with a diameter of many meters we would need? We need another technical solution..
5) Finally, we come to navigator 07 *dynamization*: *separate an object into parts that are moveable within each other.* Here we need to find a solution that *causes changes in the construction of the tower*. We need to turn the stream into a stable spiral.

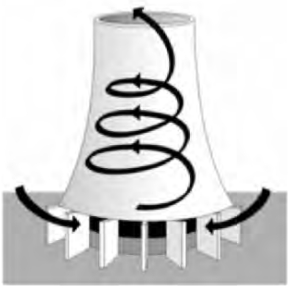


fig. 9.29. New cooling tower

To save time and space, we won't attempt an analysis of the other navigators here. For a specialist in thermal-mass-exchange with a specialty in gases, a technical construction solution would already be at this stage of the analysis a relatively easy task of professional technique: special air intake windows are installed in the intake section at the bottom of the tower that move on a vertically mounted axis so that they can be adjusted to an optimal intake angle (fig. 9.29).

Verification. A good solution mostly has a **super effect**: the intake of air from a greater distance and height from the base of the tower was increased. This eliminated even smaller whirl-pools at the intake of air into the tower!

Thanks to this construction, there is a stable spiral of air inside the tower even when the weather is still and there are no "jams". Strong winds only increase the efficiency of the tower's work!

With *minimal investment in the modernization of already extant towers,* the increase in thermal efficiency is 3-7% per year on the average. This is a considerable increase.

Let's quickly compare the solution navigators of these 5 examples:

- In example 46, the direct answer was clear almost immediately after the unification of inverse technical contradictions;
- In example 47, it was relatively difficult to arrive at the idea of underwater hydro-foils as an analogy to aircraft wings that use lift instead of aerodynamic powers after the construction of the general physical contradiction. The inventor needed a lot of fantasy free of sloppy thinking in addition to very good knowledge of physical-technical effects in aerodynamics and hydrodynamics. Normally, thought processes do not often associate real ships immediately with aircraft, even though it is interesting to note that in fairy tales flying ships often occur! However, this could also be seen as a result of sloppy thinking, as these tales arose at a time where ships existed, but before aircraft.

- The answer in example 48 occurs almost by itself in the analysis of the operative time in the reduction stage but only by means of an exact and attentive analysis just like TRIZ recommends. We needed to overcome a very strong stereotype to finally find an idea. This is the image of a house as a fixed object that is built permanently on a fixed foundation. Here we need as much fantasy as in example 47;
- With reinventing in example 49, many people guess the solution even before a thorough investigation of the problem step by step. This is the case because there is already a lot of metaphorical information for orientation in the assignment and in the description of the required properties of the wall. Despite this, a solution with the use of easily accessible resources is just as useful. Try to consider this problem without information for orientation and invent a new "wall" in a different way.
- The process for a solution in example 50 requires knowledge and considerable inventive power which is what the inventors had, too. The secret to this solution is the fact that the inventors had already done special research on atmospheric phenomena like tornadoes for many years. When specialists from the power plant industry turned to them to investigate "atmospheric phenomena" in power plant cooling towers, the researches applied their special knowledge directly and they created a tornado in the cooling towers!

We still have quick comment about example 50. This is simultaneously a simple and a complex solution. It seems simple because it was already present. This is why even very difficult tasks seem easy when they're solved. In addition, an assignment is no longer as interesting when you already know the answer from the start. I didn't relate the real story of the development of a complex invention so that you wouldn't groan and come to the conclusion that only highly specialized professionals have the capability to invent. Invent things yourself with TRIZ and you will achieve just as much! The combination of 4 navigators led you towards the solution, didn't it? Look at our reinventing again and you will see that this is the case.

It is clear that people who solve problems don't all have the same capabilities, motivation, and education. This is why the results and effectiveness of the synthesis of ideas are different. However, long experience with the teaching and application of TRIZ instruments has clearly shown that it is without a doubt useful for everyone who has learned it well. As opposed to all other techniques, TRIZ provides the possibility to *learn how to think inventively and to invent.*

TRIZ teaches you to constructively apply the experience of other inventors that has been accumulated in TRIZ instruments. Everything else depends on your motivation, capabilities, and knowledge. You can find useful recommendations about how to improve your personal chances to find solutions to problems in section 17. *Integration of TRIZ into professional activities.*

We should not forget one thing that is always part of the development of brilliant ideas. This is something that is not easy to perceive or put into words, something that is usually associated with chance, with the combination of conditions, with luck. And I hope you have lots of luck! This is exactly what makes the game with the unknown so interesting. It means you can discover something that *no one* *in the world knows except for you*! Prior to you, prior to your invention, this thing did not exist in the world! You brought it to life!

9.4 Classification of the A-Models of Transformations

The development of TRIZ led to the first **specialized transformations** for solutions to technical contradiction, the **specialized A-navigators**. At first this was a short list of 10-12 recommendations for the algorithm of inventing ARIZ-1961 that was similar to a preliminary list of control questions from brainstorming. In ARIZ-1971, this list was developed to a table consisting of 40 navigators. Special A-matrix was developed for the selection of navigators where the concepts represent 39 factors with either a positive or a negative value in the model of the contradiction. At the end of the 1980's, we restructured the A-table by ordering all of the navigators in the A-matrix according to their frequency of use and we restructured the A-matrix itself by ordering the concepts according to system and physical properties. In addition, a special method for the combination of navigators was formulated - the CICO method (see section 11.4).

In the middle of the 1970's, the first rules were formulated in TRIZ for solutions to physical contradictions as well as the first 18 models in which actors appear as physical and "technical" fields and material. These were then further developed for ARIZ-1977 into 77 **complex transformations** that were then called standards or **A-standards** in our version. At the end of the 1980's, an **Algorithm for the Selection of A-Standards** was worked out for TRIZ.

At the beginning of the 1980's, a complete table of fundamental transformations was developed for TRIZ (published in ARIZ 1985). We call these transformations fundamental because at least **one of them is present in every solution**.

Tables of basic transformations were compiled in the course of several years in classical TRIZ that are better known under the description **technical effects**. The models themselves are actually not intended to be direct solutions to contradictions. Instead, they represent a list of different physical, geometric, chemical, and other phenomena, the application of which led to interesting and important inventions. It is this character of the models, namely, that they are based on physical-technical effects, that explains why they are considered to be essential effects that provide principles to put technical ideas into praxis.

The use of the transformation models requires considerable experience and special capabilities. The necessary rules and examples can be found in the sections that follow in this textbook.

The selection of the model class for transformations (fig. 9.30) depends on the type of the model of the contradiction or the resources selected. However, this is generally not problematic.

The general rule of the transformation models that you should learn and remember is the fact that every one of these models is completely neutral towards the problem to be solved.

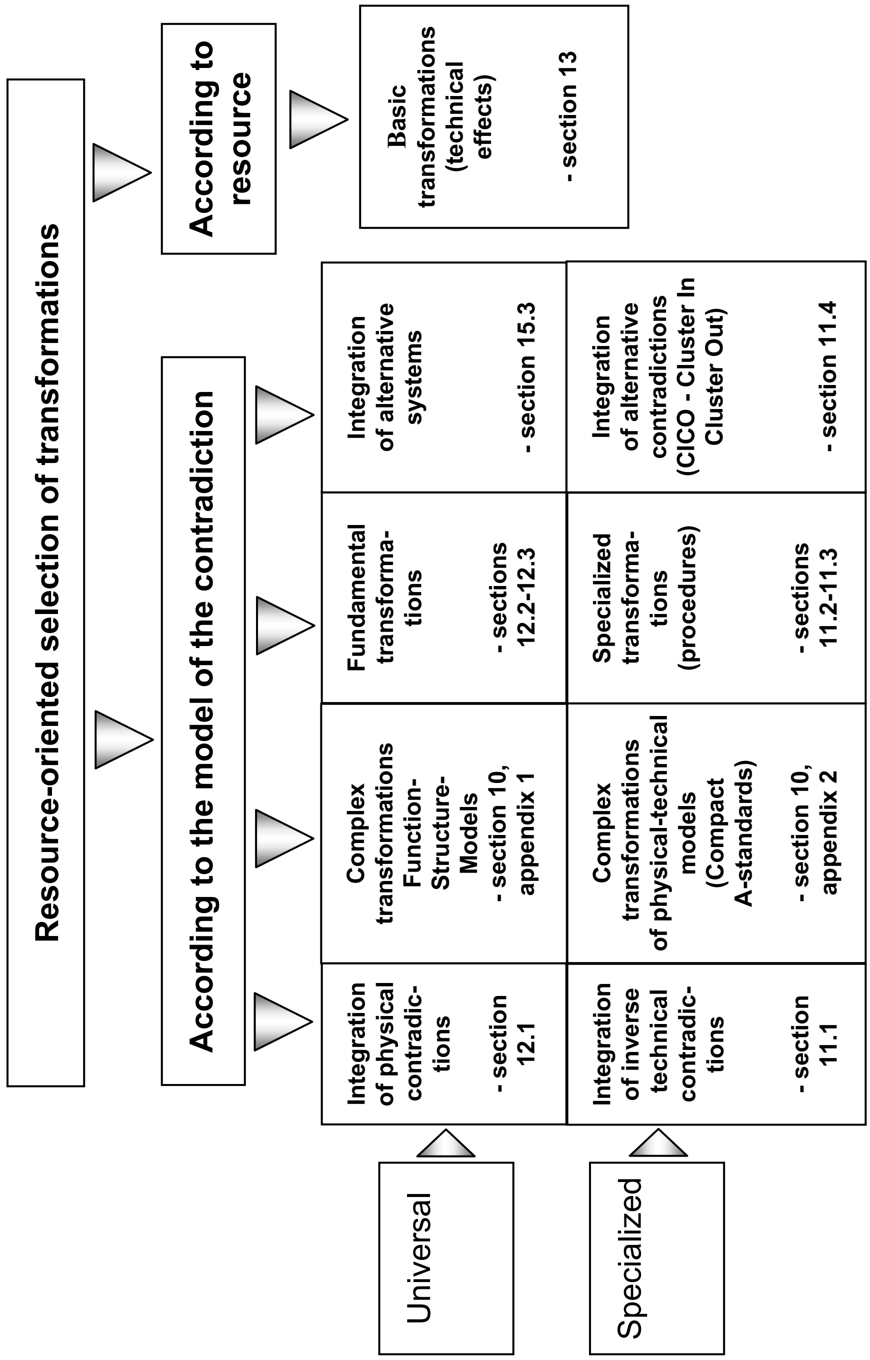


fig. 9.30. Classification of A-models of transformations

The transformation model you choose can only help if several conditions are fulfilled simultaneously:

1) You **understand the essence** of the changes that the transformation model foresees;
2) You **interpret this model** with parallel phenomena and analogies in accordance with your problem;
3) and the most important point is that **you complete changes and remove or resolve the problem by applying** the transformation recommended.

It is also a very important rule that the problem is solved only when the following requirement is completely fulfilled - the contradiction no longer exists!

Exercises 6 – 9

7. ***Ice cubes.*** Many types of refrigerators still have templates to make ice that aren't compatible with the ideal result that's then produced. Levers break the ice out of the template in such a fashion that the cubes are distorted. Use functional ideal modeling to create a template from which the ice can remove itself.

8. Aggressive liquid. To carry out tests of the effect of especially caustic liquids on metal cubes, the cubes are laid in a tray and then the liquid is poured over them. The tray is then often useless after a single experiment. Formulate the ideal final result and suggest a change in the experiment.

9. Candle shades. In many restaurants, long cylindrical candles are covered with shades so that the candle light doesn't shine directly in the eyes of the guests and staff. But, the light of the candle sinks under the shade when it burns down. What can be done to keep the light of the candle under the shade?

10. Stars on the Kremlin. Large stars are mounted on the Kremlin's high towers. Their diameter is more than 6 meters. How can the danger that they will be damaged by strong winds be reduced?

11. Teapot. When there's very little liquid left in a teapot, the tea leaves can easily spill out of the pot into a cup. Of course, tea bags or tea balls can be used, but this is not always possible, especially when several teas are combined into the mix desired. The teapot itself should prevent the tea leaves from spilling out with the remaining liquid.

12. Toy. Children grow, but their toys stay small. What would happen if some play things grew, too? Make suggestions about possible constructions.

13. Transition from the beach. To prevent the transfer of sand on shoes from the beach to nearby pedestrian zones, we can ... [continue this sentence].

14. Training for platform diving. Previously, divers suffered from abrasions or even more serious injuries in training when they had problems with their dive or with the landing in the water. How can we reduce the danger of injury while diving?

15. Subway trains. At night, on Saturday, and on Sunday all subway schedules foresee that trains run with fewer cars. This can be uncomfortable for the passengers. Which additional economy measure is used in these time intervals? Could this method become the main measure instead of changes in train schedules?

16. Guy de Maupassant and Gustave Eiffel's tower. It is well known that Maupassant opposed the use of the Eiffel Tower after the World's Fair in 1889 in Paris. He signed a public letter along with other important personalities that expressed the opinion that the tower would damage the sky line of Paris indefinitely. It would be visible from all possible perspectives in the city and would therefore rob the inhabitants and visitors to the city of the pleasure of the traditional city silhouette. Today, the Eiffel Tower is one of the symbols of Paris. A journalist who knew of Maupassant's viewpoint regarding the tower was once very surprised to meet him in the tower's restaurant. How did the writer explain to the journalist his frequent visits to this restaurant?

17. Direction in which a liquid moves in a pipe. Let's return to example 35. Imagine that the ice plug has to be installed on the side from which water flows. We don't know which direction this is. We have to determine the correct direction quickly because it's an emergency!

18. Display cases in a shoe store. Shoes are usually stored in shoe stores in cases with boxes of different shoes. How could we install cases along the display sections to show the different kinds of shoes offered when the number of types and styles changes often?

Classical Navigators of Inventing in the A-Studio

Most often inventors use two or three procedures that they command well. Inventors who work methodically use five to seven.

TRIZ increases the available creative tool-box with dozens of procedures that, taken as a whole, offer a rational scheme for solutions to problems.

But, a targeted search in no way excludes intuition. Quite the contrary: orderly thinking creates an atmosphere that stimulates moments of intuition.

Genrich Altschuller

10 Navigators for Standard Solutions

10.1 Tables of Complex Transformations

The tables "Function-Structural Models" (appendix 1) and "Compact A-Standards" (appendix 2) were included in the tables of complex transformations for teaching purposes. The recommendations in these tables are in very general form and therefore allow for different interpretations and concrete applications. This means that an idea for a solution can deal with several resources or it can be a combination (a complex) of several transformations, for example, consisting of specialized A-navigators or physical technical effects. This special property also led to the term "complex transformations".

The table "Function-Structural Models" is designed to produce a *general solution* in 6 kinds of system conflicts that can be reduced to structural models that can then be represented in the table. *Solutions in a general form* that are provided for two model groups with up to 3 models per group respectively focus primarily on the search for more economical solutions in accordance with the strategy *Minimum Assignment* (see section 14.1 *Development of Systems*). These models and the principles for solutions that they apply occur quite often. This is why they were called "standard models" in TRIZ.

The table "Compact A-Standards" contains more comprehensive recommendations to implement standard transformations from the table "Function-Structural Models". These recommendations (altogether 35) were divided into 5 groups that reflect the mail contents of the transformations. Essentially, the table "Compact A-Standards" represents an adapted TRIZ-table of "standards" that contains 77 standard transformations. The adaptation was run to prevent too much information from appearing in the original complete table. The compact table is much simpler, at least for your first familiarization with the standard models.

The general scheme for the application of complex models is as follows:

1. a function-structural model of the conflict is constructed in the operative zone in the *diagnostics* or the *reduction* stage;
2. if the form of the function-structural model corresponds to one of the types in the table, we can move to the *transformation* stage to find a concrete solution based on a general solution that is selected from this table;
3. more specific recommendations can now be selected from the table "Compact A-Standards" that correspond to the direction selected for the search for a solution;
4. if it is difficult to select recommendations that fit perfectly while considering the special properties of the concrete task at hand or these recommendations are difficult to interpret, it is necessary to move to other models, for example, based on contradictions.

We can now examine a few practical teaching examples while keeping the rule of this textbook in mind: from the simple to the complex. Our goal is to demonstrate the necessary methodological steps in working with the tables and other models. There are a few technical details that cannot be shown in a textbook like this one because we simply don't have enough room. This is precisely why we use the practical main operations to investigate the examples. Accordingly, the sections with descriptions of examples are characterized here as "application principles" for solution models.

10.2 Application Principles for Complex Transformations

Ex. 51. Barbell discs. Noise results when barbells are dropped to the floor in a gym and it's not very good for the floor, either. Let's construct the functional-structural model of this problem situation (fig.10.1).

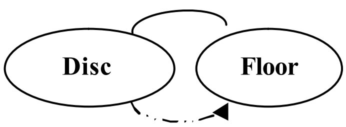


fig. 10.1

The floor effects the discs positively by stopping their movement. But, the discs influence the floor negatively as described above. We use the "Functional-Structural Models" table (appendix 1) to select the first model where the discs correspond to component **B** and the floor to component **A**.

These are recommendations from the outer right column and their interpretation:

- *replace or change the material of one or both components*: manufacture the disc out of a softer material (but then it will be to large for a weight like a steel disc); make the floor out of a harder or sound-deadening material (expensive!);
- *add a supplement to the components or to their environment or its surface*: attach a thick rubber ring around the discs (control solution 1); lay a thick rubber mat on the floor (control solution 2);

- *change the character of the action*: lower the barbell slowly. This has a negative effect on training although special technical solutions can be constructed that don't limit the athletes' freedom of movement.

Ex. 52. Connectors made for conductor units. Gold contacts in the connectors of certain conductor units have very good (minimum) contact resistance. But, they wear quickly because gold is a relatively soft metal. This results in an increase in contact resistance until it's no longer acceptable. Then either the connector or the entire unit has to be replaced.

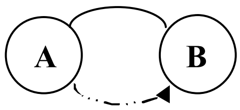


fig. 10.2

The scheme that represents this problem also applies to the male and female parts of connectors (fig. 10.2). This means that here the parts **A** and **B** have the same value. The scheme corresponds to the second model from the "Functional-Structural Models" table.

The recommendations from the outer right column are analogous, although their interpretation requires knowledge of physical-chemical processes in pairs of contacts and is therefore understandable to specialists:

- *replace or change the material of one or both components*: we can't do this because of the general conditions of the connections' use;
- *add a supplement to the components or their environment or its surface*: studies have shown that the addition of small amounts of diamond to the gold increases the contact resistance by 5-10% and the life of the contact by 300-500%;
- *change the character of the action*: don't close contacts. Instead, you just push on the female part so that no wear occurs. This has no effect in devices that are installed in moveable systems that work with vibrations and striking movements.

Ex. 53. Copper conductors on microchips. In 1997, IBM announced that it's possible to replace aluminum conductors in micro-schemes with copper. Copper is a better conductor and connections can therefore be constructed out of copper that are only 0.2 micrometers wide to replace aluminum connections that are 0.35 micrometers wide. Essentially, we can return to the previous model for this example, although we'd like to investigate a more comprehensive model (fig.10.3). The room saved makes it possible to place three times more electronic components on a chip, to increase work speeds, and to reduce energy use.

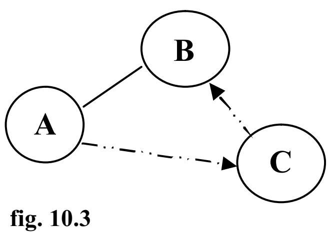


fig. 10.3

But, the copper atoms blend into the silicon base and disrupt the functions of the scheme by changing its properties.

The copper conductors **A** improve the functional performance of the entire system **B** but slowly influence the properties of the silicon base **C** in such a way that the entire scheme **B** gets worse.

Structure 5 from the "Functional-Structural Models" table is closest to this example. Again, an interpretation of the recommendations from the outer right column requires knowledge of physical-chemical processes in semi-conductor materials.

But, the mechanism for a solution to this problem is universal and does not depend on any "specific origin" of the assignment. The most important aspect is the similarity of the models - the real model and the standard model from the table. This is precisely what we want to show in these examples.

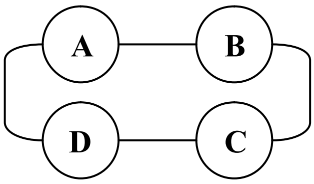


fig. 10.4

This is why we suggest *that we change the composition by introducing a mediator*. A layer of isolation can be installed between the silicon and the copper conductor where IBM controls all knowledge about the layer's composition. It's useful to record the models that result. The model for this example can be found in fig.10.4 (**D** – mediator, layer between). Lines without arrows show neutral interaction.

Ex. 54. Granulate to remove oil. Well-known porous floating granulates can soak up oil well. This kind of granulate can be spread on the surface of an oil slick from a tanker accident. But, the granulate can be carried away by wind and wave action.

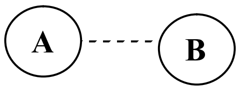


fig. 10.5

It's clear that this problem is about model 5 - ineffective or missing effect (fig. 10.5). Let's imagine the ideal final result: the grains of granulate **A** and **B** "hold onto each other" so that they are not carried away by the water.

It's possible that there is a combination of two standard solutions for this problem: S1 (Addition of supplements) and S2 (Increase in controllability) – Create the action needed by using additional fields. If we look at two compact standards, we come quickly to a control solution: magnetic particles are added to the granulate so that the grains attract each other strongly. There's also a positive super effect: this kind of granulate helps contain the oil slick on a relatively small surface without spreading.

Ex. 55. "Armored" bottle. Glass bottles have no negative influence on the liquids stored in them. They can be recycled indefinitely. But, they are heavy and they can be broken.

A truly complete model of the properties of a glass bottle **A** (fig. 10.6) includes the positive effect on the liquid stored **B** and the potentially negative effect on a possible transport system **C** due to its relatively high weight and on the environment **D** if the bottle breaks.

Competing plastic bottles can have a negative influence on the liquid stored in them over time. They can influence the smell of stored water, for example.

Their low weight and unbreakability is their advantage. They cannot be reused to the degree that glass bottles can be. We can construct the following model for this system (fig. 10.7) that represents an *alternative system to the glass bottle in all parameters*.

With the glass bottle we have a system that has developed through the addition of a supplementary function - increase in hardness with simultaneously reduced weight.

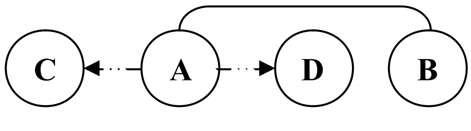


fig. 10.6

This contains an extremely strong classical contradiction. A harder bottle needs thicker walls that then increase weight. Standard S4.3 - *Increase the functional load on the system and its parts* fits this problem in form.

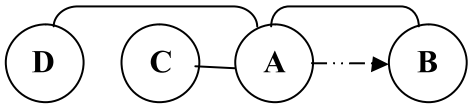


fig. 10.7

A plastic bottle is well suited to this standard as well as the recommendation to introduce supplements. For example, something could be added to the inner surface of the bottle so that it no longer comes into direct contact with the stored liquid.

Standard S4.1 *Combination of a system with another system into a more complex double or poly-system* fits both systems. This kind of combination is especially useful for alternative systems like the one we have here (for details, see section 15.3 *Integration of alternative systems*).

Such a system was developed in Düsseldorf. A glass bottle was treated with "armor" consisting of a transparent polyurethane film only 0.1 mm thick. The thickness of the glass was reduced by 1.4 mm with the same hardness. A 6-pack of 1 liter bottles weighs 3.5 kg less than with normal glass bottles! A 0.33 liter bottle weighs half as much as its glass prototype. Even when a bottle is broken, the plastic envelope prevents the shards from flying in all directions. The bottle can be reused 70 times and then remelted.

Ex. 56. Razorblade by Gillette. Razor blades have undergone long development. But this development is by no means finished! More that it is so prestigious and useful to introduce something new into the "old" systems. What could we think of next for the holder of the razor blade? The structural model is not very informative here (fig. 10.8). Several movements have to be made to get a clean shave. This increases the time needed. This is why we can represent the arrow here as an interrupted line, as an ineffective action.

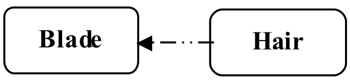


fig. 10.8

A beard influences the blade negatively in that it slowly makes the blade dull and therefore reduces the effectiveness of the primary function. This is a combination of models 1 and 6.

Generally we can speak of an increase in the functional load on the edge of the blade. In this case, we should begin with an interpretation of the standard S4, for example, with the recommendation to create double or poly-systems. This is precisely what Gillette did: the new razor has three blades mounted in parallel at optimal distance from each other. The razor shaves up to 3 times more beard with its

3 levels in one stroke. A super-effect is fewer strokes and less time needed to shave and longer life for the razor. Of course, this example should be investigated again regarding the influence of the elasticity of hair at various distances from the pores on the success of shaving with one, two, or three blades.

Ex. 57. Stadium "France". The seats of track and soccer stadium "France" in San Denie (suburb north of Paris) are protected with a roof shaped like a horizontal disc with an opening in the center (fig. 10.9). The disc hangs on lines from 18 steel poles at a height of 50 meters. Measures had to be taken in planning that prevent too much noise that then disturbs the inhabitants of the nearby neighborhoods. The model of the functional interaction of the components looks like this (fig. 10.10).

fig. 10.9

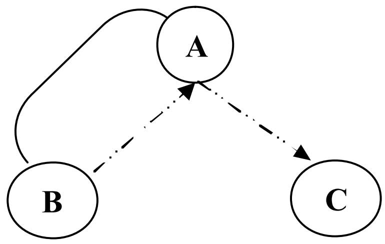


fig. 10.10

The roof **A** protects the public **B** from bad weather and too much sun, although it reflects noise out of the stadium and spreads it to the neighboring suburbs **C**. Reinventing shows that the model of figure 10.10 consists of models 1 and 5. Therefore we can start with standard S1, for example, add supplements S1.2 and S1.5. The control solution was to use synthetic insulation on the inner surface of the disc to absorb noise.

Ex. 58. Concrete constructions. Here we would like to investigate different inventions that are based on different procedures to introduce "supplements". These supplements have nothing common. This shows the universal character of TRIZ and the possibility of its wide use in almost every area. TRIZ models are models for thinking, concretely for inventive thinking, but not models for special professional knowledge or for processes with special industrial techniques. TRIZ models have interdisciplinary character. They were derived from inventions and support the creation of new inventions. The useful models serve for continuous use by engineers in project planning or administration.

The relationship of the four inventions and their combinations to each other can be easier understood in (fig. 10.11). This or that recommendation from all five compact standards can be found in these examples.

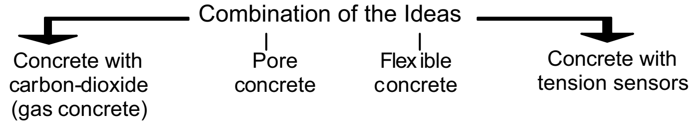


fig. 10.11. Scheme of the connection of technical solutions for this teaching example

Concrete with carbon-dioxide. Concrete supports for Japanese high-speed trains last only about three years and must then be replaced. Clearly the increased life of these parts would have a considerable economic effect. With time, the hardness of concrete increases under natural conditions as a reaction to the carbon-dioxide that is present in the air. A result of this reaction is that the concrete turns into limestone. However, this process takes a few thousand years! The concrete in the supports has very small pores. The increase in hardness comes very slowly because the initial reaction with carbon-dioxide produces water that fills the pores and then prevents more gas from entering the concrete. To accelerate this process, these parts were treated in pressure chambers. But, this procedure was not effective.

In 1994, the American engineer R. Jones discovered a procedure to harden concrete with the help of so-called hyper-critical carbon-dioxide that occurs at a pressure of more that 73 atmospheres and at a temperature of more than 31°C. *Under these circumstances, carbon-dioxide becomes a liquid* that then has the ability to easily enter materials and soak on object completely. A few minutes with this procedure achieved as much as nature in a few thousand years!

This kind of concrete is twice as hard as normal concrete. Two super-effects have been discovered in this new procedure. First, the new procedure prevents steel parts in the concrete shapes from rusting. This often helps keep concrete constructions hard. Second, there is a remarkable ecological effect in the truest sense of the concept that damage can be turned into advantages (see fig. 6.8 with recommendations for the selection of resources). The cement in concrete is manufactured from limestone or marl by burning this stone in cement ovens. This produces large amounts of carbon monoxides from burned lime and from the heating materials used. The new process to harden the concrete consumes large amounts of carbon dioxide and compensates to a large degree for these damages to the environment.

Reinventing shows which standard recommendations are at hand here and how they work:

S1.4 – *the supplementary material can be a derivative of material already present in the system*: the carbon-dioxide used earlier is changed;

S1.8 – *normal supplements are added, but in concentrated form*: the change was caused by a considerable increase in the concentration of a normal supplement;

S1.11 – *the material is derived by changing the aggregate state of a part of the object or of the environment*: the increase in concentration was achieved by changing the aggregate state of the supplement used: carbon-dioxide was changed into a liquid state;

S2.1 – *transform a part of the object into a controllable system*: hyper-critical carbon-dioxide has much more controllable properties than in gas form;

S2.4 – use of a *phase transition of a material*;

S4.2 – *acceleration of the development of relationships between system parts*: increase in the intensity of the influence of carbon-dioxide on concrete.

The goal of this example is to give you the chance to follow the construction of ideas for a solution and to understand the principle with which you can also examine effective standard recommendations and apply them to your own tasks in your field. Here it's extremely important that the selection of recommendations is made on the basis of the contents of the problem, not by constantly leafing through the standards, although this is also possible in extreme cases. In any case, it is useful to follow the following advice: the recommendations should be examined with enough time to understand and interpret them according to the conditions of the task to be solved.

Pore concrete. So-called pore concrete with pores with a diameter up to 3 mm is used widely in construction. The pores make up to 90% of the material. Pore concrete has many advantages: low weight and excellent heat insulation properties and at the same time water vapor and air porosity similar to wood constructions. This concrete is not flammable, not toxic, nails can be driven in it easily, it can be easily sawed, and it's easy to drill holes in it. But, expensive equipment (such as pressure containers, foam generators, and grinding aggregates) is needed to produce this kind of concrete. In addition, the size of the pores is variable and they are irregularly distributed in the concrete.

In the Institute for Concrete and Steel-Concrete in Moscow, a technique was developed based on special chemical supplements that create pores with a certain size that are evenly distributed in the material. The equipment mentioned above is then not needed for production.

For teaching purposes, it's sufficient to define which standards are present in this invention. Above all else, we should note that adding more pores to the material corresponds to putting standard S1.5 into praxis. Additionally, standard S1.10 plays a key role here – *the material that makes pores is added in a chemical bond from which it is removed at a certain time.* However, it's just as important to keep standard S5.3 in mind – *use of the possibility to implement functions at a micro-level (at the level of material and/or fields)*. This is an example of a considerable reduction of a system because expensive, energy intensive, and ineffective equipment was made unnecessary!

Flexible concrete. The same institute in Moscow developed a technique to produce steel concrete as flexible shapes! They are useful to assemble irregular outer surfaces such as outer walls. This allows the installation of a layer of thermal and humidity isolation between the inner wall and outer flexible surface.

Normal steel-concrete walls are not flexible because a hard metal inlay is used for its steel core. The goal of this kind of assignment is de facto to increase the functional possibilities of the object (further development according to standard S4.3), to use the possibility to distribute incompatible properties between the entire system with its flexibility and a part of the system (the outer surface of the product) with the opposite property hardness (reduction according to standard S5.2), and the transformation of a part of the object (material) into a controllable system - use of special inlays and of a special manufacturing process (raise the controllability according to standard S2.1).

fig. 10.12

The flexibility of the shapes (fig. 10.12) is made possible by using *pre-stretched hardened steel cables* as an inlay. The manufacturing process includes a thicker mixture and special thermal moisturizing.

As a result of the new technique, light and strong shapes can be constructed with a thickness of 3 – 6 cm, a width of up to 3 m, and a length of 12, 18, and 24 meters!

Concrete with tension sensors. Special examples of steel-concrete products are developed to test construction products. A network of tensometric sensors is added along with metal inlays to concrete mixtures to measure the inner tension of a construction. This is clear use of standard S3.4 – *introduction of supplements into already extant material including the environment or/and onto the surface of the object to create easily measurable fields to assess the state of the object under observation.* This kind of solution could also be used in actual construction projects in the walls and foundations of buildings where very precise products are manufactured, in buildings in seismically threatened areas, bridges, sky scrapers, and telecommunication towers in order to continuously observe deformations.

Combination of ideas. Good solutions usually set off a whole series of new ideas (see also section 17.2 *Development of a Solution*). For example, the following suggestions were made for the further development of processing with liquid carbon-dioxide.

Paint doesn't flow easily into the pores of dense concrete and it therefore cannot easily prevent moisture from penetrating. But, when colored elements are treated during the manufacture of construction parts with liquid carbon-dioxide, the liquid closes the outer pores and penetrates deep under the outer surface. The last result has yet another super-effect: the life of the color is increased. Here we find the standards S1.1, S1.2, S1.8, S2.1, S4.1, and S5.3. Examine them together in reference to this example. These standards function in the following example, too: introduce materials such as polymers into concrete using liquid carbon-dioxide that dissolves the materials well. The result is flexible properties for the concrete that can be useful for flexible upper layers in road construction. Liquid carbon-dioxide is relatively stable and can also be used to treat the outer surface of constructions that already exist. This is how it's possible to apply quality colors to larger flexible concrete shapes to make constructions more resistant to acid rain and natural atmospheric phenomena.

In conclusion, we can summarize as follows. Regardless of the apparent simplicity and perhaps even partial triviality of the recommendations that the formulations in the standards contain, we should keep in mind that they are all models of great inventions and that their selection for concrete application has a strong influence without making more complex models necessary. Even better results can be attained when standards are used together with the laws and directions of system development. And finally, these models don't replace professional knowledge. Instead, they help structure the problem situation and suggest directions for solutions.

11 Navigators for Solution to Technical Contradictions

11.1 Integration of Inverse Technical Contradictions

It often happens in certain situations that the formulation of the contradiction already directly predicts the idea of a solution. But, engineers who are not familiar with TRIZ don't use contradiction models like TRIZ recommends and they therefore have no possibility to quickly find simple and effective solutions to many standard problems. On the other hand, systematic use of TRIZ models ensures goal-oriented and disciplined action for solutions to problems and helps develop the capability to quickly recognize real possibilities or limitations when generating a solution.

Simple examples can be used to demonstrate that without TRIZ modeling, their solutions would take considerable time or would be purely coincidental. Situations belong to these examples in which examination of the inverse contradiction predicts an idea for a solution almost directly. This is especially the case for those models that show inverse behavior from the completion of the primary operation towards the achievement of the useful main function of the object.

The author of this textbook formulated the *"Methods for the Integration of inverse Contradiction"* in 1987 based on similar examples. The essence of this method is as follows:

- construct a direct and inverse contradiction;
- construct an integrated model that contains only the positive properties (plus-factors) from alternative descriptions of the functional actions of the actors and from models inverse towards each other.

Look again at the contradictions in section 9.1, contradictions like in fig. 9.1 *Generalized graphic form for the representation of binary contradictions*.

Ex. 59. Grape vines (solution using the integration of inverse technical contradictions). In this example, we have the extremely interesting possibility of already solving the task in the construction of contradiction models in the *reduction* stage. Let's examine this possibility by setting the inverse contradictions (fig. 11.1).

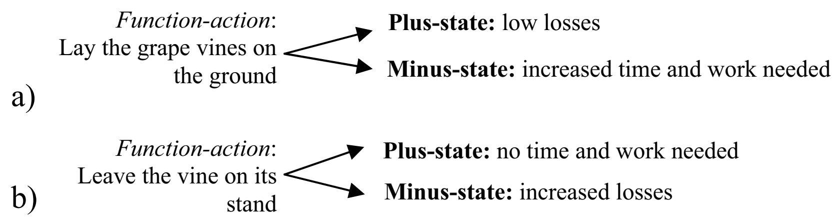


fig. 11.1. Binary models for example 6: a) "direct"; b) "inverse".

To come to the decisive model with a direct prediction of a solution, we only need to combine the inverse functions and actions and the plus-factors from models 11.1a and 11.1b: “Lay the vine on the ground” *and* “Leave the vine on its stand”. The result “slight losses” *and* “no loss of time and work” results in low work effort to lay the vines on the ground. *To lay the grape vines on the ground* is a necessary function so the goal could be just to reduce the work effort of this operation. This is why this construction was also made *dynamic.* Please note that the problem of the main action was also solved using the inverse model – *leave the grape vines on their stands, but lay the stands on the ground!*

Ex. 60. Heating silicon plates. In one of several operations, silicon plates were heated with a thermal lamp installed as strip above the plates. A finely wound spring functioned as a heating element in the strip. But, the middle of the spring reached a higher temperature than the edges. These heat variations caused the plate to deform. How was the system subsequently improved?

Let’s assume that the *diagnostics* stage is described in the assignment. The drawing (fig. 11.2.) complements the primary information. While we move to the *reduction* stage, we can construct models of the contradiction.

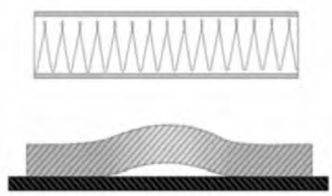


fig. 11.2. Heating and deformation of silicon plates

The technical contradiction is that a normal thermal field (the spring of the inductor) heats the entire plate (the receptor), but overheats its center. The inverse contradiction is that a weak thermal field (spring) doesn’t overheat the center of the plate, but it also doesn’t heat the edges sufficiently. It seems that TRIZ dictates that the inductor should be changed and that we need an exact description of alternative processes.

This leads to the idea that the *method of the integration of inverse contradictions* could be used for a solution here. When we move to the *transformation* stage, we can construct an integrated model by taking the best aspects of both contradictions: *a normal thermal field heats the edges of the plate well, a weak field heats its center well.* Doesn’t it also seem to you that a relatively easy creative step is all we have to take after we think about this description? We can widen the steps of the spring in the center so that the thermal field gets weaker at that point! Make an exact drawing!

As a contra example, we can turn to the fact that the integration of technical contradictions didn’t result in the effect desired in example 13 and in other similar problems. It’s almost impossible to predict an idea for a solution because alternative actions have no clear functional description (fig. 11.3) and they don’t clearly show how the shards can be removed (or not removed!). We see a simple negation of the main action.

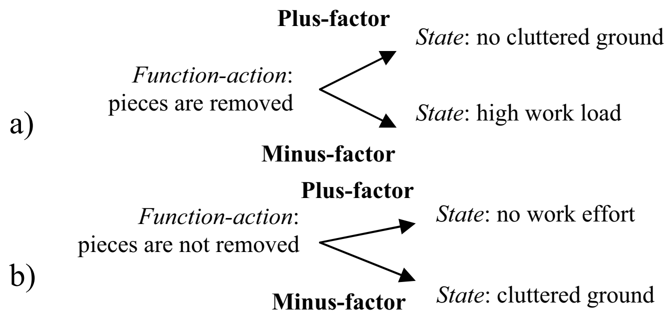


fig. 11.3. Binary model for example 13: a) “direct”; b) “inverse”.

11.2 A-Table and A-Matrix of Specialized Transformations

The “procedures” belong to the best known and also surely the most popular of the TRIZ instruments. The examples we’ve already examined have surely provided you with a certain image of these instruments. We would now like to firm up the ground rules and make some special aspects of the application of the procedures more concrete. Of course, not all tasks solve themselves in the *diagnostics* or *reduction* stages like in the previous section 11.1. This is where we begin our search for a procedure that resolves or removes the system contradictions that ensue, or more precisely - *to remove the conditions that cause the contradiction.*

This is no longer a “single” chain of logical operations. Now we have to search. Is it possible to speak of a scientific method in such a case? Yes, certainly.

First, the models guide our search closely. The specialist looks for a procedure to change the *concrete conditions* that have caused the system contradiction instead of searching for any kind of idea “insight”. The specialist knows what is needed and therefore searches only for things that help achieve this goal. Models for the solution desired are procedures that are known in technology but have not yet been used for the task or in the field at hand. There is no magic formula, but there are procedures that are sufficient for most cases.

Second, the search runs according to a ***rational scheme,*** essentially according to the Meta- or Mini-ARIZ. Each technical assignment is unique in its own way, each task has something that will never be repeated. Our analysis makes it possible to get to the hear of the matter – *to the contradiction and its causes.* Then the situation changes immediately.

We can repeat again one of the most important discoveries of Genrikh Altshuller in his own words:

1. **There is an infinite number of tasks for inventing, but relatively few *types of system contradictions*.**
2. **There are *typical system contradictions* and there are *typical procedures* to resolve / remove them.**

But, this discovery was first put into praxis in 1971 in Altshuller's *A-matrix for the selection of specialized A-navigators* (appendix 3). In *Algorithm of Inventing* in 1961, the contradictions had not yet been categorized into types and the algorithm was just a *list of navigators* that was similar to a set of control questions from brainstorming! This list grew to 40 navigators by 1971 (appendix 4 *Table of specialized A-navigators*)!

In 1961, ARIZ recommended that we consider all navigators that had been collected to that point for "simple" navigators often used in real inventions to and including "complicated" ones that scarcely occur in praxis. In this book, we've ordered the navigators in the tables according to the frequency of their application in the A-matrix! The most frequent procedure is number 01, then 02, etc. Certainly this also corresponds to the frequency of application in reality. The table shows more than 100 constructive recommendations including sub-navigators. Of course, experience is needed for their selection.

This is why the A-matrix became an extremely useful instrument for the selection of navigators, especially for those who are just starting to learn about TRIZ. The matrix function is a navigation for a transition from contradictions to navigators for their solution in the *transformation* stage.

The transition occurs like this:

1) use the conditions of the problem situation to construct a technical contradiction;
2) select the plus-factor for the positive property of the contradiction from the A-matrix that corresponds best with the physical-technical content of this property;
3) select the minus-factor from the A-matrix like in point 2;
4) note the numbers of the navigators in the A-table from the box where the line with the plus-factor and the column with the minus-factor meet;
5) consider the chance to interpret the navigators from the A-table in accordance with the conditions of the task at hand in order to remove the respective contradiction.

Comment about point 1: The attempt to use the descriptions of initial steps into the A-matrix for a preliminary definition of conflict factors in the contradiction model can result in inappropriate models because their physical contents can then be distorted.

Comment about points 2 and 3: When several plus- and minus-factors are present as steps into the A-matrix that are close to the positive and negative factors in the model of the technical contradiction, it is useful to use these factors to select additional navigators from the A-table, too. The method for the integration of alternative technical contradictions "CICO" can also be used in such a case (section 9.4).

It makes sense to mention for qualified professionals who constantly work with resources that the steps into the A-matrix were restructured in two groups by the author: system-technical factors from 01 to 14 and physical-technical factors from 15 to 39.

11.3 Application Principles for specialized A-Navigators

We need to stress that the navigators to resolve contradictions [2] are formulated generally. They are similar to a candy costume: they must be made to fit the individual requirements of a task. And now we turn to the special aspects of the use of A-navigators – from the "simple" to the more complex and to groups of navigators.

Ex. 61. Extinguishing fires at oil and gas drilling sites. A fire at oil or gas sites is a tremendous environmental catastrophe. It is extremely difficult to extinguish this kind of fire. Tanks fire at the opening of the well and bombs are dropped to extinguish the fire by covering the well with earth. It's impossible to use other techniques to approach the well because the entire area for several dozen meters around is heated to temperatures of several hundred degrees. There have been cases where this kind of fire lasted for months or even longer. Hundreds of thousands of tons of material are burned and the environmental damage is considerable. The ground and water around the well are then contaminated with oil products.

Let's construct the initial technical contradiction. We need to move technology close to the well in order to stop the flow of oil, but the fire prohibits this. A reduced model is plus-factor 10 *ease of use* and minus-factor 13 *external damaging factors*. These are our navigators and their interpretation:

04 *replacement of mechanical matter* – here we at least have the association that it's necessary to find a new working principle. This is a change in the structure and dynamics of the forces and fields, i.e., a new principle to prohibit, to stop the fire (let's not use the term "extinguish the fire");

05 *separation* – separate oxygen (air), oil, or gas from the fire zone, prevent these materials from approaching the fire zone;

23 *use of inert media* – the problem dictates that this would be the use of a foam generator to prevent oxygen from getting to the fire zone. This technique has proven ineffective;

29 *self-servicing* – An ideal model would be that *the well itself prevents oil or gas from reaching the surface during a fire*!

The last suggestion looks like the best one. How can this be done? Incidentally, together with navigator 05 we can formulate the idea to bore an additional auxiliary well at a slant that meets the shaft of the burning well at a sufficiently safe depth.

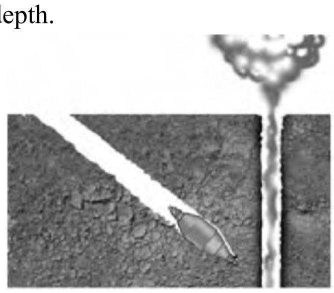


fig. 11.4. Underground vehicle drills to the shaft of the burning well

Then explosives and other solutions could be brought into the burning well through this auxiliary shaft in order to close it with a kind of "plug" at a safe depth.

For our control solution (fig. 11.4), a method was developed in Russia where a special "underground vehicle" moves to the shaft of the burning well at an angle from a safe distance.

The vehicle can work like an underground bulldozer at that point where it meets the shaft of the well to slowly close it completely with stone or earth.

We should also note that navigator 29 also plays an important role in this control solution because the "underground vehicle" uses *self-guiding system* by orienting itself on signals that were previously installed in the auxiliary shaft.

Doesn't this solution remind you of the utopic work of Jules Verne called "Journey to the Center of the Earth"? The idea introduced here is just one of several developed in the 1920's for underground vehicles to lay pipes and cables, tunnels and shafts to explore for raw materials and mine gold and diamonds.

Ex. 62. Jeans as ... fertilizer. In El Paso, TX, factories process jeans by washing them in hot water with stones. This treatment is ordered by known jeans manufacturers, such as Levy Strauss. Jeans are also processed with sand blasting machines. A result of this processing is cotton waste. One factory alone processes 300 thousand jeans per week and produces 50 cubic meters of cotton waste. Let's reduce the initial contradiction to standard descriptions for steps into the A-matrix: *productivity* as a plus-factor and *internal damaging factors* as a minus-factor. At the point where the first line and the 14^{th} column meet, we find a box with the navigator 01 *change in the aggregate state*, 06 *use of mechanical oscillations*, 21 *transform damage into use,* and 23 *use of inert media*. Of course, navigator 21 is especially interesting here: use damaging factors to achieve a positive effect. The control solution is to apply the cotton waste as fertilizer to plowed fields. The *verification* showed that the grass harvest increased by several factors and the fertility of cotton and wheat seeds increased by 60%. Texas is a dry state and the cotton waste can store water 4 times better than the untreated ground.

Ex. 63. Something new is often what's been forgotten! Here we would like to reinvent again while we also suggest new ideas. One of the most serious problems on the streets is that often there's too little information about the condition of the roads traveled. This information is sometimes partially available on the radio, for example about traffic jams. This applies to highways and larger roads and the information is usually insufficient. Sometimes it's important to receive operative information that a driver could pass on to vehicles behind. This could be reports about speed limits due to construction that didn't previously exist in a certain area, unexpected problems - cyclists or pedestrians, sudden road damage or icy patches, etc. This kind of information would be especially useful when sight is limited, such as at night. Information about technical or medical help or warnings, about children on board of a vehicle would be just as useful. It's also clear that the higher the speed, the more important punctual information is.

This last observation could be understood as an initial technical contradiction that we can then reduce as follows: 22 *speed* as a plus-factor and 12 *loss of information* as a minus-factor. The recommended navigators are 10 and 11. We can now construct a general portrait of the idea for a solution.

10.a: *use a copy of an unavailable object instead of the object itself* – The report about a hindrance is precisely the information that copies the object that cannot be directly observed by the vehicles that follow;

10.b: *replace an object or a system of objects with their optical copies* – for example, replace the object with signs or words that are transmitted back to the vehicles that follow;

11: *make a fixed part of an object moveable* – A device could be mounted in the operative zone on the trunk of the vehicle ahead that uses an optical navigator to transmit information to the following vehicles.

At the end of the 1980's, Ford already tested a display on an Aerostar that was mounted above the rear bumper. This kind of display with moving lines of print is often used in subways, in train stations, and for advertizing. Control is maintained using function keys that transmit short standard messages to the display. One of the problems with such a navigator is the uncomfortable selection and use of the keys. We can return to an "old" idea with new possibilities that was taken from technology for cellular phones: voice commands can be used to transmit the message desired. Develop this idea further and get an effective idea patented.

Ex. 64. Rescues in avalanches. Every year dozens of mountain climbers and skiers die in avalanches. There's very little time to start any kind of rescue actions when an avalanche starts unexpectedly. This also explains the low reliability of various proposals for avalanche rescues.

Time and *reliability* are conflict factors. The reliability of rescue operations needs to be improved. If we turn directly to the A-matrix, we find the following group of recommended navigators: 05 *separation*; 11 *inverse action,* and 28 *previously installed cushions*. Let's examine the most important recommendations from these navigators: separate the part needed from the object (the person to be rescued); carry out an inverse action (the person surfaces from the snow) in place of the action that is given in the conditions of the task (the person sinks into the snow); undertake disaster preparations in advance to compensate for the relatively low reliability of an object. A generalized model would look like this: disaster equipment that keeps people on the surface of the snow so that they can't sink is a part of everyone's standard mountain equipment. The ideal result would be that an X-resource that doesn't complicate any standard equipment is always carried in the operative time in the mountains. We need a "life-ring" in an avalanche! But, no one carries this kind of ring on their back. The demands on resources are as follows: the system resource should not be complicated, the space resource should not take up much space, and the energy resource cannot use much energy to be effective in action. This is quite a bit but it is still not sufficient for constructive predictions.

We should put together a few more conflict properties: *complexity of construction* as a plus-factor and *energy use of the moveable object* as a minus-factor. This allows us to fix one of the factors as positive and attainable in the hypothetical system and another one as negative that requires improvement. This clearly concentrates on a *mini-strategy* to achieve high quality for a solution without essential complications. We find supplementary recommendations here: 04 *replacement of the mechanical matter*, 05 *separation* (repeated); 13 *inexpensive short-life object as a replacement for an expensive long-life one;* 14 *use of pneumatic and hydraulic constructions*. As a control solution (fig. 11.5), the German entrepreneur Peter Aschauer developed a new life-saving device.

fig. 11.5. Inflatable life-sack

The key navigator that led to the solution was number 14: use gaseous or liquid parts in the object instead of fixed ones – *inflatable* and water-filled *cushions*. Aschauer developed an inflatable sack out of bright orange nylon that is carried in a small backpack and can be quickly inflated with compressed oxygen from a small bottle.

People in danger can open the bottle. Here it's clear that recommendations from navigator 05, 11, 13, and of course from 28 were simultaneously put into praxis. Use your knowledge of the control solution as a background to complete practice reinventing with this navigator by yourself.

Surely you've already noticed that *despite our comment about point 1* (see section 11.2 above) we've used first, an incomplete construction of models of contradictions and second, steps into the A-matrix to model the conflict properties.

Here we would like to show that in praxis there are often situations where beginners (quite often!) but also experienced users of TRIZ ignore the comments we made to make an express analysis. This is dangerous for beginners because it slows and distorts the command and application of TRIZ principles. In such a case, it is better to examine all of the navigators in the A-table! It is clear that this is not exactly effective praxis for self-study, but at least we can show the logical and sufficient selection of steps into the A-matrix as well as how to proceed *for a correct solution to the task at hand*.

Ex. 65. Sorting metal waste. Above all else, metal waste must be sorted out when processing defect or worn out machine parts and metal shapes for reuse. For example, types of metal or different grades of one metal often need to be separated out. Sorting by hand brings good results but it's very unproductive. This is because these components have to be sorted out individually from waste and then measured and analyzed. Then the pieces must be transported to where they are collected according to categories. The use of automatic precision analyzers is also not effective because they don't work well under production conditions. For example, color distorts certain details of the measurements. It would be useful to use other navigators at least for preliminary sorting that are more effective as an industrial technology.

The technical contradiction is that sorting requires higher productivity even though work by hand is needed due to the negative influence of disruptive factors: the high weight and measurement of the pieces, color, transport of individual pieces to collection sites, etc. Our reduction of the initial description leads to the following results (fig.11.6).

The selection of navigators from the A-matrix shows the following groups: a) 01, 10, 35, 37; b) 01, 05, 06, 13; c′) 01, 11, 18, 21; c″) 01, 06, 21, 23. The frequency of navigator 01 *change in the aggregate state* is especially noteworthy. Here are the main recommendations from these navigators:

01,a: Transition to pseudo-states (pseudo-liquid);
01,b: Change in the concentration or consistency, etc.

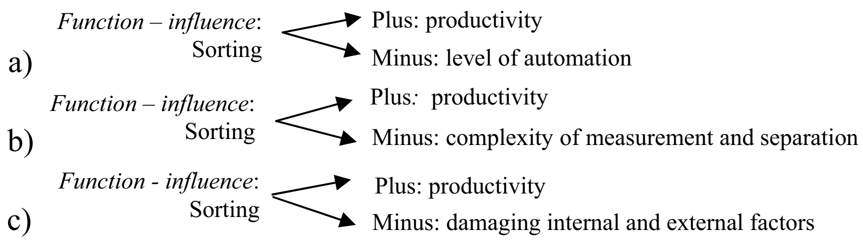


fig. 11.6. Alternative binary models for example 65

As example 01.1 that illustrates a possible application of navigator 1, we'll apply the "use of magneto-rheological or electro-rheological liquids with controllable viscosity from liquid to solid state". You can find out about the purposes and composition of this kind of liquid in technical reference works.

The Japanese firm *Hitachi* created a control solution with tubs containing a magneto-rheological liquid in which the waste to be sorted was placed. The components "sort out themselves" into metal types because the density of the magneto-rheological liquid can be controlled with a strong electromagnet so that the pieces rise in groups according to their specific weight! Then they can be collected from the surface of the tub and sent to a collection site for their specific type.

And what can we do with toys? If you think that this is not seriously meant for engineers, then think about how important it could be for your child or other children for whom you create a wonderful invention!

Ex. 66. Microsoft patents ... a doll! Games with spatial objects are a means for the intellectual and emotional development of children that can be universally used. Parts for building and construction and dolls are a perfect example. The problem here is that it's difficult to talk to dolls, they can't tell children stories, can't watch interesting and useful TV shows with them, can't laugh and cry with them, can't ... You can continue this list until you replace the words *they can't* with *they can*! But first we need to reinvent a patent for a wonderful doll from Microsoft. We will find an unexpected problem that also comes from the A-matrix!

Here we'll take the doll as a universal means for the development of children. We assume that a doll cannot actively communicate with children, although this is perhaps possible in a few limited situations. Clearly there is no feedback of information. Our reduction results in the plus-factor 02 *universality, adaptability* as opposed to the minus-factor 12 *loss of information*. Oh, now we have a problem because this box in the A-matrix is empty!

Well, let's work with the A-table. The navigator we already know 04 *replacement of mechanical matter* is especially interesting with the following recommendations:

04,a: replace a mechanical system with an optical, acoustic, or ... olfactory one, etc.;
04,b: use electromagnetic fields for interaction with the object;
04,c: move from fixed fields to temporally changeable fields.
A successful application of the navigator can be found in example 46 *blackboard*.

We can also add navigator 29 *self-servicing*: *the object must function by itself to carry out auxiliary operations.* It also seems potentially useful to "ommunicate" using navigator 36 *feedback* that is either ineffective or absent from normal communication between toys and children. As a control solution, Microsoft patented a system (fig. 11.7) that includes a doll and a television!

fig. 11.7. System with a "living" doll from Microsoft

A hidden noise background is provided by a weak radio transmitter to a receiver in the doll who then begins to react "intelligently" to the events on TV. It says its opinion, discusses event, and shows emotions. Everything that's brilliant is really simple and this doll from Microsoft demonstrates this again.

Of course, the question about what to do in similar cases remains. About 20% of the boxes in the A-matrix are empty.

First, it's possible to work with the contradiction to find other plus and minus-factors that can also be associated with the conflict properties.

Second, it's necessary to work directly with the A-table to investigate the navigators and sub-navigators with the goal of finding effects and recommendations that are similar in character to the effects desired. This is precisely what we wanted to show in this and in other examples.

Third, you can also fill in the boxes yourself with references to navigators from inventions that you know. This is why the software *PentaCORE* (see section 21.3) has the function that users can continue to shape the A-table and A-matrix with their own examples and references.

Ex. 67. Protection against unauthorized entry into vehicles. Let's assume that a person enters you car with criminal intent and attempts to start the engine. How can this theft be prevented? Let's construct the contradiction like this: protection for the vehicle against entry by unauthorized persons needs to be reliable. We can select a strategy of "self-protection" for the vehicle, but we should not exclude the possibility that there's also active protection, i.e., interaction with the unauthorized person. If we think of the unauthorized person as a "damaging external factor" and of the self-protection of the vehicle as the concept "damaging factors of the object itself", then again the box where line 14 and column 13 cross in the A-matrix is empty. But now we can use another strategy to work with the A-table. We'll carry out an express analysis of the 10 most effective navigators and then we'll put the navigators with the best results in generating ideas in this box for future use.

It's always useful to document the process of a solution in a table (fig. 11.8).

Nr.	Navigator	Interpretation of the navigator	Examples of ideas
01	Change in the aggregate state	Change the properties of the materials in the operative space	Raise the temperature of the seats to an unacceptable degree
02	Preliminary action	Facilities should be activated from the best location and without delay	This navigator can be treated like a system requirement although some facilities should be excluded from functioning while driving
03	Segmentation	Disassemble an object into individual parts, increase the degree of separation	Separate the sources of the influence so that they're difficult to destroy
04	Replace of mechanical matter	Apply non-mechanical influences	Use tear gas or gas with an intolerable odor. Here there are many possibilities if we consider biological effects.
05	Separation	Influence only the main function without damaging other functions	We can also think of this navigator as a system requirement
06	Use of mechanical oscillations	Use of mechanical vibrations with variable frequency	Use of loud volume or ultra-high frequencies
07	Dynamization	Effects should be optimal in every step	Shape the effects in various ways so that the location of their installation is difficult to find
08	Periodic action	Use impulse effects	Create unexpected effects to which it's very difficult to adapt
09	Change in color	Change the color of an object, change the degree of transparency of the environment	Change the transparency of the windows, make the air opaque, use a permanent color, use invisible markings to make the perpetrator visible
10	Copying	Use simplified and less expensive copies of components, change the measurements (size)	Use inflatable sacks that hinder the movements of the perpetrator

fig. 11.8. Short version of the teaching example – express-solution to a problem

A firm in Berlin developed security navigators based on different gas mixtures to protect apartments and vehicles as a control solution. In apartments a strong tear gas is emitted after warning sounds that is not harmful to furniture, walls, and domestic devices. When a vehicle is started, its interior is filled with white smoke that is odorless and harmless. The smoke makes it impossible to drive for a sufficiently long time and it draws the attention of passersby who can then alert the police.

We should test the possibility of selecting other plus and minus-factors. For example, we can try to find a "universal means" that ensures protection from the "damaging external factor". Plus-factor 02 *universality, adaptation* and minus-factor 13 *external damaging factors* lead to a group of navigators with numbers 01 and 09 that we've already used and that are present in the control solution as well as to navigators 28 *previously installed cushions* (in this situation something like 02) and 31 *use of porous materials,* both of which we can use for orientation.

By using the results of our express analysis, we can fill a box in the A-matrix, or even two boxes on diagonals 13 and 14 with the following navigators 01, 04, 06, and 09.

Ex. 68. Wind power plants. Wind, meaning atmospheric streams, is one of the environmentally best and cleanest sources of energy. Many of these systems that we all know look like aircraft propellers installed at a height of several dozen to 100 or more meters (fig. 11.9). However, the possibility of further increases in efficiency is exhausted for such plants with a horizontal axle. In many countries wind power plants are now being tested that were constructed with vertical rotating axles (fig. 11.10). It's easy to see that wind direction is not crucial for such facilities. They also have other advantages.

fig. 11.9. Wind power plant with horizontal rotation axle

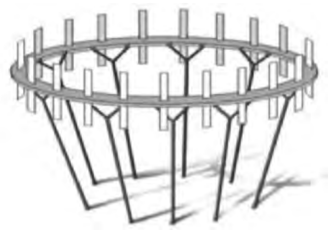


fig. 11.10. Wind power plant with vertical rotation axle

We know that we can increase the performance of these power plants considerably by raising it to a height of up to 6-8 km. However, this brings a series of problems specifically related to the weight of the facility and the cables that connect it to the earth. The working life of such a plant also plays a critical role because lower temperatures at high altitude produce increased friction.

We have an entire set of problems here. The first of these is weight. The technical contradiction is that the installation of plants at high altitude ensures that they work at maximum capacity. We have to solve the problem of how to bring the plant to such a high altitude and how to install it. The plus-factor 36 *power* conflicts with the minus-factor 32 *weight of the moveable object*. For learning purposes, we would like to comment on only one of the number of recommended navigators, number 32 *counter-weight*: compensate for the weight of the object with its relationship to other objects that have lift; compensate for the weight of the object with an opposing aerodynamic influence on the environment. In the control solution by Russian specialists, a balloon in the shape of an "air strip" was suggested that could then lift the power plant to a high altitude (fig. 11.11). Here the wires also have a gas-filled casing that compensates for their weight and the weight of the cables that anchor the entire construction and prevent unwanted movements or altitude changes.

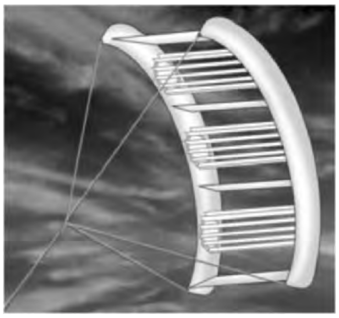


fig. 11.11. Wind power system "air-strip"

3 rotating power plants are on the "strip". The main problem is friction in the support rings above and below the rotors. We should formulate yet another technical contradiction: long life and the automatic function of the system without service under conditions with damaging external factors. Here it's certainly possible to construct a few alternative models. Let's look at some of them. The most associated plus-factors are degree of automation, reliability, user friendliness, functional time of the moveable object, stability in the state of the object.

The most appropriate minus-factors are complexity of the facility, damaging external factors, length of the moveable object along the movement of the rotors in their supports, loss of materials (wear), fixed state, temperature, loss of energy to overcome friction.

Keep in mind that we are still reinventing even though we already know the control solution. Imagine what kind of work this would mean if you had to undertake this analysis of all pairs of conflict properties. You would get 35 pairs of contradiction models! But, there is a hidden simplification of the solution here because the same navigators appear constantly. We should try to use these first. The CICO method that will be introduced in the next section 11.4 is designed to work with just this kind of "contradiction systems".

At this point we need to avail ourselves of an express analysis of the solution process based on one of the physical technical models: plus-factor 23 *functional time of the moveable object* as opposed to the minus-factor 13 *external damaging factors*. We can now examine this group of navigators and their interpretation while keeping the special properties of resources while the system works:

04 *replacement of mechanical matter* – Apply the principle of a magnetic mounting with relatively little energy use that is produced by the plant anyway;

07 *dynamization* – A portion of the energy should be used to control the continuous adjustability of the individual rotor blades to optimize the function of the entire system by reducing the resistance and load of the supports;

21 *transform damage into use* – The high speed of the air streams at high altitude can be used with the low temperatures to produce slick surfaces on ice and air cushions;

38 *homogeneity* – The outer surfaces that come into contact with these slick surfaces should be manufactured from the same material.

The control solution of the Russian specialists is a linear step motor to start the rotors that is transformed into a magnetic mounting for support purposes:

Ex. 69. Loud net. Thousands of dolphins die every year because they are caught in fishing nets. They swim into the nets after fish that have been caught and are then caught themselves. How can we reduce the danger of these nets for dolphins?

We can formulate two versions of a functional ideal model:

the dolphins avoid the net *themselves*;

the net repels the dolphins *itself*.

The physical-biological resource and contradiction is that dolphins have an organ for echo-location but that the net is not acoustically "visible".

The selection of standard factors for this example is anything but trivial. We have neither direct analogies for a description of acoustic signals nor parameters. There is also no appropriate description for the negative phenomena that are related to the nets' weak reflection of echo signals. In such cases, we can turn our attention to metaphorical analogies, for example, compare the sound with light or thermal fields. Then we could choose step 35 *brightness of the lighting* as a plus-factor. As a minus-factor that is related to the construction of the net we can choose step 10 *ease of use*. We can use this new TRIZ formulation to describe the ideal functional model with high probability like this: an X resource that in no way makes the net more complicated ensures good "visibility" of the net for the echo-location of the dolphins. Let's examine the navigators from the A-matrix:

04,a: Replace the initial mechanical system with poor acoustic reflection properties with a new system that reflects acoustic signals well;

04,b: Move from non-structured fields to structured ones;

10,b: Replace an object with its acoustic copies (notice that we've replaced the term "optical"!).

At this point, navigator 08 cannot be interpreted. However, we have enough facts to formulate the idea of a net with special, integrated mesh shaped like spherical and parabolic plastic reflectors. These elements would reflect the echo-signals of the dolphins much better. The control solution of the German zoologist Sven Koschinski looks just like this model. Experimental tests show that the visibility of the net is increased by 50-60%. This is not bad, but it's certainly not enough.

But, we have found the key principle that can be used to improve the system with the help of TRIZ instruments. We can shorten our description by quickly formulating the technical contradiction in reduced form: plus-factor 04 *reliability* and minus-factor 07 *complexity of construction.* This results in navigators 08, 10, 18, and 40.

Here the following navigators can be easily interpreted in order of their importance:

10 *copying*: This navigator appears several times and also corresponds to the situation, as it's the only way to create a signal that warns the dolphins about the danger;

18 *mediator*: Use an object that passes on or transmits an action. Supplementary active acoustic reflectors can be mounted on the net with a capacity of 115 decibels, a frequency of 2.9 kHz, and sound up to 90 kHz. This sound was selected to scare dolphins away, but not the fish to be caught;
08 *periodic action*: Move from permanent effects to periodic ones. The “call” that resembles the dolphins’ own is produced 70 times per minute;
40 *uninterrupted useful function*: Carry out a function completely and without interruption. The number of reflectors on the surface of the net with a length of several hundred meters and more must be sufficient.

And the idea had to be verified again in praxis. Tests show 90% effectiveness. But, there is still 10% left! We could now use the goal of preventing the dolphins from adapting to the warning signals. Our reduced technical contradiction is plus-factor 02 *universality, adaptation* and minus-factor 07 *complexity of construction.* Here the key navigators are 04 *replacement of mechanical matter* (transition from fixed fields to temporally changeable ones) and 07 *dynamization* (the characteristics of the object should be changed so that they are optimal at every step). A common interpretation of the navigators leads to the conclusion that the signals need to be randomly emitted.

This example shows the development of an initial idea based on its verification in praxis and the formulation of new models using test results. Here we completed reinventing for teaching purposes instead of generating new ideas and so we could say that this example demonstrates *dynamic reinventing.* It’s important to note that the practical perfection of products and production is based on TRIZ instruments following an analogue procedure.

The last example in this section demonstrates *static* instead of *dynamic* reinventing of an object. The example is not an “industrial” object such as a tooling machine or an aircraft (although we’ll also be concerned with such objects!) However, we can assume that this example is easy for readers to understand.

Ex. 70. “Raclette”? Why not?! Let’s examine this example of a device with many little frying-pans to prepare food from several sides, like for instance, from the non-technical perspective of the user (fig. 11.12).

fig. 11.12. “Raclette”

Here we would like to find as many creative ideas (navigators) as possible for this object.

Our analysis is shown in the table below (fig. 11.13). You can see that there are 25 navigators related to a relatively simple object!

№	Navigator	Interpretation
1	**03 segmentation**	A large frying-pan is divided into 6 or 8 smaller segments.
2	**35 unite**	Smaller pans are combined into a unified construction (Combine similar objects in space) and simultaneously heated (Combination of similar operations in time).
3	**05 separation**	The frying-pan is separated from the kitchen (like from one system) and brought into the dining room (into another system); the smaller pans are "separated" from the frying-pan (as a system) and placed on the table.
4	**12 local property**	The system and its parts have different functions and every part has the conditions that correspond best to its function.
5	**20 universality**	There are multiple functions such as side dishes that are prepared together with food in the pans or the addition of a grill.
6	**34 matryoshka**	The small pans can be placed into the larger frying-pan.
7	**02 preliminary action**	All components must be prepared in advance for cooking
8	**37 equipotentiality**	Everything is close and there is no need for a strenuous transport because of the proximity of all resources on the table.
9	**11 inverse action**	People don't go to the "stove", the "stove" comes to the people and is directly at the table: the "stove" has become moveable!
10	**22 spheroid-shape**	The spherical and elliptical form of the frying-pan and the arrangement of the smaller parts as segments of the whole system is very comfortable for the user
11	**07 dynamization**	The "portable" stove represents an asynchronous dynamic process in which individual dishes can be prepared in the corresponding pans; the communication of the participants at the table is made dynamic by means of an interesting and unifying "technological process"
12	**16 partial or excess effect**	It is difficult to satisfy every taste when cooking, but it's easy when everyone cooks their own dish according to their own taste.
13	**19 transition into another dimension**	Multi-stage composition of the work surface, heat conservation
14	**09 change in color**	Transparent covers; different coloring for pans to differentiate between them
15	**08 periodic action**	Dishes are prepared in different time intervals as desired.
16	**40 uninterrupted useful function**	All parts function at the capacity that is optimal both for each part individually as well as for the entire system.
17	**21 transform damage into use**	"Kitchen smells" are transformed into the "aroma" of delicious dishes.

18	**36 feedback**	The quality and quantity of the system can be easily optimized because each person takes as much as needed. For some it's more, for others less.
19	**18 mediator**	The heating frying-pan functions like a central "moderator" for communication!
20	**29 self-servicing**	Everyone serves themselves!
21	**10 copying**	The psychology of communication connects everyone through the repetition of behavior. From a technical perspective, there's a simpler, more efficient, and more pleasant copy of the stove on the table.
22	**38 homogeneity**	The shape and materials of all of the pans are the same although their markings can be different.
23	**15 Discard and renewal of parts**	Used components of the dishes can be reserved if needed.
24	**01 changes in the aggregate state**	The dishes undergo necessary changes in the "aggregate state" of their components; flexible changes in the kinds of preparation
25	**17 use of composite materials**	Flexible changes in the composition of the dishes

fig. 11.13. Perceived navigators for "Raclette" (composition of the little frying-pans)

The goal of this example was to demonstrate the broad possibilities of a correct creative interpretation of the navigators regardless of their extremely limited and often even poor description.

For the time being, that's it for our examination of the application of the A-navigators. I would like to mention Genrikh Altshuller's words again: there is no magic formula, but there are navigators that are sufficient in most cases. TRIZ is certainly no dogma, so you should continue with your improvisations and fantasy games!

11.4 Integration of Alternative Contradictions – the CICO-method

Perhaps you asked yourself while using the A-tables and navigators (section 11.2 and 11.3) whether it's truly possible that the basis of every concrete invention in only one certain navigator? The author of TRIZ has the following answer to this question. There are only a little more than 100 elements in the periodic tables. Yet the real world is infinitely richer because the chemical elements react with each other to build complex materials and entire classes of even more complex materials.

The investigation of such synthetically combined combinations of navigators is an extremely difficult task because we can derive 780 pairs, 9,880 triplets, and more than 90,000 groups of 4 from the 40 navigators in the A-table. This is what makes combining "combinations" so complicated. It's not easier to examine real inventions either, although it's easier to use them to recognize the advantages of a concrete composition of navigators. But, experienced specialists sometimes use the A-tables without the A-matrix for their preliminary investigation of a problem and for an express analysis. This is what they do:

1) They look through the entire table and choose a few promising navigators;
2) They select combinations of two, three, or more navigators when possible.

A more effective method is the goal-oriented clustering of navigators on the basis of a combination of several TC's or using the selection of several appropriate factors for the step into the A-matrix for the TC selected.

This is the CICO-method (Cluster In Cluster Out):

1) Formulate the TC and, after you have more experience, several TC's;
2) Select several synonymous steps into the A-matrix for each variation. This is the actual Cluster In navigator, i.e., the construction of an entire group of synonymous steps for both the plus and the minus-factors of every TC;
3) Note all of the recommended methods;
4) Create a list that orders the value of the methods where the most frequently recommended method is first, the next most frequent is next, etc. This is the Cluster Out navigator in which we eventually get a group of methods where first the most frequently encountered methods are consistently listed and less frequent ones follow according to their frequency;
5) Carry out an analysis of the methods beginning with the first one.

Let's examine an example of a "retro problem".

Ex. 71. "Lid" on a chimney. Various protective devices such as small roofs or baskets are installed over chimneys to prevent snow and rain from falling in. We'll call them "covers".

Diagnostics. The problem is that most covers are shaped like in fig. 11.14. They only partially protect chimneys from rain, snow, and especially from strong wind. More complex shapes usually narrow the diameter of the chimney and make the flow of smoke more difficult.

fig. 11.14. Cover of a chimney

Reduction. This is at least a double physical contradiction. The cover has to be *wide* and *close* to the chimney in order to guarantee good protection from rain and snow regardless of the wind. It has to be *narrow* so that the wind can't destroy it and *far away* from the opening of the chimney so that the smoke can flow out freely. The operative zone includes the exit of the chimney (receptor) and the cover (inductor). It is clear that we only want to change the cover here, but an obvious idea is not immediately evident. We can therefore formulate several FIM.

Macro-FIM: This is an ***X resource*** that neither complicates the system in any way nor does it cause any negative super effects, although it works with other available resources to ensure that the opening is securely protected from rain and snow regardless of the wind and that the smoke can move freely.

Maxi-FIM: The operative zone ***itself*** protects the exit of the chimney and lets the smoke blow away freely.

An analysis of the fundamental transformations doesn't provide us with an obvious idea at first glance, although we can say that spatial, structural, and energy resources seem "to be very interested in a solution". We can assume that the shape and structure of the cover needs to be modified – a more complex construction with a few specialized functional parts is perhaps possible. It's also possible that we'll need an energy source to put the cover into action. Here you could certainly ask the question, what about the requirement of no additional complications in the system? We'll examine the first part of the answer at the end of this solution because it's possible that the material used and the cost of the new construction is marginally higher then before. This does not correspond to the assignment's requirements. Albert Einstein[56] provided the second part of the answer: it has to "*be simple yet not simpler than what's simple!*". This means if a construction doesn't fulfill the appropriate requirements, then its simplicity or low costs make no sense at all.

We can construct a technical contradiction to step a few steps away from the stiff formulation of the physical contradiction, but not from the FIM! Quite the contrary - we want to strictly hang onto the FIM.

Let's formulate the IFR-1 generally as the removal of "damaging factors that influence the object" and use this IFR as a plus-factor 13 for the appropriate step into the A-matrix. We then select the appropriate minus-factors from line 13 (see the table in fig. 11.15).

Pos.	Number of the minus-factor and its explanation		Navigators from the A-matrix
1	21	*Shape* – will probably get more complicated	21, 03, 12, 01
2	10	*Ease of use* – decreases, for example, if something has to be turned on and off.	05, 29, 04, 23
3	07	*Complexity of construction* – increases if certain control elements and drives need to be installed	21, 08, 14, 17
		Total of different navigators:	11

fig. 11. 15. *Cluster In* for the first plus-factor 13 *external damaging factors*

Let's represent the IFR-2 as the "level of automation" and use it as plus-factor 03 for the appropriate step into the A-matrix. We find at least one minus-factor in line 03 (see the table in fig. 11.16).

---

[56] Albert Einstein (1879-1955) – leading physicist of the XXth century, discoverer of the theory of general and specific relativity.

Pos.	Number of the minus-factor and its explanation		Navigators from the A-matrix
1	07	*Complexity of construction* – can increase, but we don't want this!	07, 18, 02
		Total of different navigators:	3

fig. 11. 16. *Cluster In* for the second plus-factor 03 *level of automation*

We can assume that the solution to the problem is the IFR-3 as a kind of ideal "shape". Then we can select the probable minus-factors from line 21 in the A-matrix (see the table in fig. 11.17).

Pos.	Number of the minus-factor and its explanation		Navigators from the A-matrix
1	10	*Ease of use* – can decrease if something has to be opened or closed, etc.	09, 07, 10
2	07	*Complexity of construction* – can climb!	16, 14, 03, 04
3	08	*Complexity in inspection and measuremenst* – nothing should be measured or controlled. Everything should function correctly by itself.	07, 11, 23
		Total of different navigators:	9

fig. 11.17. *Cluster In* for the third plus-factor 22 *shape*

Transformation. The combination of 17 different navigators from this table results in one (07) that appears 3 times, five that occur twice, and 11 that are listed once. You can find the steps to the solution and the result of reinventing the problem that I saw for the first time in Germany in the table in figure 11.18. I gave this solution the name "helmet" because of its similarity to a knight's helmet. Precipitation cannot fall into the chimney even when there's no wind. Later I saw this solution in Finland, too.

Verification. This is really an ideal solution: the cover *itself* promotes the best possible flow of smoke and protects the chimney from precipitation regardless of the strength and direction of the wind!

Some practical ideas can be immediately found in this solution (fig. 11.19) that was invented by an unknown master. This is precisely the kind of *solution ideas for problems with very strong contradictions* that were condensed in TRIZ into *"models"*. Here we find models like "*dynamization"* - the "helmet" was made moveable, "*local property"* - protection is provided exactly where it's needed, "*asymmetry"* - the weather vane has a raised tail that is influenced by the wind, "*matryoschka"* - the axle for the "helmet" is installed internally in the chimney "*transform damages into use"* and *"self-serving"* - the stronger the wind, the more stabilly the helmet is fixed in the best direction.

№	Frequency of the navigator		Interpretation of the navigator
1	3	07 dynamization	Clear interpretation: *the cover has to be moveable*!
2	2	03 segmentation	The cover has to be divided into certain parts that function independently with the following properties desired: "protection" from rain and snow, "moveability" for better protection, etc.
3	2	21 transform damage into use	The situation is most difficult when there's strong wind! But, strong wind is also a *free "energy source"!* **The key idea is almost ready** – *Wind needs to make the cover move!*
4	2	04 replacement the mechanical matter	The essence of this navigator is the application of "more easily controllable" fields. Here the wind changes its direction – *it should move the cover into the best possible position* to ensure protection against precipitation! How can the position of the cover be maintained? Stop! **We need a type of weather vane** because such a device always point stability in one direction regardless of the strength of the wind. **So we need to attach a weather vane to the cover!**
5	2	14 use of pneumatic and hydraulic constructions	What more do we want! The very best would be "an automatic machine ***with a pneumatic energy source and pneumatic-mechanical drive***"***!!!***
6	2	23 use of inert media	Comment: If we think about this navigator further, we note that there is a super effect of the "weather vane"! While thinking about the concept "vacuum", it's clear that ***strong wind*** creates a zone of low-pressure air directly under the cover that makes the flow of smoke easier! Other covers limit the flow because they created "jams" that raise the air pressure at the exit of the chimney.
7	1	12, 02, 11, 16, 08, 18, 29, 10, 09, 01, 17	

fig. 11.18. *Cluster Out*: Unification of the navigators from the table *Cluster In*

The new construction is not really more complicated than the previous one, but it has many advantages!

fig. 11. 19. "Helmet" to protect a chimney from rain and snow

Objectively, a good solution puts several creative ideas into praxis. This is why it's so important to investigate extant inventions with reinventing methods to follow the ideas created by inventive thinking for a transformation from "what was" to "what then came"!

This means we can say that certain methods recommend that we look for the solution "in one move" like in a miniature chess game where only one move is possible. But, complex tasks can often be solved only with 3, 4, or even 5 moves, regardless of how brilliant they are. The groups of methods here are therefore oriented *towards the creation of combinations with different moves* - and this is even more the case because we can't predict in advance how many moves a solution to real problems in inventing will take. We also see that an exact examination of the methods allows us to observe how they support each other. *A "system super-effect" is the synergy of these methods!* The group of methods *describes and predicts the shape of the future solution in a certain way* and connects the ideal final result with the new principle to be sought and the future construction.

12 Navigators for Solution to Physical Contradictions

12.1 Integration of Physical Contradictions

The key idea of the method is analogous to the integration of technical contradictions. This is about the unification of incompatible demands starting with a direct description of the contradiction model. This is more difficult with a physical contradiction because the incompatibility seems to be even more incompatible and acute. The description of a physical contradiction is often not functional, meaning it contains inverse and incompatible *properties of a state* instead of inverse *effect procedures.* This is why there are clear differences between the *Method for the Integration of Physical Contradictions* (proposed by the author of this text book in 1989) and the *Method for the Integration of Inverse Technical Contradictions.*

The Method for the Integration of Physical Contradictions requires a clear solution to the contradiction using the dominating resource. It therefore assumes creative and intuitive efforts and professional knowledge of the physical-technical effects and constructions that are potentially suited for such a solution.

The steps of the method can be formulated as follows:

- formulate a physical contradiction with two incompatible requirements (factors);
- reduce the initial model to a *constructive form* in which both factors are represented as a goal and as positive factors;
- divide the constructive model into two models for each of the factors respectively; find independent alternative technical solutions for each of the factors;
- construct an integrated model for each of the factors on the basis of the integration of independent alternative technical solutions in which the physical contradiction is no longer present and both previously incompatible properties exist.

Comment 1: You should immediately try to formulate the physical contradiction in a constructive form as recommended in classical TRIZ. Here you may skip the first step in the method.
Comment 2: Dividing the contradiction model into two models is a procedure for the description of the generative process of an idea because experience can help to find an integrated solution directly with a constructive model. Here you may skip the third step.

Here, too, there is no magic formula. Instead, it is important that the conflict properties are separated into time, space, structure, or materials (energy) - see here the following section 12.2 *Table of fundamental transformations*. But, the integration of *separated* models of the same initial physical contradiction allows us to overcome psychological difficulties regarding the problem. This can create a bridge for the development of an idea in that previously "incompatible" properties exist and function together perfectly to make the useful main function possible. It will continue to be useful to study section 15.3 *Integration of Alternative Systems* to integrate separated models. Let's examine examples in the usual way from the "simple" to the "more complex".

Ex. 72. Heating silicon plates (Solution based on the integration of physical contradictions). In example 60, it was easy to combine the inverse processes of heating silicon plates with each other. This occurred by connecting *inverse effects* to heat the plates in the center and at the edges. This is more difficult when integrating incompatible physical models because a transformation has to be found and implemented that isn't obvious and on the surface – *a solution to the conflict in space and structure*. Therefore the *states* required in the contradiction are initially extracted from the initial physical contradiction. Then the possibility of their independent *technical implementation* can be tested in which the integration of alternative technical solutions in a construction is possible. For example, this can happen by *changing the structure* of the inductor to make the properties required possible *in separated zones in space*.

Let's slowly go through the steps of the *method for the integration of physical contradictions*:

- We construct the initial model of the physical contradiction: the thermal field *should be strong* to heat the plates at their edges and it *should not be so strong* that it overheats the center;
- We reduce the initial model to a constructive form with positive incompatible properties: the thermal field *has to be strong* to heat the plates at the edges and it *should be weak* to heat the plates in the center;
- This is the technical solution for each of the separated models: the heating spring needs *a large number of spirals for a strong* thermal field in the inductor and *a low number of spirals for a weak* thermal field;
- The integration of this alternative solution leads to the control solution that you already know from example 60: the number of spirals at the center of the heating element is lower than at the edges.

In this solution, the spring of the new (integrated) heating element has taken on a *heterogeneous structure* to ensure that the required conditions for heating are met in *different spatial zones*.

Ex. 73. “Kill two birds with one stone”. The manufacture of certain products requires that a driven nail is removed again. This occurs when nails are used temporarily to connect details but subsequently need to be removed. This is often difficult to do without damaging the material where the nail and especially the head sit. The sharp tips of special pliers or a similar sharp and hard device has to be pressed into the material to reach behind the head sitting on the surface of the product or sometimes even sunk deep into the material.

We can now reinvent an interesting idea that was developed in the Ukraine. Let’s construct the model of the problem situation as an initial physical contradiction.

Component : Head of the nail

- ***First state:*** deep in the material ► so that the nail can hold the product
- ***Second state:*** not deep in the material ► so that the nail can be easily held

The initial model can now be reduced to a constructive form and separated into two independent models. Please pay attention to the scarcely noticeable, yet clear difference that we want to demonstrate here for teaching purposes.

First model

Component: Head of the nail — already present in the material — so that the nail can hold the product

Second model

Component: Head of the nail — not present in the material — so that the nail can be easily held

We can now perceive two independent solutions. First, the nail is driven in as usual and its head sits on the surface of the product or sinks under the surface. Second, the nail is driven in so that there is a space between the lowest part of its head and the surface of the product that is sufficient to easily grab the head and pull the nail out. So now we need to overcome a psychological barrier and combine two solutions to invent a nail that unites incompatible states.

fig. 12.1. Nail with two heads

The control solution (fig. 12.1) is that the nail has two heads with a space where it can be pulled out. The lower part is on the surface and the upper part lets the nail be pulled out.

The dominant resource is functional-structural because the number of elements in the object was changed so that every element fulfills a special function. The auxiliary resources are spatial in the change of the shape of the object, *temporal* because the new parts of the object are used in separate time intervals, and *material* in the increase of the parts used in the construction of the nail.

If you're interested, you can now attempt a detailed verification of this solution to assess its advantages and disadvantages regardless of whether it's only for teaching purposes or for professional goals.

Ex. 74. Safe with a double floor on the beach. If you want to prevent the wind or thieves from taking your valuables while you're on the beach, you need a technical solution that is based on easily accessible resources. Here we would like to formulate the solution in its reduced form while keeping comments 1 and 2 about the method's steps in mind.

Let's assume you go to the beach with something, a suitcase, a safe, or a refrigerator, whatever. You take your air mattress and some kind of sun protection out and put your clothes, money, and documents there, too. You can put drinks, books, or toys there at the same time, too.

We'll carry out just two steps (2 and 4) of the method for this construction (I've chosen the term "safe"):

2. The safe should be light for transport and heavy so that neither the wind nor thieves can carry it away. Imagine a light safe for the transport of your things and another heavy one at the beach where you can easily put the light safe. You have a kind of double safe or at least one with two walls;

4. Now two constructions need to be put together into one. We now assume that the even the only transportable integrated safe has two walls, or for example, a double floor. The space between the floors can be filled with sand, small stones, or even with water, things that are readily available on the beach. This is precisely the idea of a sand safe that was patented by an inventor in Great Britain.

The dominant resource is material in the changes in the weight of the safe brought by the addition of external material. The auxiliary resources used or considered are structure and space – the safe has two walls and can be locked with a lock at the entrance/exit for filling the space between the walls; and a temporal resource – the safe has a different weight at times that don't overlap.

This object can be further developed in a very interesting way.

12.2 Tables of Fundamental Transformations

The special role that the models of physical contradictions play in solutions to problems in inventing can be explained by their "position" in the operative zone. A physical contradiction is a very precise expression for the essence of a problem that is the central point in every operative zone.

Certainly you've already noticed in the previous examples that there are also transformation procedures and models for physical contradictions that make the generation of new ideas easier. The A-tables 5-7 also help here with procedures and standards for solutions to physical contradictions.

The somewhat less than comprehensive main table 5 *Fundamental Transformations* is shown in figures 12.2-12.5. Here we need to explain some of these illustrations.

Most of the examples illustrate a certain dominant resource, for example a spatial or temporal one that corresponds to the main transformation. But, other resources are also part of the implementation of transformations and often prove to be essential. This is why a few examples could also simultaneously illustrate other transformations well.

Let's examine the illustrations of fundamental transformations as examples and practice exercises for the formulation of physical contradictions and the analysis of resources used.

Ex. 75. Fundamental transformations in space. Here are examples of models and solutions to physical contradictions in figures 12.2:

a) Vehicles that come to crossings on one level *can collide*, *but they shouldn't collide* to prevent accidents and material damage.

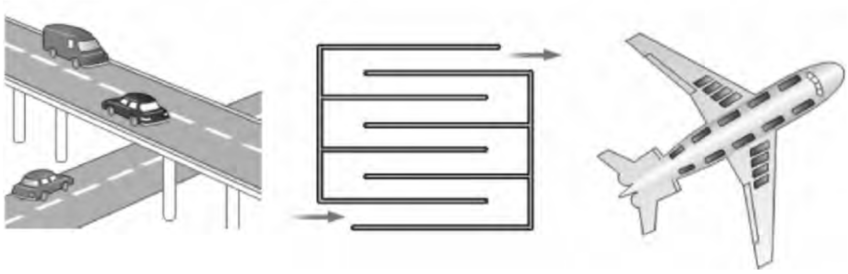
The solution is to separate the roads into different levels with a bridge or a tunnel (dominant resource - spatial).

b) Large crowds *need to be ordered* to prevent disturbances while moving and injury from pushing and trampling in narrow passages, but they *should not be ordered* outside of these passages.

The dominant resource here is spatial in two aspects: the separation of the operative zone and the determination of a certain direction of movement in the operative zone. The solution also uses a structural resource as the structure of the movement depends on the width of the passageway - single file, double file, etc. A spatial-temporal resource can also be used to limit the number of passersby in the operative zone – entry for small groups up to temporary barriers at specific time intervals.

c) *As much fuel as possible should be* on board and *as little as possible should be there* so that the plane's balance can also be correctly maintained by fuel use.

Here we have a spatial resource - hollow spaces are used in the wings, a structural resource - the fuel is divided into several parts, and a structural-temporal resource - fuel in the outer spaces of the fuselage and the wings is used first.



a) Location of crossing highways at different levels

b) Separation and structure of space to order lines of people

d) Use of hollow spaces in a construction

fig. 12.2. Examples of fundamental transformations in space

Ex. 76. Fundamental transformations in time. Here are examples of models and solutions to physical contradictions in figures 12.3:

a) See example 75, point a);

The solution is that the conflicting streams cross the intersections one after the other (dominant resource - temporal).

b) A boat *needs a mast* to hold its sail in open water and *should not have a mast* so that it can easily travel under bridges.

The boat also has a flexible form as a spatial resource during the operative time where a hinge is present as a dynamic element in the mast. During the operative (conflict) time, the mast doesn't fulfill its useful main function and it fulfills this function outside of the operative time. Altogether, this made a solution in time possible.

c) A laser beam *has to draw neighboring lines* to make complete drawings and it *should not draw neighboring lines* so that the plate doesn't get too hot and the precision of the drawing is maintained.

Delays in the movement of the laser to a neighboring line can cause the material to be processed to overheat. A spatial resource (the path of the beam) and a material resource (thermal conduction and radiation of the material) also play a part in the solution of the contradiction.

a) Separation of crossing traffic streams in time

b) The mast is pulled in while travelling under the bridge

d) The path of the laser on neighborin g lines is split up temporally

fig. 12.3. Examples of fundamental transformations in time

Ex. 77. Fundamental transformations in structure. Here are examples of mod-els and solutions to physical contradictions in figures 12.4:

a) A bicycle chain *has to be flexible* to run precisely on gears and chainrings and it *should be stabile and solid* to transmit relatively large forces between gears and chainrings.

A structural solution is that parts of the system (links) are fixed and not flexible while the entire system (chain) is flexible. Analyze the role of other resources, too.

b) A rescue-slide needs to be shaped outside of the operative time interval during disasters in such way that *it takes up very little space* and during the operative time *it needs the optimal shape of a life-slide*. In this example, our attention is directed towards the contrast between "soft" elements and a "hard" system as a whole. During the operative time, the work of a rescue-slide also requires energy and the volume resources of compressed air (material) as well as changes in shape as a spatial resource.

c) Parts with a complex shape *must be solid and solidly pressed together* for processing and *they should not be solidly pressed together* to prevent damage to their outer surfaces.

a) Chain links are not flexible, the chain as a whole is flexible

b) The soft elements make up a "solid slide" in their working state

d) Moveable cylinders create a reliable press for complex details

fig. 12.4. Examples of fundamental transformations in structure

Here there's a dominant spatial-structural resource between the working surfaces of the press. Special moveable cylindrical elements are installed on a special frame that closely surround all details with a complex shape as the press surfaces get closer to each other to evenly distribute the pressing force onto a larger surface. This guarantees a solid grip on the details during processing.

Ex. 78. Fundamental transformations in material. Here are examples of models and solutions to physical contradictions in figures 12.5:

a) The amount of material *needs to be small* to make the engine function efficiently and *it needs to be large* so that the difference in volume before and after burning is sufficient to carry out this function.

This is an example of a solution in material in a gasoline engine. In the burning process of a mixture of a small amount of gasoline and air, the hot gases produced push with very strong force on the piston that moves in the work cylinder. The energy produced is strong enough to set the piston into motion that is then transmitted through several mechanisms to the wheels of a vehicle. These wheels push away from the ground and the result is that the vehicle is pushed forward. Analyze the role of other resources.

b) Sun glasses *should change their transparency* in relationship to the intensity of the light and *should require no action* from the wearer for this adjustment.

The ideal solution in material is that chromatic lenses change their transparency themselves in relationship to the intensity of the light!

c) *A flash should accompany* photographs to ensure high quality photos and it *should not be present* so that the pupils of people in the photos aren't red (negative effect "red eyes").

To prevent "red eyes" on photographs, a temporal resource was used along with the biophysical effect of the reaction of eyes to a flash. A weaker flash occurs just before the actual flash.

a) Production of useful energy by burning material

b) Chromatic lenses change their transparency themselves with changing light

c) The initial flash narrows pupils and prevents “red eyes”

fig. 12.5. Examples of fundamental transformations in material

We’ve just essentially blitz-reinvented 12 technical solutions from which at least half are inventions. These comments are a small text about understanding and uncovering resources in systems and processes.

Tables 6 and 7 instrumentalize the fundamental transformations using the A-standards and A-procedures. Many standards and procedures can be coordinated with certain fundamental transformations in accordance with the direction of their recommendations. Precisely these standards and procedures were entered in the tables as detailed and practical transformation models.

Now we can move to more complicated tasks.

12.3 Application Principles for Fundamental Transformations

Ex. 79. Training for platform diving. This is one of the best known TRIZ assignments. The problem situation is that bad dives sometimes occur in platform diving training. It’s certainly possible for divers to be injured if they land incorrectly. How can we increase the safety level in training?

First we’ll transform the administrative contradiction in this question into a more constructive model of the physical contradiction:

Component: Water
- should be “hard” ▶ according to its properties
- should be “soft” ▶ during bad dives

It is clear that material and structural resources are of interest for a solution to this problem. The material (water) needs to be changed in a certain way and if possible only in a limited section of the system - not in the entire pool. A temporal resource plays an auxiliary role. This means the solution is in effect only for a certain part of the operative time when the coach sees that a dive cannot be correctly completed.

Let’s go to table 6 *Fundamental Transformations and A-Compact-Standards.* A quick look at the table shows that some of the positions could be interesting here. We want to show them here again with their interpretation in reference to the conditions in our problem (fig.12.6).

We can note the ideal functional model at the micro level: an X resource as *material or energy particles* is present in the operative zone and, along with other extant resources, ensures “soft water”.

We now have the concrete goal to change the state of the material (water). We could do this by connecting the water to another resource. So now we can turn to the search for resources in the system and its environment. The most available resource is air. The control solution is to add air to the water! The opening of a system is installed in the operative zone on the floor of the pool that emits air and reduces the size of the air bubbles with a diffuser. These small bubbles enrich a water column in the operative zone with air. Then there is a water-air mixture for a specified time that quite a bit less dense than normal water. Bad dives are then less dangerous.

Separate **in structure**	**System transition 1-c:** the system as a whole is equipped with the property C and its parts with the property anti-C.	The entire body of water in the pool is the system. The operative zone is a part of the system that is the water at that point where the diver enters the water. It could be a defined as a cylinder 3 meters wide and as deep as from the surface to the floor of the pool. And this part of the water should be “soft”.
Separate **in material (energy)**	**Phase transition 1:** Change in the phase state of a part of the system or its environment	The liquid cannot compress itself. This is why it’s so tough when there’s quick contact with it. The water cannot move quickly out of the way and cannot compress itself. To make the water soft, flexible, compressible, we need to reduce its density, for example.
	Phase transition 2: „Double state“ of a part of the system (transition of this part of the system from one state to another in accordance with functional conditions)	Some other kind of water with another density turns out to be impossible. Accordingly, a controllable change in the properties of the water in the operative zone and in the operative time could be our goal. Is it better to do this for every dive where the desired change in the properties of the water would require a certain delay?

fig. 12.6. Selected models of fundamental transformations for example 79

You should now investigate the possibility of solving this problem with the help of the standard transformations (section 10.2).

Ex. 80. For those who love lawns but don’t like to mow them. The problem is already evident in the description of this example. It can be formulated as an administrative question/contradiction: how is it possible to cut the lawn less often?

First let's transform the administrative contradiction into a physical one:

lawn < mowing is necessary for a lawn that looks good
mowing is unnecessary - no further comment

fig. 12.7. Model of the physical contradiction of example 80

Clearly we need to introduce some kind of material resource that causes material changes. We see, too, that temporal and spatial resources play a role but as auxiliary resources, not as decisive ones. They help reach the goal that the lawn grows to certain length and then it stops growing. The role of the structural resource cannot be clearly determined here. If we turn to the table, we find at least three interesting procedures from which two belong to a structural resource.

System transition 1-b: from the system to the anti-system or a connection of the system with the anti-system.
System transition 2: transition to a sy stem that functions at a micro-level.
Physical-chemical transition: Appearance and disappearance of material through segmentation - connection, ionization – recombination, etc.

fig. 12.8. Potentially important transformations in example 80

The achievement of the ideal result is in total agreement with the first two transformations and the second is closely related to the third. *The question is still where to find and use this result if it already exists or to create a mechanism for such an ideal process.*

The control solution was developed at the University of Canberra in Australia as a material that slows the growth of grass. While working with the growth hormones of plants, scientist there discovered how to produce a material with inverse properties that slows the growth of the lawn by a factor of three. When the lawn is watered with liquid that contains the anti-growth stimulator (reducer), the intervals between mowings increase by several factors.

As a super-effect, the application of this new material is also promising for grain production. The length of the grain stalks is reduced and this makes the grain more resistant to wind, water, and the effect of the wheels of vehicles.

Ex. 81. Which is better – helicopter or airplane? We've already reinvented VTOL's for teaching purposes (see example 4). The key idea was to use procedure 07 *dynamization*. Different ideas and their combinations were used in aircraft construction: separable engines - for extra lift at take-off and landing and then to fly horizontally; adjustable wings (together with the engine); adjustable engines; adjustable jets for jet aircraft; adjustable propellers with adjustable drives from fixed engines; adjustable flaps on the wings to control the direction of air or gas streams, and others.

What motivates the development of this kind of aircraft? Today the helicopter is clearly dominant in the sky. Just like in many other areas of inventing, the invention of the helicopter was initially for military purposes. Non-military uses for helicopters were first considered in competition with other ideas. This kind of application practically covered the entire field of VTOL's and consists of rescue services and medical aid, police patrols, scientific observations, tourism, and taxis, too. However, the helicopter is yet another example of psychological laziness – *it already exists* and other technical ideas remain the "realm of fantasy". Everyone forgets that this technical system comes from military technology and uses a lot of fuel that is relatively limited on the earth. This state is still a *global criterion for quality and effectiveness*. Specialists know that compared to a helicopter, an airplane is five times as effective and is considerably safer. This higher safety comes from the fact that airplanes make an approach and land in a gliding path.

Only recently have we seen examples of the development of alternative systems for non-military purposes, although based on devices with military application, of course. For example, Bell Helicopter TEXTRON developed together with Boeing the model Bell/Agusta 609 on the basis of military models by Bell from the light helicopter Bell Boeing V-22 Osprey up to the Bell/Agusta HV 609. Incidentally Bell has already been one of the pioneers of VTOL development since the beginning of the 1950's.

Still, well-known aircraft constructions with adjustable engines (wings, etc.) have simply reused the principle of the helicopter – vertical take-off and landing. This was achieved with large propeller blades and a vertical axle. Can the economic properties and safety of VTOL's at least with light loads up to a ton be radically increased so that they become serious competition for helicopters and "hybrids" out of helicopters and airplanes?

If we simplify the model to its extreme like TRIZ recommends, we can say that the propellers of a hybrid airplane create a stream of air that is directed vertically at take-off and landing.

In other words, can we develop a hybrid aircraft that stems from an airplane and not from a helicopter?

If we use a normal airplane as a prototype, we have to "teach" it to direct air down effectively. This idea can be our ideal final result. Let's transform the administrative contradiction into a physical one:

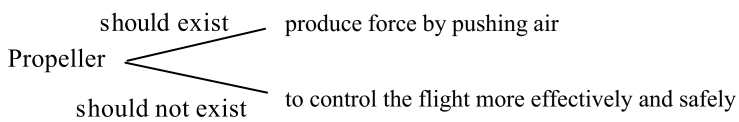


fig. 12.9. Model of the physical contradiction for example 81

The dominant resources are temporal, spatial, and structural. The temporal resource plays a role because a strong conflict is related to two *time phases* of the flight – horizontal and vertical. The spatial resource is to *turn the stream air around in space*. The structural resource is to at the very least use the principle "inversion" to *do without a helicopter take-off and landing* to find a new procedure for take-off and landing along a vertical axis. Here the character of the resources that appear is very complicated, so we should turn to the table *Fundamental Transformations and specialized A-navigators* (appendix 7):

Relationship to the A-procedures		Interpretation
01 Separate **in space**	**05 separation:** separate the disruptive part, stress the necessary part. **19 transition into another dimension:** increase the level of freedom of an object, fully use construction in several layers, sides and other surfaces. **34 matryoshka:** slowly store an object in another one, put an object in the hollow spaces of another one.	The stream of air should be separated as a controllable object and directed in necessary directions by guiding it through the fuselage, wings, and other parts of the aircraft. For example, the stream could be used instead of a stabilizing rotor.
02 Separate **in time**	**07 dynamization:** make an object or its parts moveable, optimize the characteristics of the process (the object) in every step. **18b mediator:** connect an object temporarily with another easily removable one. **40 uninterrupted useful function:** remove pauses and interruptions so that all parts of an object function continuously at full capacity.	Turn the stream of air around using a mediator, ensure continuous guidance. Examples are the redirection of jet stabilizers in helicopters - MD Explorer by Hughes Helicopters and McDonnell Douglas with no rotor in the tail; Redirection of slots in the wings of hybrid aircraft.
03 Separate **in structure**	**03 segmentation:** break down the object into its parts. Increase the degree of segmentation. **11 inverse action:** do an inversion instead of the action that seems to be appropriate to the conditions at hand. **12 local property:** move from a homogenous structure to a different one so that every part can carry out its function under the best possible conditions. **35a unite:** connect similar objects or ones determined for neighboring operations.	Divide the stream of air into controllable parts. Control how the air is directed using a mediator (see the MD Explorer above) instead of how propellers spin. Combine parts with similar functions to increase the reliability. An example is the twin motors of every propeller in the Bell/Agusta 609.

fig. 12.10. Important transformations and their interpretation for example 81

In our control solution, the Moscow Aircraft Institute (MAI) patented a solution that utilizes the best ideas from the construction of VTOL's together with the key ideas for the control of air streams through flexible adjustable vanes (fig. 12.11). The aircraft has three propellers that are driven by two gas turbines (fig. 12.11a). The nose propeller kicks in only at take-off and landing. The side propellers function at all times. Guidance and movement are controlled by the position of the vanes (fig. 12.11b) that are much more precise with much better control at take-off and landing than adjustable propellers. In horizontal flight, the air intake and control vanes in the nose are closed.

Ex. 82. Prosthetic devices for vessels. Support prosthetic devices (tubes, springs, etc.) are implanted in a large number of operations on blood vessels, in the walls of the esophagus, on gall passages, and on other vessels. Prosthetic devices give vessels the desired shape by expanding or contracting them. There is a strong contradiction in both cases because the diameter of the prosthetic device does not correspond to the diameter of the damaged vessel. This means that narrow vessels need a wider device and large vessels a narrower one. The use of long devices with flexible properties is very complicated because it's either difficult to maintain their tension when implanting them internally or inversely without tension when they're implanted on the vessel externally. A prosthetic device is needed that puts itself into the desired state that is then the initial state of the operation.

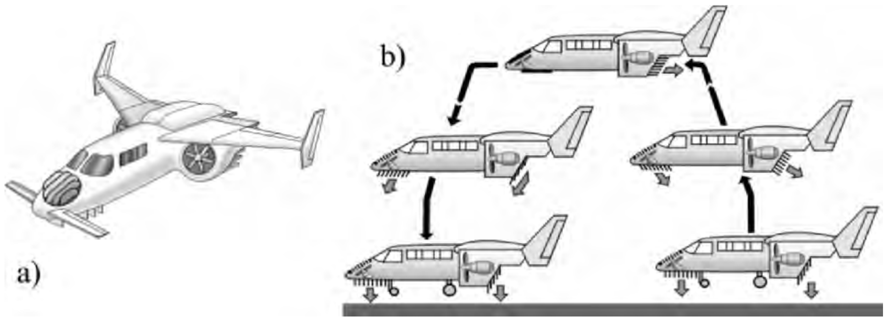


fig. 12.11. VTOLMAI: a) aircraft and b) flight phases

First model of the physical contradiction is that the device has to be small during the operation to be successfully implanted into the vessel internally and it needs to be large to maintain its position in the vessel after the operation.

Second model of the physical contradiction is that the device has to be large during the operation to be successfully implanted onto the vessel externally and it needs to be small to maintain its external position on the vessel after the operation.

Here it's important that the models of the contradiction themselves strongly conflict with each other because the place opposite demands on the material of the prosthetic device! Can this "absolute incompatibility" be resolved? It is clear that we need to initially consider a spatial resource - increase or decrease the measurements, a temporal resource - the time interval of the device's function during and after the operation, and a material resource: we need a material with special properties. Ideally this material would have two stabile states where the transition between them can be controlled.

In the table of *Fundamental Transformations and A-Compact-Standards* (appendix 6), there is an interesting example under point 4.2 with the use of a material that keeps its shape. If you don't know anything about this kind of material, it would surely interest you to look it up in appropriate reference works.

As a control solution, the Scientific Center for Surgery at the Academy of Medical Science in Russia, the Moscow Institute for Alloys and Steel, the Russian State Medical University, and other institutions have developed a series of different prosthetic devices for vessels based on metals that keep their shape. An example is a spring out of nickel-titanium that is twisted into a narrow spiral at a temperature of ca. 0° C. It's implanted through a small incision into the vessel where it slowly warms up to body temperature. Its diameter increases to the desired size and it then expands the vessel. The operation takes less than an hour and can be made without anesthesia with observation on an X-ray screen. In the opposite case, the device consists of a number of open rings that are spread again at a temperature of 0° C so that their diameter is larger than the vessel in question. After reaching body temperature, the rings close and create a series of circles that securely surround the vessel. They prevent it from expanding.

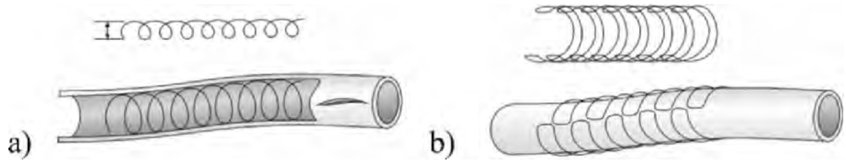


fig. 12.12. Prosthetic device for vessels: a) internal; b) external

Ex. 83. Natural light in the meeting hall of the German Parliament. A large cone with 360 mirrors (see also example 31) that reflects daylight directly into the meeting hall hangs under the central point of the dome of the Reichstag when seen from the center of the observation platform (fig. 12.13).

There is a physical contradiction that light is constantly required because the mirrors are stationary and this light should also not be present on days where the brightly shining sun blinds people in the meeting hall. Here a spatial and structural resource is clearly dominant. We can find an entire series of appropriate procedures in appendix 7 with effects that we need to examine in our description of the control solution.

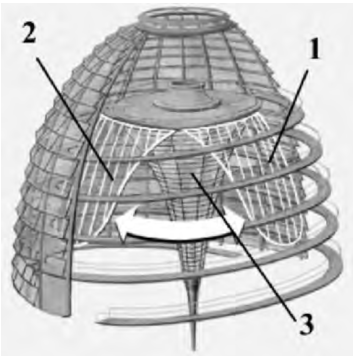


fig. 12.13. Natural illumination of the meeting hall

To redirect excess sunlight from the mirrors (05 *separation*: separate the disruptive part of the light; 12 *local property*: every part needs to function under optimal conditions - the mirrors) **we need a previously installed shade** (18 *mediator:* include another object temporarily; 28 *previously installed cushions* and 39 *preliminary counter-action*: disaster measures and inverse effects need to be planned in advance)**, that has a shape similar to the upper part of the dome** (22 *spherical-shape*: move from flat surfaces to spherical one) and **is installed around the cone 3 with mirrors, and that follows the sun's movement from the starting position 1 to the final position 2** (07 *dynamization*: the characteristics of the object should be optimal in every step, the object should be moveable; 22 *spherical-shape*: change to a rotational movement; 39 *transition to another dimension*: transition to a spatial movement).

A description of the procedures was integrated into the description of the solution on purpose so that you can understand the functions of the procedures in context in a detailed way. You should read the description carefully and think about the fragments in bold as many times as is needed until the entire description is understandable as a whole.

Ex. 84. A gas turbine by SIEMENS. You can read in every reference book that the most important factor for the effectiveness of turbines that are installed in thermal power plants is the level of their efficiency. This factor is somewhat better with large turbines. However, as turbines get larger, their reliability and working life suffers. Above all else, this problem stems from the relatively short life of the turbine blades because they are subjected to the thermal and mechanical load of hot gases.

Stage 1 diagnostics. The short life of the turbine blades is caused by the extreme mechanical and thermal load to which they are subjected. This load often comes in one extreme moment and in cycles. The extremes can be causes by destructive resonating vibrations. Cyclical thermal loads lead to accelerated material stress in the blades.

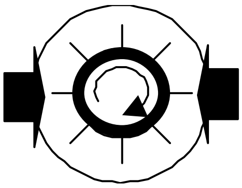


fig. 12.14. Scheme of a turbine prototype

This is why the turbines are often temporarily offline to repair the blades. Clearly this has a negative effect on the turbine's output. In previous constructions (fig. 12.14) there were two symmetrically arranged heating chambers in which a certain number of burners were installed respectively, for example, 8 in each chamber. When two or three burners went offline, the entire turbine had to be shut down to maintain the level of efficiency and due to the possible danger of destructive vibrations.

When the heating chambers are online, hot gases press against the blades and cause the turbine to spin. It is clear that the blades are subjected to maximum mechanical and thermal stress directly at the heating chambers. Then the pressure on the blade and its temperature sink until it spins to the other chamber. This happens twice during every rotation of the turbine.

Stage 2 reduction. The operative zone is the working surface of the blades. An analysis of both versions of the contradictions (fig. 12.15) shows that the *ideal final result could be that the hot gases apply continuous pressure to the blades at a constant temperature.*

blade
- is subjected to periodic stress and a mechanical load as given in the design of the turbine.
- should be subjected to a constant mechanical load without sudden stress as this increases the turbine's working life.

a) F_m - model

blade
- is subjected to sudden thermal loads as given in the design of the turbine.
- should be subjected to constant thermal load without sudden stress as this increases the turbine's working life.

b) F_t - model

fig. 12.15. Models of the physical contradiction

We can also see from our analysis of the resources that the flow of energy (pressure on the burning gases) is not continuous and that this doesn't correspond to the ideal functional model. Accordingly we could search for a solution where the construction of the turbine is coordinated with the requirements of an ideal final solution.

For our purposes, it seems necessary to search for resources that are in a larger operative zone instead of on the surface of the blade. They could be in the functional space where the blades move, for example. The most important resources include space - the entire space around the turbine including a part of the turbine itself that is in the immediate proximity of its functional space (this could be devices or auxiliary systems) and time - the time of the blade's movement between the heating chambers (this span of time should be as short as possible).

Stage 3 transformation. According to table 7 (see appendix), the contradiction we have here can be solved only with transformations in space, time, and/or structure. Shouldn't we create a "portrait" of the solution in general form by implementing these recommendations?:

19 transition into another dimension: Use of multi-level construction, use of neighboring and other surfaces;

34 matryoshka: place an object in a hollow space of another one;

02 preliminary action: arrange objects so that they can function more quickly;

40 uninterrupted useful function: Remove pauses and interruptions, all parts of an object work without interruption at full capacity;

03 segmentation: separate an object into its parts;

12 local property: Every object should fulfill its function under the best possible conditions.

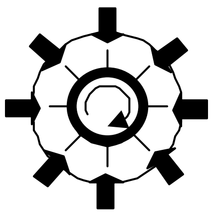


fig. 12.16. Scheme of the new turbine

Idea for a solution (fig. 12.16): The heating chambers that cause concentrated stress on the blades have to be more evenly distributed (according to procedure 03). Individual burners that are in the turbines functional space can also be used (according to procedure 19 and 34) that reduce the time required for the blades to move to the next chamber (according to procedure 02 and 40), the temperature fluctuations, and the force of the mechanical load (according to procedure 12).

Ex. 85. Aircraft of the 21st century? Air slows the movement of aircraft in addition to carrying them. The air resistance also increases in proportion to the speed of the aircraft. The energy of the fuel is used primarily to displace the air molecules that work against the forward movement (see again example 47 ship with hydro-foils). The air heats the nose of the plane to almost intolerable temperatures.

This is why aircraft need to fly at hyper-sonic speeds such as 10 M (the Mach number describes how many times faster than the speed of sound the plane flies) at high altitudes where the air is thinner or even at the edge of outer space.

However, there are fundamental problems with the development of hyper-sonic aircraft: 1) construction of high-speed engines; 2) energy for board systems; 3) fuel for the engines; 4) over-heating of the nose.

We'd like to reinvent a solution to these problems using the hyper-sonic aircraft *Neva*. Its concept was developed by an engineering team in St. Petersburg. For flights at hyper-sonic speed, direct current air-stream engines are used (fig. 12.17).

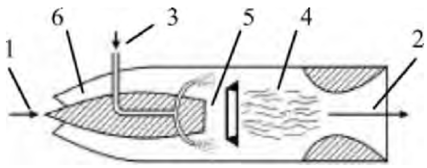


fig. 12.17. Functional principle of the direct current air-stream engine

Their functional body is air 1 that enters the engine through an air intake and exits from a jet as hot gas 2. Fuel 3 is burned in the engine that heats the functional body. The heated air expands and is pushed out of the jet together with the burned products and the aircraft is thrust forward. The problem is to attain super or here hyper-sonic speeds at the exit of the functional body from the engine.

The solution was to use an afterburner to re-ignite the initial mixture. This has no future at speeds of 10 M or more.

In addition, the air has to be very dense prior to the heating chamber 5 and this is done using the special diffuser form of the intake 6. But, higher air density using mechanical resistance slows the aircraft.

Here are the **models of the physical contradictions**:

1) *The compression of air in front of the heating chamber* of the engine is necessary for the engine's work and it should not happen so that the aircraft is not slowed down.
2) *The gas exhaust from the jet has to be accelerated* to reach super-sonic speeds and this acceleration should not happen because it contradicts the procedure for acceleration that use an afterburner.

The existence of contradictory processes at the intake and exhaust of the engine leads us to believe that it makes sense to select *structural direction* 3.2 from the table *Fundamental Transformations and A-Compact-Standards* (appendix 6) as well as directions because clearly *material-energy resources are present here*. The impossible requirements of the compression of the intake air and the acceleration of the mixture show that a new functional principle is needed. Here we see a further instrument of TRIZ for the first time – the physical effects (see the following section 13). There are similar suggestions for the use of magnetic fields for gases in positions 5, 6, 12, 17, and 28 in appendix 8.

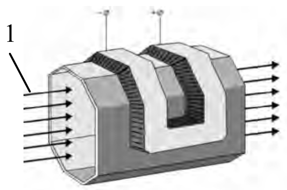


fig. 12.18. Functional principle of the MHD generator

If we searched in technical literature, we would soon come to the concept of magnetic-hydrodynamic (MHD) generators although they are actually used to produce electrical energy (fig. 12.18). Let's assume that the air is ionized at the intake of the engine. Particles of ionized air 1 produce electrical energy in the loops of the MHD generator when they "fly" through it. But, this slows particles down!

If this kind of generator is installed at the intake of the direct current air-stream motor that we know so well, this reduces the speed of the stream of intake air. This doesn't slow the aircraft and it means that an additional power plant is on board. This is an excellent example of the successful application of procedure 21 *Transform damage into advantages*: use of damaging factors, or more precisely, damaging effects of the environment to create a positive effect. The MHD generator is necessary to slow the air down and we've gotten an additional power plant. This solves problem 2.

But, how can we accelerate the gas exhaust? The builders clearly used procedure 11 *Inversion*: they sent enough electricity into the loops of the MHD generator to create a magnetic field that is so strong that it accelerates the gas exhaust out of the heating chamber by several factors. The generator became an accelerator, or in this case, an engine. The control solution was to develop a new engine for super-sonic aircraft that uses the principle of a MHD generator twice – directly and inverted (fig. 12.19).

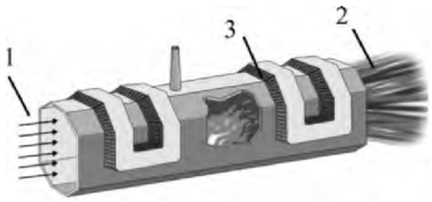


fig. 12.19. Functional principle of the engine of a super-sonic aircraft

Ionized air 1 is used as a functioning body and then an expanding ionized gas 2 can be accelerated in the magnetic field of the MHD generator 3 up to 25M. This means this method will work up to the first cosmic escape velocity. The MHD generator and engine make a very effective pair for a technical solution – a system and its inversion. Problem 1 is solved. Surely you've noticed that a question still remains: where do we get the ionized air for this engine? This is another **physical contradiction**: ionized air is necessary for the engine and it cannot be present because air molecules are neutral in a normal condition.

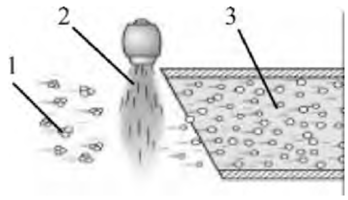


fig. 12.20. Ionization of air using a laser beam

Clearly we need to continue to work with recommendation 4.5 from appendix 6 to use a physical-chemical transition connected to the ionization of air.

If we look in reference books we will see that one of the most effective technical solutions for the ionization of air is the use of a laser beam.

A control solution is to use a laser in front of the air intake to create an ionized air stream into the engine (fig. 12.20).

The laser beam 2 transforms neutral air molecules 1 into negatively charged ions 3. The ionized air 3 flows into the first MHD generator to be slowed down and to produce electricity. A relatively small part of the electricity from the generator is used for the laser.

We can now examine problem 3 - fuel. The main fuel used for jet engines is kerosene. In the heating chamber, the kerosene is heated into fumes and the process of oxidation with oxygen starts (burning). A part of the energy is used to heat the kerosene. This is the **physical contradiction**: the fuel has to be heated into fumes for the burning process and the fuel should not be heated so that energy is not used in the heating chamber and the temperature of the burned gases is higher.

A system analysis of the functional requirements and of the structure of the entire machine shows that we need to turn again to the recommendations 3.2 and 4.5 that we just used: combine a system and its inversion with the control of the processes at the micro-level! An energy source is needed in the aircraft to heat the fuel. Look again at the initial description of problems in the development of this apparatus where you might find a free energy source! We could use the kerosene to cool the overheated nose of the aircraft! Note that this is once again an interesting application of procedure 21 *transform damage into use*.

fig. 12.21. Cooling scheme for the nose of the aircraft that pre-heats kerosene

The control solution is to build double walls into the nose of the fuselage between which kerosene circulates to cool the outer wall (fig. 12.21).

Problems 3 and 4 were solved simultaneously.

Good solutions always have positive super effects that are unexpected and unplanned!

1. The kinetic energy of the intake air was transformed from a negative to a useful factor so that it functions as an on board power plant with a capacity up to 100 mega-watts! This energy could provide a small city with energy. The laser and MHD generator use a part of this energy. The remaining energy can be used to carry out other functions of an aircraft and other work: burning space garbage, reducing ozone holes, etc.
2. The use of non-mechanical systems for the ionization and acceleration of the functioning body - a special structure of electromagnetic systems consisting of a system and its inversion - allow us to achieve the first cosmic escape velocity in flight! The energy needed is drawn from the ionized stream and used to ionize and accelerate this (heated) stream.
3. The problem of cooling the nose of the fuselage was ideally solved without the development of a special system! This causes no additional problems and no new expenses for a solution to the problem! The cooling of the fuselage heats the circulating kerosene and increases the efficiency of the jet engine!
4. A totally new extra super-effect is that the ionized air flows around the aircraft in addition to into the engine and this flow can be used to create additional lift. Electromagnets help to increase the flow under and decrease it over the aircraft!
5. And finally there's one more special effect. In addition to kerosene, there's also water in the fuel. Free hydrogen can be released from this water using thermal-chemical splitting with a catalyst. This means that the fuel can burn 5 times faster than in a engine with liquid hydrogen!

In fig. 12.22, you can find the developers' representation of the hyper-sonic aircraft *Neva* and in fig. 12.23 is both a scheme and the time needed for this aircraft to fly between different points on the planet.

fig. 12.22. General view of the hyper-sonic aircraft *Neva*

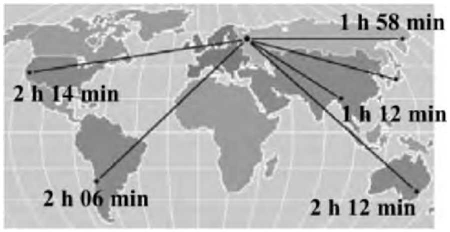


fig. 12.23. Possible flight-routes of the *Neva*

To conclude this section, we should note that the examples used were simplified and adapted by the author to make them understandable to the largest possible public. They were used exclusively for teaching purposes, meaning that they are only illustrations of TRIZ instruments. TRIZ recommends that we use examples from different fields of knowledge – this helps to overcome the psychological laziness that comes from limited professional knowledge, interests, and traditions. The author wanted to do this, too. And last but not least, TRIZ instruments function well only when based on professional knowledge and a certain level of its application. You should always keep this comment in mind and not despair if your first attempts to apply TRIZ instruments yourself are not as impressive as some of the examples shown here. This book has already changed your thinking, it has strengthened your intellectual tools. It's simply that the task you've given yourself is much more complicated than it would have been earlier or than it was before you knew about TRIZ instruments. This kind of task can only be solved at a rational time and with excellent results using TRIZ.

13 Navigators to Search for New Functional Principles

13.1 Tables of Technical Effects

Generally we can describe an *effect* as a functional relationship between two processes. This means that changes in a process described as a *cause* lead to a change in another process that is then described as a *result*. The actual functional relationship is called an *effect*. The process is usually described using certain parameters such as pressure, temperature, speed, acceleration, etc. Then a change in the value of a parameter is also the concrete implementation of the process. In an extreme case, this is also the unchanged retention of a parameter.

A model is often used in technology that connects an effect with a certain technical system (element) that implements this effect. For example, to run electricity through a metal spring heats it so that it radiates thermal energy (for the sake of simplicity, we won't consider other effects here that are present in this simple system). The electricity causes thermal radiation (result). In technical systems, the process cause is often termed a *start process* and the process result is termed an *exit process*. Accordingly, all of the elements of the system that interact closely with the start process are called the *start of the system* and those that interact with exit process are called the *exit of the system*. The effect is described with words such as influence, function, functioning, transformation, and other terms. If in the example at hand an electricity is introduced into a heating element and a thermal field comes results, we can say that the heating element completes the transformation of electricity into thermal energy. The primary physical influence that a system causes is usually fixed in the description of the system (the elements). The example could be termed an "electric heating element". The most important point in this description is the anchoring of the *principle* of the element. We could also use the description "electric heating spring", if we want to stress the construction or form of the element along with its principle.

We can generally define the *technical* effect as any influence, transformation, phenomenon, or function that is used as a principle of a technical system for the development of the system itself. For example, we could say that the principle of the heating element in consideration is based on the transformation of the energy of the electricity into thermal energy with the help of the conduction of electricity through a metal spring. In addition, the parameters of the transformation, of the material, etc. can be described because they are the conditions for the functioning of such a system.

We can differentiate between effects with one function and compound effects that consist of several functions (multi-processing and multi-parametered). The function of a technical system represents a complex interaction of a wealth of effects. Tables of physical-technical effects (physical phenomena that are used in technology), chemical-technical, bio-technical, etc. were compiled for general classification and application. To simplify the description of the effects and tables, the term "technical" is often left out and we say instead "table of physical effects", "table of geometric effects", etc.

Usually the basis for brilliant inventions is the first usage of an effect that was previously unknown and is then called an *invention* or it is an unexpected and new usage of a known effect (combinations of several effects). Remember the development of *radio technology* literally based on the effect of the electromagnetic radiation of a part of a metal conductor provided with electric current (see section 1 *invention*). Even Heinrich Hertz could not have foreseen that his invention would be put to use in praxis (he thought that the technical problems were simply too formidable) and would cause a tremendous revolution in the development of civilization.

TRIZ contains tables for the technical application of several hundred effects based on an analysis of hundreds of thousands of inventions. The content of every application is described along with its technical implementation (fig 13.1). These models of technical effects were first widely distributed with the introduction of the innovative software *Invention Machine.* Subsequently a comprehensive data bank with knowledge of technical effects was developed and is continuously updated and expanded in the software *TechOptimizer* (see section 21.1).

Characteristics of the technical effect "luminescence"	
Description	Light radiation from objects that is supplementary to thermal radiation and that exceeds the duration of light waves after the influence of its cause is stopped.
Classification	We differentiate according to the type of stimulation, for example, photo-, cathode, electrical, X-ray luminescence, etc.
Application	1. Representation of information – different TV screens 2. Perception of defects: defectoskopy, perception of the loss of material 3. Detection: luminescence analysis in criminology, medicine, geology, for protection against falsifying money and documents 4. Measurements: examination of material properties using sensors where the intensity and spectrum of light is connected to the parameters of material and fields – to chemical composition, temperature, pressure, etc. 5. Illumination: light diodes, luminous lamps (in daylight), electro-luminating condensers, etc.

fig. 13.1. Characteristics of the technical effect

Shortened tables (appendix 8-10) have also been used in which physical, chemical, or geometric influences that relate to the purpose of the table are shown for common technical effects where there are examples of an effective technical application. The examples are not shown here as we assume that users can look up any effects they don't know but have chosen as a possible principle in appropriate reference works. This simple and practical approach was also put into praxis in the software *PentaCORE* (see section 21.3) where there is an automated function to find search systems for a series of special and universal reference works that are available in the Internet.

Here we would also like to point out the relationship of effects to other transformations. It is completely obvious that physical effects are the basis for procedures like 01 *Change in the aggregate state*, 04 *Replace the mechanical material*, 06 *Use of mechanical vibrations* and many more. Chemical effects are the basis for procedures such as 15 *Discard and renew parts*, 23 *Use of inert media*, 26 *Use of phase transitions,* etc. Procedures such as 10 *Copy*, 11 *Inversion*, 19 *Transition into a new dimension*, 22 *Spherical shape*, 34 *Matryoshka,* etc, are supported by geometric effects. You can also attempt to follow the corresponding relationships of basic technical effects to fundamental and complex transformations as a very useful, if also time-consuming exercise.

To conclude this section, we would like to note that ideally the basic technical effects reflect the entire sum of humanity's scientific-technical knowledge. Systems like *TechOptimizer* and *CoBrain und Knowledgist* (see section 21.1) are developing in precisely this strategic direction. Each of us has access to just a part of this knowledge. This includes universal knowledge from elementary and secondary school, specialized knowledge from college and university studies, and knowledge from our on-going independent work with scientific-technical sources of information. Clearly we use only fraction of the entirety of this knowledge and only that part that directly relates to our individual area of expertise. We have also noticed that many brilliant inventions were developed after knowledge from other areas was tapped. It is therefore sensible to expand our creative potential by studying available data banks of technical effects and the key concepts on which solutions in other areas of science and technology are based.

13.2 Application Principles for Technical Effects

Transformations aided by technical effects are based on the *principle of analogies* or on the *direct implementation of the function needed* using known technical solutions that are adjusted to the concrete requirements of a new application. All technical systems are actually nothing more that certain *combination of technical effects* that were put into praxis in appropriate constructions. Combinations characterized by usability and absolute innovation are recognized as inventions.

To comprehend the entire spectrum and all nuances of work with technical effects is anything but a simple task even when supported by software. We would therefore like to investigate only a few examples that should help introduce and illustrate the extremely diverse instruments of technical effects.

Ex. 86. Are all nails cylindrical? A standard "cylindrical" nail penetrates well into wood but it can loosen when subjected to temperature changes and mechanical vibrations. We can say that the wood itself guides the "driving" of the nail. Let's go to the table *Geometric Effects* (appendix 10) to search for appropriate recommendations for possible changes in the "principle" of a nail. We find the recommendation *replace round objects with ones with corners* in point 9 *Reduce the controllability.* Our control solution is that in Poland a nail with a triangular cross cut is manufactured that "sits" in wood better than a normal nail.

Point 10 in the same table *increase the functional life and reliability* contains the recommendations *changes in the contact surface* and *special selection of shape*. Another control solution is that in Germany a nail is manufactured with a rectangular cross cut that gets thicker along its length symmetrically to this length so that it resembles a wood screw with threads as long as its length. In other words, there is a twist on the nail with 4 threads corresponding to the number of corners in the original quadrilateral cross cut. This kind of "nail" is a mixed construction that is easier to produce than a screw but that sits better in wood than a nail.

Ex. 87. More pleasant ... street noise. Laud, uninterrupted, and relatively monotone noise from constant traffic on the street is tiring and disrupts work. Normal jalousies reduce the noise level somewhat but the monotone sound is unchanged. This monotone sound comes from the constant spectrum (structure) of the frequency of the acoustic vibrations produced by the stream of traffic. Let's turn to the table *Physical Effects* (appendix 8) where in point 24 *Create a given structure, stabilize the structure of an object* we select the effect *mechanical and acoustic vibrations*.

Physics tells us that a so-called frequency filter can be used to change the structure of the spectrum of a complicated vibrations process, including an acoustic one. These filters are mediators and changing devices that filter out or weaken certain frequencies while they let other frequencies pass. A control solution are jalousies developed in England that are constructed with pores of differing size that implement the idea of a mechanical filtering of acoustic vibrations so well that the sound they pass on resembles the spectrum of waves at the beach. These sounds do not cause effects like exhaustion, loss of concentration, etc.

Ex. 88. Assessment of wear in engines. As an engine wears, the number of metal micro-particles in the oil that lubricates and cools the moving parts increases. It's therefore possible to estimate the level of wear of an engine by assessing the number of these particles in the oil. The problem is to find the particles and assess their number.

The following points in the table *Physical Effects* (appendix 8) seem to fit here: 5 *Indication and change in the location of an object* and 22 *Control of the state and properties in space*. We already know the *Application principles for supplements* according to the complex transformations, so we can assume that they are more promising and less complicated than other recommendations. We can turn to the recommendation *Addition of markings that transform external fields (Luminophores) or produce their own fields (ferro-magnetics) and are therefore easy to find.* In reference works it's possible to find out more about the use of luminescence so that we can attempt to interpret such examples for the problem at hand. In this particular case, let's turn to the characteristics of the physical effect luminescence shown above to look in reference works for more detailed information about exactly how the intensity and spectrum of the light of luminophores relates to the parameters of material and fields, of chemical composition, temperature, pressure, etc. We find that *metal particles reduce the intensity of luminescence*. This leads to an idea for a measuring system: when we add a luminophore to the oil, the intensity of its light sinks as the number of particles increases. This points to increased motor wear.

Ex. 89. Does a rose bloom that was still cut as a bud? To attain the maximum amount of time after cutting a rose until its sale, it can be cut before the bud is open. This allows us to provide even distant florists with roses. How can be guarantee that the buds then actually bloom?

We can search for an appropriate chemical effect (appendix 9) with the points 22 *Control of the state and properties in space (specifically the reaction to the use of photoreactive materials or indicators)* and 23 *Change in the spatial properties of an object (density, concentration, etc.).* Of course we needed preliminary investigations to clarify this question. We needed an indicator, a material, or a field whose presence in the roses provided reliable help to time the cut correctly. The results of similar examinations are well known. Starch reacts with iodine to produce a *blue* color and starch is an essential carbohydrate resource of plants. We could test the color reaction of the buds of the cut roses with iodine. As a control solution, researchers at the Wageningen Agriculture University (Holland) have determined that roses don't bloom when the starch content of the buds is less than 10% of their dry weight. The energy resources in the starch are then insufficient.

Ex. 90. Can we invent a new "principle" for a soccer ball? Let's go to point 5 *Intensification of a process* in the table *Geometric Effects* (appendix 10). The following recommendation seems to be the most interesting of the effects in this point: *Transition from processing along a line to processing on the surface* and *Eccentricity (Move the rotational axis of an object from its "symmetrical axis").*

We can relate the first recommendation to Magnus' physical effect in point 6 *Control of the positioning of an object* in the table *Physical Effects* (appendix 8). Very few people know that this effect is a scientific explanation and description of the behavior of a football with a curved trajectory. According to this effect, an object that spins in a gas or liquid that flows against its movement exerts a transverse force. The object is also pushed in the direction in which its rotation and the flow of gas or liquid work together. You can now easily analyze in which direction the ball was spinning when it "flew around" the wall of defenders, curved, and flew into the goal. Tennis players also know this effect very well, perhaps without knowing its name.

Volleyball players know another effect. When serving, a strike on the cover of the valve causes the ball to change its trajectory suddenly after a few meters, as if it jumped sideways. We can explain this effect so: initially the valve is covered by the hand of the player who serves. Then it turns slightly with the rotation of the ball caused by the opposing air until changes in the balance of the ball lead to an additional diversion from the balls initial "straight" trajectory.

A control solution based on a combination of effects is to attach a small weight with elastic bands or other material that can move during the ball's flight to change its balance. It then has a crazy flight path with unexpected diversions from a normal trajectory. This kind of ball can be used for games or to train the reactions of athletes. When the ball is struck, Magnus' effect appears in addition to the effect of the arbitrary movement of the ball's balance - which is also its rotational center - and we can see yet more unexpected movements.

Ex. 91. Strong speaker ... in your hand. The largest part of a stereo system is always the speakers, especially the speakers for low frequencies. The better the quality of a speaker, the larger the components for low frequencies. This is caused by the fact that a radiating element (electrodynamic speaker) with a large diameter is needed to reproduce low frequencies. We've already seen how the physical effect of the filtration of oscillations can be used in an unusual way in example 86. If we want to develop the creation of oscillations further, we could turn to the effect of amplitude modulation. Essentially, this procedure corresponds to point 16 *Energy transfer: mechanical, thermal, etc.* in the table *Physical Effects.* The *law of increasing optimization* (see section 15.1 *TRIZ Laws of System Development*) dictates that the final result in this example would be quality sound with low frequencies is present without speakers that produce it.

Actually it seems impossible to solve such an improbable contradiction. The American firm ATC thought differently. There developers came up with the idea to modulate acoustic oscillations with a low frequency (language, music) between 20 – 20,000 Hertz to oscillations with a high frequency between 200,020 – 220,000 Hertz and generate these oscillations that humans can't hear with piezoelectric high-frequency speakers (fig. 13.2).

fig. 13.2. New speaker

The main components at 200,000 Hertz are "read" out of the first oscillations at high frequency using exactly the same kind of speakers synchronically in the opposite phase of the high-frequency oscillations. Again we see the combined effect of a *system* (high-frequency with a certain frequency) and its *inversion* (high-frequency at the same frequency but produced in the opposite phase). This made "incompatible" properties "compatible" and resolved the contradiction.

Ex. 92. An ideal cleaning rag. A dry rag made of normal cloth or even one moistened with water often doesn't clean tiles, polished furniture, or cars well. Then people often use chemical products. According to the table *Chemical Effects* (appendix 9), this corresponds to point 6 *Control of changes in the location of objects,* point 20 *Control of the state and properties of surfaces,* point 21 *Changes in surface properties,* and especially the recommendations *Use of hydrophile and hydrophobic materials* and *Use of surface materials*. Environmentally speaking, the use of chemical cleaning materials is problematic. They can also change the color of colored surfaces or otherwise cause damage. The rags get dirty quickly and are then land in the garbage where they contribute to household and industrial waste. The ideal result would be that the rag removes dirt completely from the surface to be cleaned and then releases the dirt easily, for example, using water without chemical products. So far we have a contradiction at the functional level where no ideal result is apparent.

Let's go back to the beginning. The *water of the rag* plays the role of a "*micro-absorber*" that attracts and holds particles of dirt and the *material of the rag* plays the role of a "*macro-absorber*" or even of the *absorber* that holds both water and dirt in its pores between threads. The problem is that dirt penetrates with water into the micro-pores of the threads so that it cannot be removed by simple washing. We can now describe the initial contradiction at the "micro-level": the threads of the rag should collect water along with dirt and should not retain the dirt. But this model is not correct! TRIZ dictates that the instruments have to be defined precisely. A careful examination, even using the "thought amplifier" of the model *Dimension-time-cost* – see section 18.2, if necessary, leads to the following formulation of the *physical contradiction*: the pores between the threads retain the water with dirt well, but the threads don't retain the dirt. Here we can see that somehow the contradiction solved itself in space because the "incompatible" requirements refer to different objects!

This means that only one of the problematic requirements is left - the threads cannot retain the dirt. We can now define the required property as the lack of a porous surface on the threads or in other words as the very high hydrophobia of the threads in accordance with the chemical (better - physical-chemical) effect mentioned above. A thread made of 100% cellulose has the qualities needed here. This is precisely the control solution developed and used by the German firm H_2O-Aktiv Vertriebsgesellschaft Reinigungsprodukte mbH.

Finally, we should recognize the effective participation of a structural resource in this solution to the physical contradiction in question: a dense weave of thin cellulose threads results in a strong hydrophile that energizes water and reduces its surface tension for better absorption of dirt particles. This means that every thread of the rag (part of the system) is hydrophobic, but the rag (entire system) is a hydrophile! When washed out, the rag releases both water and dirt and it can be reused indefinitely. Because of its water attraction, the moistened rag can remove even oil and oil-based paint.

Ex. 93. Fairy tale reality. Who didn't read the fairy tale as a child about the magic mountain where sweet porridge flows? A magic word started the flow and an even more important word stopped it. Otherwise the world would be flooded with porridge, at least in that fairy tale. Today, statements by opponents of gene and nano-technology indicate that we can no longer exclude such images from the realm of the possible. Instead of porridge, we now have to consider viruses, bacteria, and other visible or invisible artificial entities, some of which may even be able to "think". Actually we would like to examine simpler and less dangerous examples here.

How can we make training shoes (or other shoes) fit perfectly? Every foot is individually shaped, but shoes are produced in standard sizes. We need a procedure where training shoes become a perfect copy of the individual foot! Let's go to the table *Chemical Effects* (appendix 9) and examine points 22 *Control of the state and properties in space* and 23 *Changes in the spatial properties of an object*. If we look at the technical literature, we quickly see that there are materials that can quickly and continuously decrease or increase the volume by many factors. They only need a small amount of a supplementary activating material, a change in temperature, or other factors. An entire class of these materials known as "intelligent gels" was developed in Japan. They were first used for training shoes that expand as the foot warms to firmly, yet gently support it. An "unsolvable" physical contradiction was solved at the level of materials using a chemical effect: training shoes have to be manufactured regardless of the individual details of feet, but they need to fit every consumer perfectly. A solution to an analogous problem is the development of "intelligent" packaging that firmly, yet also carefully surrounds any products to be shipped in a package regardless of how complex their form and fragile their material is. An example is thin glass.

fig. 13.3. "Intelligent packaging" out of "self-activating" polymer foam

In addition to the chemical effects we've already examined, we can add *Use of elastic and flexible materials* from point 19 *Change in the size any shape of an object* from the same table as above. Sealed Air Corporation has developed highly elastic polyethylene bags in various sizes that produce polymer foam when subjected to mechanical or thermal influences that then spreads evenly through out the entire volume of the bag (fig. 13.3). The growth of the sealing packaging is limited by intelligent packing itself! We can clearly consider a few "fairy tale" inventions to be prototypes for real projects.

The goal of this example is not just to demonstrate the effect of one or the other chemical effect. We also want to show that these effects can result in new technology and objects that can then be applied to problems regardless of their origin. These kinds of objects can also be found if we look in encyclopedias or other technical reference books for examples of how this or that effect was put into praxis or how necessary properties were attained. This is what we've done by concentrating on a relatively limited number of "steps" into the tables we've considered. We should note that the last example shows an effective application of foam, actually of hollow spaces in a material such as self-sealing packaging.

Here the hollow space is an ideal material that is both present and not present because it fills virtually the entire volume of the package by pushing a polyethylene cushion in every direction where there's is no resistance!

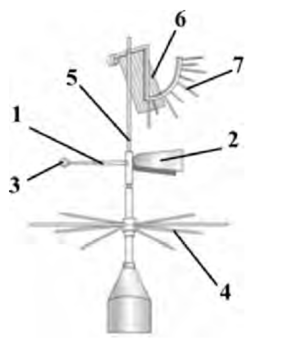


fig. 13.4. Movable weather vane

Ex. 94. Fixed weather vane! We could find a description like this in a reference book: a weather vane is a meteorological device to determine the direction and speed of the wind (fig. 13.4). It consists of two moving parts – the actual vane 1 that points in the direction the wind is blowing with tail 2 that is wind sensitive and a metal plate 6 that changes its angle according to the wind's speed.
The weather vane turns together with the rod 5 to direct the plate into the wind. The weight 3 that balances the weight of the tail shows the direction of the wind in reference to the fixed pins 4 that are arrayed horizontally. The angle of the meal plate in relationship to the curve 7 with an angle scale shows wind speed. This is a very old device that is not very precise because the vane doesn't turn and the plate doesn't move when the wind is light. The plate is also very unstable when the wind is strong.

We can formulate two similar physical contradictions:

1) the vane should be light to function with light wind and it should be small and heavy to work reliably and securely with strong wind;
2) the plate should be large and light to function with light wind and it should be large and heavy to work reliably and securely with strong wind.

Ideally for TRIZ, the characteristic "small" as it refers to properties like size, weight, or certain negative factors means that we need to try to imagine "non-weight" or "non-size", etc. A "non-vane" and a "non-plate" would not be able to move at all! This is contradictory to its functional principle, or better, to its *previous* functional principle that contained unsolvable contradictions. What if we attempted to develop a weather vane with a vane and plate with non-size and weight?! This sounds completely paradoxical – "a fixed weather vane".

Essentially we need a new functional principle for this device with the old functions that somehow work better. We can retain the old name - weather vane - with perhaps the addition of the new principle. The new principle needs to be based on the general principle of all measuring devices – either the perception and assessment of an absolute difference between a certain fixed value (horizon) and a variable value to be measured (position of the wind vane, or more precisely, the angle of the vane as it relates to the control direction, for example, north and then clockwise) or the perception and assessment of the difference between changes in two values for comparison from which one changes more quickly than the other (measure the difference).

If we use the last procedure, we can assume that many effects could come into consideration here. Try to develop fixed weather vanes yourself where the functional principle differs from those we will explain in our control solution. This solution demonstrates a general procedure to overcome stereotypes in thinking which is supposed to be the most important and useful result of this example anyway. If we consult the table of technical effects, we could conclude that the wind speed could be measured using the degree to which an object is cooled that is exposed to the wind (point 1 *Measure the temperature* in the table *Physical Effects* and the group of effects described as *Thermoelectric Phenomena*). But, how can we measure the direction of the wind with this procedure? We could cover a part of the heated object, expose the other part to the wind, and then rotate the object until we find the position in which it cools most quickly. This would mean that the wind is blowing from that direction. This is possible, but it's complicated and it requires time. Mechanical changes in position are clearly not appropriate.

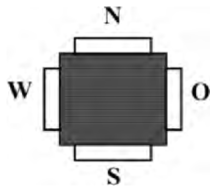


fig. 13.5. Fixed weather vane

As a control solution, a weather vane was developed at the DIMES Delft Institute of Microelectronics and Submicron Technology at the Delft University of Technology (Holland) measuring 5 x 5 mm^2 that consists of an integrated silicon circuit with a thermal sensor on every side (fig. 13.5). The circuit is heated from below evenly. The circuit cools slightly on the side where the wind is blowing and this is immediately registered by the appropriate sensor. When the wind blows from a diagonal direction, two sensors register the different cooling effect on those two sides where they are mounted. The greater the wind speed is, the more pronounced is the cooling. The direction of the wind is determined by the circuit based on the differences in current that are produced by the sensors. This example also shows a terrific solution that reduces a system – exclude superfluous, ineffectively functioning, or unreliable elements (see section 15.2.4). This new principle makes it possible to develop a compact system without movable parts that functions in a broad band of wind speeds from 10 centimeters up to 60 meters per second.

Ex. 95. *Perpetuum mobile* for humanity?! An even more impressive example of this kind of reduction is an idea for the development of hydrogen "fuel". Our lazy thinking causes us to think immediately about the development of a "new" engine with internal combustion where hydrogen is burned together with gasoline as a "fuel" to combine with oxygen and produce water as waste. We could imagine that this kind of engine would be absolutely ideal and this is really remarkable in itself. But, reality actually looks better in this case - much better!

The reason is that the new “hydrogen engines” by Daimler-Chrysler don’t burn anything because they no longer function with internal combustion! This is really a new technical revolution the meaning of which again our lazy thinking prevents us from understanding. Surely the automobile of the future will be strictly ecological with a high level of efficiency and an extremely reliable power plant based on an electric motor. But - it will still be fueled externally at gas stations with hoses. It is precisely this retention of old methods to service and steer cars that prevents us from noticing the coming revolution. This shows us clearly that grandiose, revolutionary changes come in civilization without being noticed. We can only hope that they will all be as positive as the development of new cars that we’ll describe with the term NECAR (New Electric Car). NECAR is one of the test series of this kind of car at Daimler-Chrysler today.

This example should not be reinvented here, but rather examined as a leading example of the practical development of an entire complex of physical-chemical effects. These are effects that above all else are the basis of the functional principle of a new energy source. But, they also stem from a new drive and energy system for cars although the application of this new idea is certainly not limited just to that. I hope you reach your own conclusions from this point that are as important as in reinventing.

In fig. 13.6, you find two variations of an energy cell for Necar: I – based on previously produced hydrogen and II – based on hydrogen produced in the car itself.

In scheme I, hydrogen is directed through a porous anode 1 where a catalyst 3 causes its protons to penetrate a membrane 4 (PEM – Proton Exchange Membrane) into a cathode 2. This results in a negative electrical charge in the anode and a positive one in the cathode. The combination of hydrogen with oxygen in the porous cathode actually does produce water as a waste product. The primary energy cells are then connected with each other into large batteries. They can then provide power for a direct-current electric motor and the car’s other energy needs.

Scheme II was developed from a subsidiary of Daimler-Chrysler called XCELLSIS. It differs from the first scheme only in its production of hydrogen directly in the car out of a mixture of methanol and water. This reaction produces heat and carbon dioxide, but three times less of the latter than in the most modern and “cleanest” internal combustion motors today. The developers of the Necar have therefore described it as a “non-emission” car. Normal gas stations can be adapted to provide the Necar with methanol. But, the first scheme surely interest manufacturers of larger vehicles, too. These vehicles could be equipped with hydrogen tanks that could be exchanged in trucks and busses without risk.

The development of the Necar ends the almost 150 year era of the internal combustion motor – one of the leading inventions of civilization and also one of the biggest sources of pollution (see example 112 and section 15.3). They believe that energy sources based on this principle will become so effective and flexible that they will be applied all the way from mopeds and lawn mowers to and including laptops and cell phones.

To conclude this example and this section, let us again stress that the most radical changes originate in inventions that are based on new principles for technical systems. The essentials of this kind of inventions are always new knowledge and discoveries that are the result of scientific research. This knowledge is the intellectual basis needed to expand the data bank of technical effects and for the invention of new systems with new functional principles.

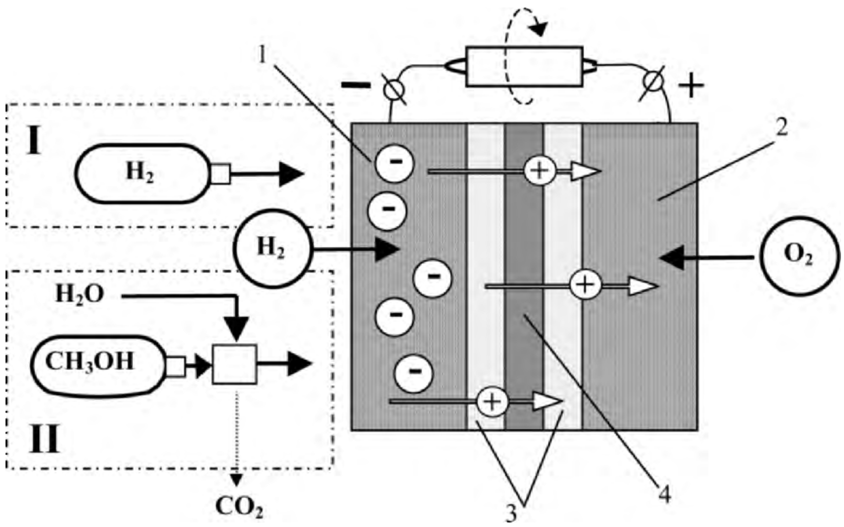


fig. 13.6. Hydrogen power plant in a car:
I – with “pure” hydrogen; **II** – with hydrogen from methanol

Exercises 10 – 13

19. Advertizing poster (1). Advertizing posters can be seen everywhere – on busses and street cars, on houses, and in building entrances. These posters have a layer of adhesive on the back and they therefore have to be adjusted carefully before they’re hung. It’s very difficult to adjust them because they are then easily damaged. The contradiction is that it has to be easy to hang them, but they have to be durable and hang correctly. What can we do here?
20. Advertizing poster (2). How can we produce a poster that covers the entire outer surface and the windows of a bus? Passengers also need to be able to see out of the bus?!
21. Teflon in any pan! How can we treat any pan, let’s say a fryer you already have at home, so that nothings sticks and burns in it?
22. Door bell. How can we make your door bell chime everywhere in your apartment or house?
23. Tire wear. How can we make a tire provide reliable information about its level of wear itself.
24. Neutralizing the exhaust gases of a cold engine. Exhaust gases from a cold motor that was just started are especially harmful. How can we prevent these especially harmful gasses from being released into the atmosphere?

25. Heating garments. Normal clothes don't heat. They are a passive system that holds the heat produced by the body. Make suggestions about which principles would be possible for actively heating garments.
26. Micro-tweezers. What kind of tweezers could be used to work securely on vessels in the brain when the size of the work space at the tip of the tweezers is barely 0.5 mm?
27. How do eagles and birds of prey live? How can we undertake uninterrupted observations of nests for several months when the observers don't want to sit the whole time, for example, on a neighboring rock?
28. White light diode. It is well known that semi-conductors radiate blue, red, and green light. How could we get white light from a miniature light diode?
29. Mirror for a telescope. How can we construct a mirror out of glass ceramics with an ideal parabolic curve for a telescope with a diameter of 8 meters?
30. Freezing berries and fruit. Extant devices that quickly freeze fresh berries and fruit start a preliminary frost process on the production line so that the products don't freeze together during the subsequent deep-freezing. These products are then removed for final freezing from the line in such a way that they are sometimes damaged. How can we improve the whole process and prevent damage to the fruit as well?
31. Standing tooth brush. Tooth brushes are put in a glass or a holder in the bath room so that they can dry. Use your school knowledge of physics to develop a tooth brush with a new functional principle that allows it to stand by itself.
32. Training for mountain climbers. How can we set up practice sessions for mountain climbers in gymnasiums where the conditions are as realistic as possible and the "rock surfaces" are not always the same?
33. Super swing wheel. A super swing wheel is a disc that is produced with a ring-shaped winding 1 from a hard band (wires, fibers) onto a disc-shaped cast carrier 2 from, for example, duralumin. This kind of wheel can function as an energy source for a few hours in a car or for the development of robot systems with a mechanical functional principle under explosive conditions where sparks are extremely dangerous.

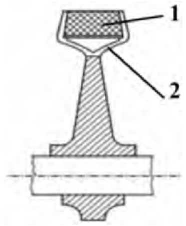


fig. 13.7. Construction of a super swing wheel

Their are no carrying centers that can deal with the gigantic distortions when the wound band no longer presses on the center at accelerations of 100 g (g - free fall acceleration). The destruction of the disc starts at the holder of the band. We know that compensators for the gap between the band and disc don't hold either and that their destruction also destroys the center. Do you have an appropriate idea for the development of a reliable center and an entire super swing wheel?

34. Testing lines. How can we test the contact lines and connectors of high-speed trains where electricity flows at up to 1000 amps and trains reach a speed of up to 500 km/h? The technical requirements dictate that the lines have to be able to handle at least 2 million contacts with the connectors!

Strategy of Inventing

The projection of technical systems was still an art 100 years ago. Today it has become an exact science through systems development.

The appearance of TRIZ and its quick development is no accident. It is a necessary development dictated by the modern scientific-technical revolution.

Work "according to TRIZ" continues to displace work "done by feel". But, human rationality is not idle: people will always think about more complicated assignments.

Genrikh Altshuller

14 Control of Systems Development

14.1 Development of Systems

TRIZ cannot predict the future, although you can use it to make a prognosis about the development of every technical system.

The basis of these prognoses is general laws (meta-models) of systems development that resulted from the investigation of several hundred thousand inventions. Many of these inventions were oriented towards the improvement of one and the same type of system for several decades. The meta-models of development include so-called "TRIZ Laws", "Lines of System Development", "Laws of the Expansion and Reduction of Systems", the models "Multiple-screens" and "System Transitions", the method "Integration of Alternative Systems" and other models.

Technology and science are getting even more multi-layered. The specialization and differentiation of knowledge continues ever more rapidly. The negative side of this process is the increasing danger of the distortion and modification of the positive global goals of systems development. The criteria used to assess the progressive or regressive aspects of systems already developed are being dissolved by the egoistical or selfish interests of this or that production team or because of political ambitions.

Should we, could we do something about these dangerous tendencies? A requirement would be that engineers and scientists become familiar with the strategic laws of systems development and that they use them for the goal-oriented development of systems with the criteria of global usability in mind.

The life cycle of every technical system (TS) from its invention to the end of its production and use is determined by a large number of interactive factors. The largest "influential" groups are shown in fig. 14.1*.

Use systems protect extant TS's from the destructive influence of the environment. Here we should note that ever TS "ages" continuously under the environment's influence.

Modernization systems ensure modifications of TS's according to the conditions of their use. Here, mutually influential systems (for example, a detail of a processing instrument) constantly increase the wear of a system, shorten the working life of a concrete example of a TS, or even destroy it.

Usage systems (for example, car drivers) can use a TS carefully, i.e., with the plus (+) sign at the appropriate arrow, or they can cause it to wear, i.e., with the minus (-) sign. In the long run, every concrete example of a TS is subjected to wear systems that have an extremely negative and destructive influence with the minus (-) sign.

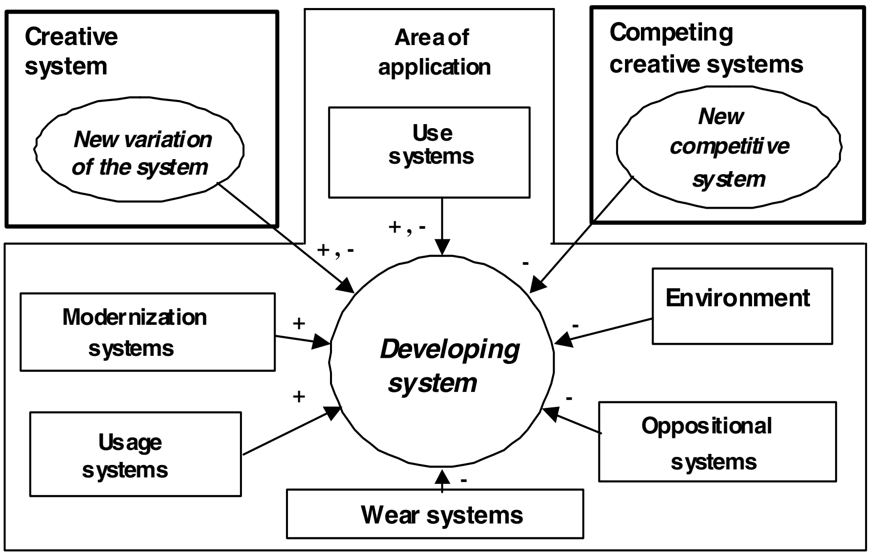


fig. 14.1. Interaction of a developing system with the environment during the time of its life cycle

Creative systems including a large group of inventors, builders, manufacturers, and sales personnel (!) ensure the continuous perfection of TS's in accordance

* The idea of this scheme was proposed by my teacher, known scientist and system engineer, professor Alexander M. Shirokoff (1924-2003) at the beginning of the 1960's.

with the "Law of the Growth of the Ideality" (see the next section). *But, this is deadly for current examples of TS's to the same degree regardless of whether they are replaced by competing products or by examples from the same manufacturer.*

The evolution of artificial systems continues with extremely dramatic contradictions. To reach the maximum integral effectiveness of extant patterns, we should strive for maximal longevity. However, the manufacturer is forced to create new patterns much earlier with the results of long use as well as with the possible appearance of competitive products in mind. Inventors and their "sphere of influence" need extremely good inventive abilities to control the development of the kind of TS already manufactured and to complete its modernization and the replacement of older types and generations. The answer to the question whether some kind of "best" product or a series of products that will definitely lead their markets can be invented *10 years in advance* by correctly using inventive techniques for every coming task only be answered with ... NO!! This is because only practical tests in accordance with the cycle shown in fig. 14.2 can provide real criteria for the control of systems development.

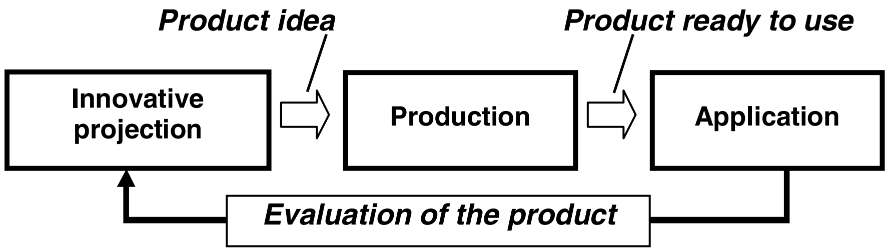


fig. 14.2. Interaction of developing systems with the environment

Real evaluations are necessary for the development and improvement of effective developmental scenarios. And, the earlier this is done, the better. But, this also means the risk of constructing new product patterns while everyone is simultaneously *searching for new ideas*. We can use the methodologies of inventive creativity to continuously make development prognoses sufficiently in advance. The key aspects and alternatives in the development of systems are shown in fig. 14.3. One of the practical results of a systems analysis has to be the decision for a certain strategic direction in coming changes to an existing system of for the development of a new system. This is why the concepts *"minimum task"* and *"maximum task"* were formulated in classical TRIZ. The first conception is more important because it presents a strategy that can reach the best result with "zero effort". This concept is quite different from familiar principles in mathematical optimization that provide the chance to work in an extreme case with minimum effort when we expect that the results will by maximized (mini-max models). This is why the concept *"minimum task"* has a psychological meaning because it creates advantageous conditions to achieve the "ideal result" while it mobilizes creative resources to reach the best realistic results.

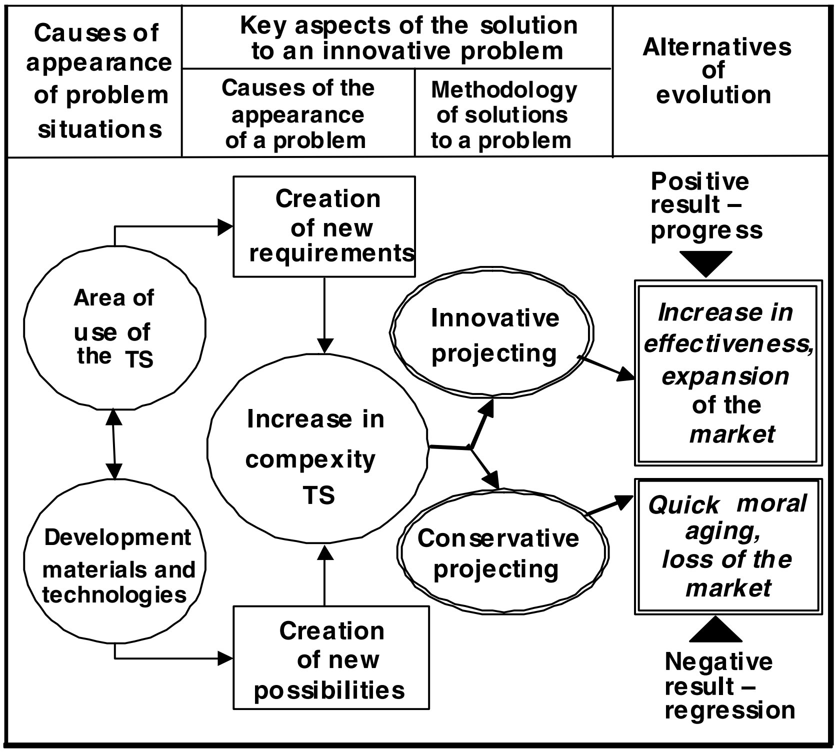


fig. 14.3. Key aspects and alternatives in the development of systems

Here we should note that the assignments can be difficult as well as simple in every one of these strategies (fig. 14.4). The table shows that tasks can be divided into 3 categories:

- **"Correction tasks"** – to remove or resolve negative functions, naturally without decimating the properties of the positive main functions;
- **"Alternative tasks"** – for the search for another procedure (principle) to complete the positive function while resolving an extant negative function at the same time, or to reach a higher level of the implementation of the useful function;
- **"Removal tasks"** - for the search for a procedure that makes the completion of the useful function unnecessary.

Now I'd like to come to the conclusion of the story I started in section 7.1. On the next day, two engineers (the employees of my opponent in the discussions from the previous day and the head of the R & D department of the machine firm) came to my booth. After a 30 minute demonstration of the *"Invention Machine"*, the only thing that dampened their enthusiasm was the conviction that they could not get their company leaders to buy this software! Certainly I already had a lot of experience with this problem of judging the size of companies by using the size of their booths at fairs, but here I had made a mistake. Their booth was remarkable, but what I first discovered in our discussion was really amazing. This firm has more than 50 specialists at work in the R & D department that are concerned with the development of new products. Again, I gave them my business card.

Meta-Strategy		**Complexity of a problem**
Minimum task	**Maximum task**	
The decisive resource is known (TRIZ instruments)	**The decisive principle is known** (TRIZ instruments)	**Low**
We can select resources (TRIZ instruments)	**We can select principals** (TRIZ instruments and methods for integrating alternative systems)	**Middle**
No resources can be perceived (Reformulation or substitution of the task)	**No principles can be perceived** (Transition to a synthesis of a system)	**High**

fig. 14.4. Meta-strategy for the solution to a problem situation

I was soon invited to visit them and our second meeting resulted in the following discussion:

- Why are your sales not more successful than in other firms?
- There are lots of manufacturers with similar products on the market.
- Do your products offer obvious advantages?
- Yes, but none of these are really large. The field is conservative with its own history and tradition. It is difficult to offer something unusual.
- Could you offer your products at a lower price?
- No, the production costs are very high with lots of metal and labor
- Well, what do the 50 R&D specialists do?
- ?!
- Your engineers didn't reveal the number of your R&D specialists. But I don't understand your goals. When you have demand and a market, regardless of how traditional and conservative it is, then there are always only two ways to sell successfully: either you offer better quality and new functions, or you lower prices with the same quality.
- It is difficult to reorganize our production.
- Yes, if it's not planned in advance.
- Everyone watches changes made by others very carefully.
- Reductions in production costs can be made quietly. Then you can make profit unnoticed by the others for a few years even with the same market position.
- But quality is more important.
- Good. Make sure your people are well qualified. Use that time to prepare changes that you introduce to the market first. Whoever tries to catch you then will be in the same situation that you're also in right now.

I received an order from the *"Invention Machine"* a month later. But, the initial situation described above is still often the case for too many leaders in industry.

And that's not all. As in every year, I spent two days in Hannover at the industry show 2001. And again I noticed a fantastic text that doubtless shows an extraordinary talent for self-representation that can really only be compared to people from the USA. I read the following words on a large sign in the entrance to the train station in front of the show:

> We didn't invent a fire - unfortunately
> (because we didn't exist yet back then).
> We can do everything except speak standard German.

I think we need to praise the sensational technical achievements of this region as well as the courageous humor of the sign's author. The firm I mentioned here is from Baden -Wuerttemberg so they can be optimistic about this story.

14.2 "Ideal Machine"

Synthetic (technical) systems (sub-systems, construction groups, parts, elements, materials) are developed to fulfill ***useful (positive) functions*** **(PF)**. One of these can be defined as the ***main positive function*** **(MPF)**, as a function that determines the ***purpose of the entire system*** (sub-system, construction groups, parts, elements, materials). Other positive functions are extra functions and main functions. There are also undesirable (negative) functions **(NF)** and a ***main negative function*** **(MNF)** in a system that represent the main challenge to its further development. Negative functions NF reduce the level of implementation of the positive functions of the system PF or lead to other undesirable negative effects, for example, for neighboring systems.

One of the main characteristics of the development of technical systems is a change in size. This can go in either direction - bigger or smaller. An increase in size is typical for many transport and processing machines - bulldozers, dry freighter, oil transport, passenger and freight aircraft. On the other hand, control and measuring instruments, communication media, and computer are all getting smaller. This phenomenon was recognized and analyzed with TRIZ and it led to the extremely constructive conception of the "ideal machine".

The concept of the "***ideal machine"*** **(IM)** is just as useful a metaphor for the purposes of "TRIZ" as the concept of the "functional ideal model" (FIM) and the "ideal final result" (IFR). It also makes the latter concrete in a certain way. However, this metaphor has a more essential meaning that was first formulated precisely and used constructively in TRIZ. Intensified and metaphorically the definition sounds like this:

The ideal machine is a solution that reaches the ***ideal result*** although the ***machine itself does not exist***

or:

The ideal machine is a solution that achieves the ***main useful function*** with *no additional effort.*

This means that the machine should have *zero weight, no size, should cause no extra costs, not use any energy, not produce any pollution, etc.*

Of course, TRIZ understands the ideal final result as the extremely precise and consistent demand to find the model of the effective function required, not as an arbitrary and wonderful result. This has to happen without the unjustifiable use of additional and expensive resources that are difficult to find. At this point I would like to note that the concept of effectiveness is in no way as trivial as it may sound. This is especially the case because it is a complex system of concepts that is also evolving. Regardless of the way we evaluate its effectiveness, the "ideal image" of a TS improves in the following strategic ways:

1. increase in the number of functions of the system
2. increase in the quality of system's functions, represented by an increase in the main parameters such as speed, performance, productivity, etc.
3. reduction in the use of all kinds of resources in the development, application, and disposal of the system after its useful life expires
4. reduction in negative effects on the system's environment.

We can now examine the formal expression used in systems technology and in TRIZ for the evaluation of effectiveness:

$$E = \frac{\text{Sum of the positive effects}}{\text{Sum of the negative effects}}$$

The positive effects (factors) include all positive evaluations of the desired uses of a system in the interval of its life cycle.

The negative effects or factors include all costs that accrue while achieving positive effects as well as all damages to the environment or other neighboring systems that occur.

Effectiveness E is a universal measure to evaluate an event. If the goal can be reached only with great effort, then the solution is ***not effective.*** A solution achieved with acceptable effort can be understood as ***effective*** or at least as ***acceptable***. If a solution reaches its goal and provides additional results than were unexpected, then we can call it ***highly effective***. Additional, supplementary results are also called ***super-effects.*** These are precisely the solutions known as inventions. These are the solutions that are our primary interest.

In most cases, effectiveness is evaluated on the basis of special formal mathematical functions. The ideal figure for this value would be if E continued indefinitely. Mathematically, this is the case when the numerator approaches infinity and the denominator approaches zero. But this hardy occurs in reality!

Therefore we would like to conceive of the expression mentioned above here only as a *qualitative model* that reminds us that the denominator should be as small and the numerator as large as possible. When we say that systems strive for an ideal image, then we have this kind of qualitative interpretation in mind.

The axis of all developmental directions is the "ideal machine". Today, this axis unites all of the forms of aerodynamic race cars that all seem similar at first glance to the Soviet TU-144, the Concorde, the Soviet multi and reusable space vehicle "Buran", and the American "Space Shuttle". Surely even more examples occur to you.

When a task is solved using the method of "trial and error", the search usually goes in the direction of the "vector of psychological inertia" or, in the best case, in all possible directions. When inventors use TRIZ to come closer to a solution, it is possible to focus the search sector. The solution sought will bring them close to the "ideal machine". This will then become the most promising direction for their search. It is clear that the "ideal machine" has to be correctly defined in every concrete case. A truck that transports a 3 ton load weighs ca. 1.5 t. Something like 30 % of the engine's performance is used to transport the construction of the truck itself. A truck designed to carry 15 t weighs about 5 t. The portion of the useable load compared to the engine's performance has clearly increased and this brings the machine closer to its ideal. A 140 ton vehicle developed for strip mining can be unloaded in 15 seconds! This is considerably less time than for the unloading of 28 five tonners.

An ideal helicopter or aircraft would just be a kind of "flying cabin", even though aircraft engines already astonish us today with the relatively small measurements and their incredible performance when carrying high loads at high speed.

14.3 Growth Curve of the Main Parameter of a System

Technical systems go through ***functional development*** and can be characterized by a large number of functions. Every function is characterized by parameters such as speed, weight, or productivity. The first two parameters are "simple". However, productivity is a complex property that can often only be defined with difficulty. Three parameters of TS's are special and central: effectiveness, security, and reliability (military systems have yet another one - working life). Effectiveness can include the relationship of such parameters as "fuel used for a 100 km stretch" and "speed needed for this stretch", meaning that we can represent the economy of a car in reference to the speed required.

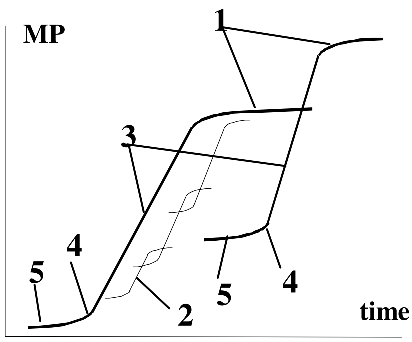


fig. 14.5. S-curves of the development of the main parameter of the TS

One of the parameters can be considered a *main parameter* **(MP).** This is not always effectiveness, for example, for a race car that is supposed to achieve a new speed record. The evolution of systems can be observed by examining changes in their parameters, i.e., based on ***parametric development,*** sometimes the development of just the MP.

For a computer, this parameter is the speed for computing test assignments (or the frequency for constant conditions of data processing and the RAM capacity, etc.). For a jet fighter, it's the maximum speed available.

The level of development of TS's is often shown using the MP with the graphic s-curve of its increase (fig. 14.5). The slow decrease in section 1 demonstrates arrival at the developmental limit of a TS in its present form. The curves 3 show the development of the types of the TS. These curves bend and stretch the lower curve 2 that shows the development of generations of the TS. The points (section) 4 and 5 are concerned with the appearance of inventions that helped lead to a technical field (5) or improved it greatly. If we turn back to fig 3.2, we can order the "position" of inventions from the appropriate stage on an s-curve. We should also mention that the economic effectiveness of any invention can be very good. Even small improvements at the first stage can be very useful in mass production. But, the creator of an invention at stage 4 or 5 has real advantages when the strategy "*new product on the market for the first time*" works.

As an example, a group of s-curves that show the increase in the speed of transport systems is shown in fig. 14.6.

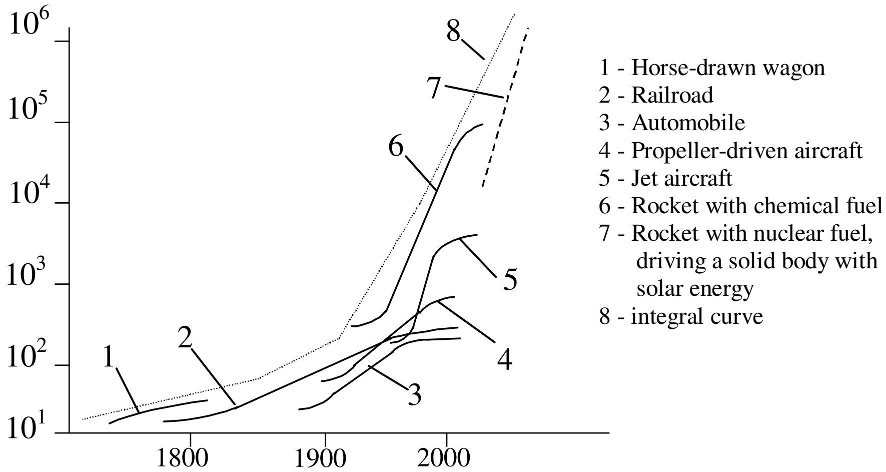


fig. 14.6. Increase in the speed of transport systems

Machines are relatively weak when they first appear but then incorporate a wealth of inventions to get stronger with time. Fig. 14.7 illustrates the 200 year history of the ***functional development*** of a ship's propeller [1]. The inventive ideas moved on three different paths. The prototypes were the blades of a wind mill, Archimedes, screw to hoist water, and the water wheel. Each of these prototypes was further developed by the efforts of inventors in different countries. However, these three chains of invention moved closer to each other until they led to the development of the modern ship's propeller we know today. Thousands of inventions made one after the other are behind every perfected technical system. 20,000 patents and copyrights were have even been awarded for a "system" like the pencil!

Every invention drives the development of a system a bit further. The system does not change in the pauses between these intervals. It helps to recognize that earlier these pauses were very long, that machines were developed very slowly (see fig. 14.7). The circuitous path from an idea and the first experimental models to the practically applied product took centuries.

Another example is the idea of an electric light bulb that first arose at the beginning of the 19th century. The first attempt to produce light using a glowing conductor was successful in 1840. But the first light bulb designed for mass use was developed 39 years later!

An example from the 20th century is the idea of an optical quantum generator was developed in 1952[57]. The first tests of this device occurred two years later and after 6 years the first industrial production of different lasers started.

This does not mean that the process of the further development of the construction and application of lasers is concluded. The size of lasers varies from fractions of a millimeter up to several meters and the radiation performance of experimental lasers could cover the entire capacity of the power plants of the United States in a short pulse. Lasers write and read information in fax machines and compact discs, they can heal people, and carry out measurements in the atmosphere. Lasers investigate distances on stretches up to the moon and cut metals. They draw on crystals with a size of 1-2 cm^2, micro-processors with several *millions* (!) of elementary cells for circuits and provide spectacular light and music shows that can be seen from far away. They transmit thousands of our telephone conversations with light conductors and create three dimensional “living images in the air”... Well, this is how you win Nobel prizes!

Incidentally, lasers are also “death rays”, just as Herbert Wells[58] and Alexei Tolstoi[59] noted. Lasers can burn and explode rockets and aircraft from the earth or from outer space, they can kill people. But this has nothing to do with the system. This is only because people handle them that way, just like they can use nuclear energy either as a weapon or as an energy source. There are many examples of this. It is well known that the military use of technical systems was and is one of the main driving forces of their development in human history.

But, what happens with systems after they’ve reached the highest level of their development (see stage 1 on the s-curve in fig. 14.5)? The unavoidability of the replacement of the system is clear, although the limits of the system’s development are understood as the limits of development generally. The apparent impossibility of taking leave of the familiar system causes anxiety and is hypnotic. The replacement of the system can run into extreme resistance by manufacturers who want to continue to produce these systems.

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[57] In 1964, the physicists N. Bassov, A. Prokhorov (both ex-USSR) and Ch. Townes (USA) received the Nobel prize for the development of the laser principle

[58] Herbert Wells (1866-1948) – known English novel and science fiction author

[59] A.Tolstoi (1883-1945) – known Russian author who wrote the novel “Peter the Great” and the fantasy novelle “The Hyperboloid of Engineer Garin”

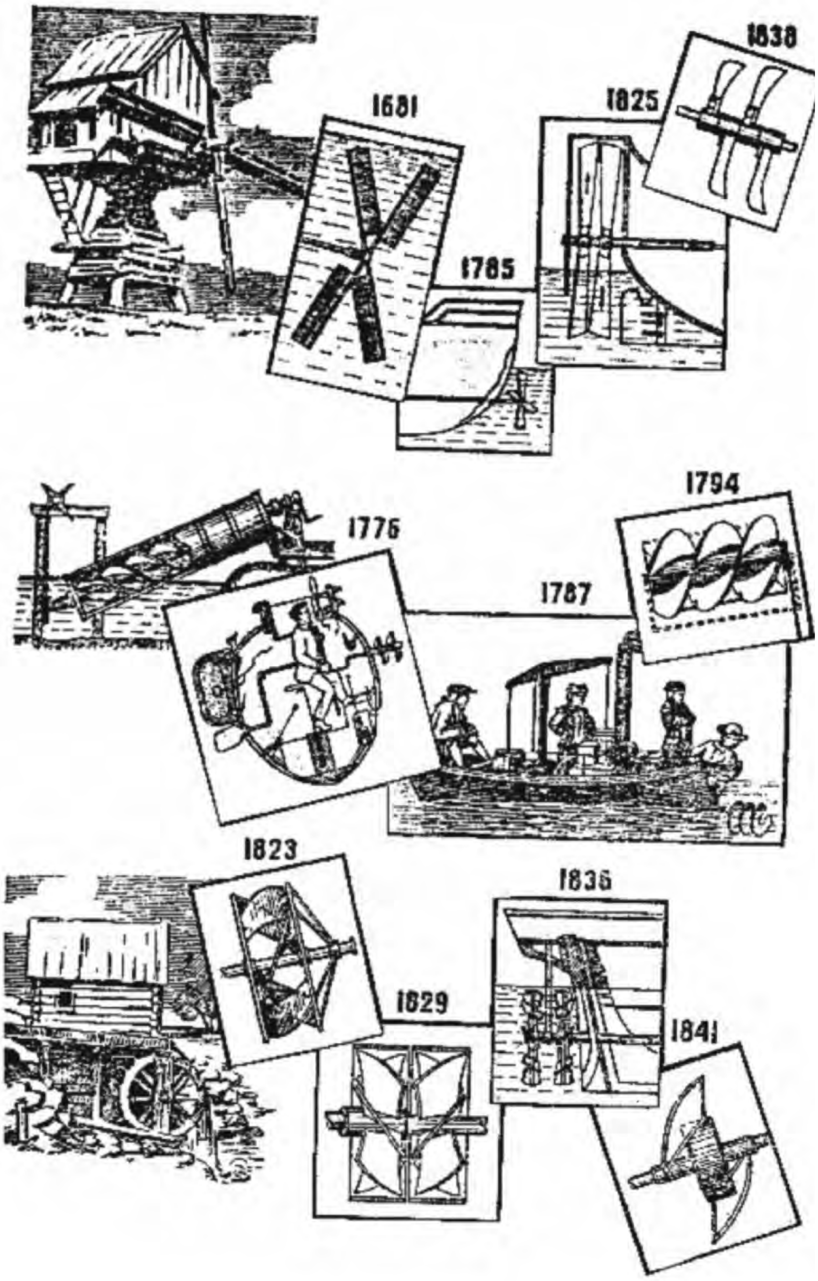

fig. 14.7. The history of the development of a ship's propeller (beginning)

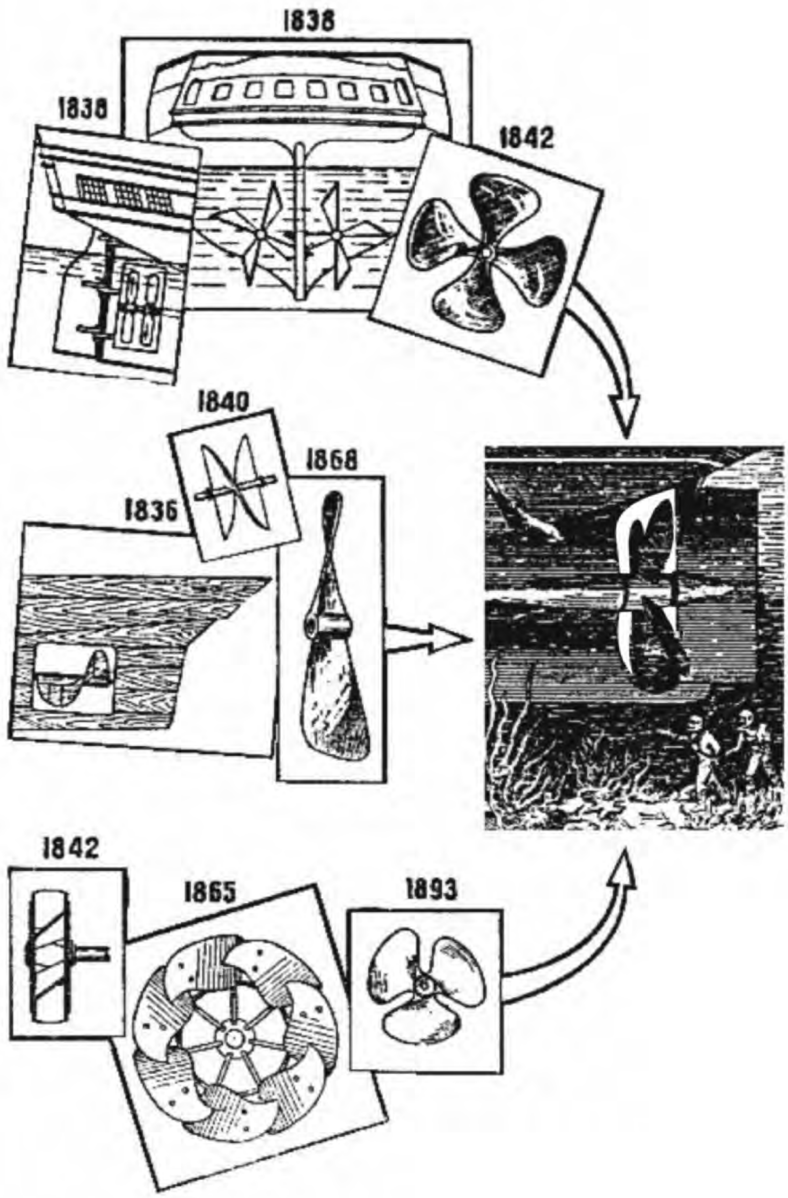

fig. 14.7. The history of the development of a ship's propeller (conclusion)

This is the case for environmentally destructive systems (giant aircraft, over-sized tankers), or for those that resist the possibilities of other systems (cars and trains). The vice president of General Motors John de Lorian once expressed the thought, if just a small part of those means that were used for improvements in internal combustion engines had been used for the development of accumulators, we would have already had an economic auto a long time ago.

A transition to a new system does not always mean the end of the application of a system from the previous generation. For example, today sailing boats and modern diesel electric ships, jet and propeller-driven aircraft, cinema and television, freezing factories and deep freezers, bicycles and automobiles, restaurants and kitchens at home, transportable and fixed TV sets and radios, etc. all exist at the same time.

The number of cinemas increased dramatically in the 1930's. The theoretical limit would have been reached long before a cinema came for every person. And something similar to this happened: television sets - *a cinema for every person* arrived on the scene! It seemed that the television would be the next step after the cinema by absorbing it as a subsystem within itself. This happened to a great degree especially with the computer control of TV systems. But we can see the parallel existence of cinema and television today, even though a computer produces audio and video effects today in the cinema that due to volume limitations cannot be reproduced in the space of an apartment.

However the television can be understood as a super-system, a system at a higher level than the cinema. Television is the most current news, a conference room, and finally, events shown in real-time.

It is entirely possible that the car will not be replaced by an electric automobile, but by a completely different transportation system where the car (or an equivalent means of transportation) becomes just a subsystem. Altshuller made this prediction. It's interesting that in Belarus in the city of Gomel another inventor produced a similar hypothesis at the same time as Altshuller that later became his life goal. This was the young engineer Anatoly Unitsky (see the following section 15.3 *Integration of alternative systems).*

In the section *Strategy and Tactics of Inventing,* the main principles of TRIZ and models to consider the objective laws of systems development are discussed. These models are neutral towards the concepts progress or regression. Their positive or negative assessment depends completely on the moral judgement of those who use them.

Still, we hope that something globally positive will manifest itself objectively in the system of these models that will support progress despite wars and sickness, despite elemental catastrophes, and starting with nature or technology. We can try to express this globally positive something by quoting the title of one of the most interesting stories by Jack London[60] – *Love of Life (1905).*

---

[60] Jack London (1876-1916) – famous American author

15 Classical TRIZ Models for Innovative Development

15.1 TRIZ Laws of Systems Development

On the basis of what we've already discussed, we can now define the main law of TRIZ that expresses the general goal of inventing:

> **LAW OF THE GROWTH OF THE IDEALITY**
> All types of systems strive to increase their effectiveness ("ideality") in the span of their life cycle.

In other words, *development is evolution directed towards increasing effectiveness. The most important aspect of an invention is that a technical system makes a transition into another one in such a way that this transition reflects the process of the further development of technical systems and runs according to objective laws.*

Let's examine the classical TRIZ laws that were created before the middle of the 1970's. These laws were divided in TRIZ into three groups and were called as in the laws of mechanics – "Statics", "Kinematics", and "Dynamics" (division into groups and fig. 15.1 edited by the author - M.O.).

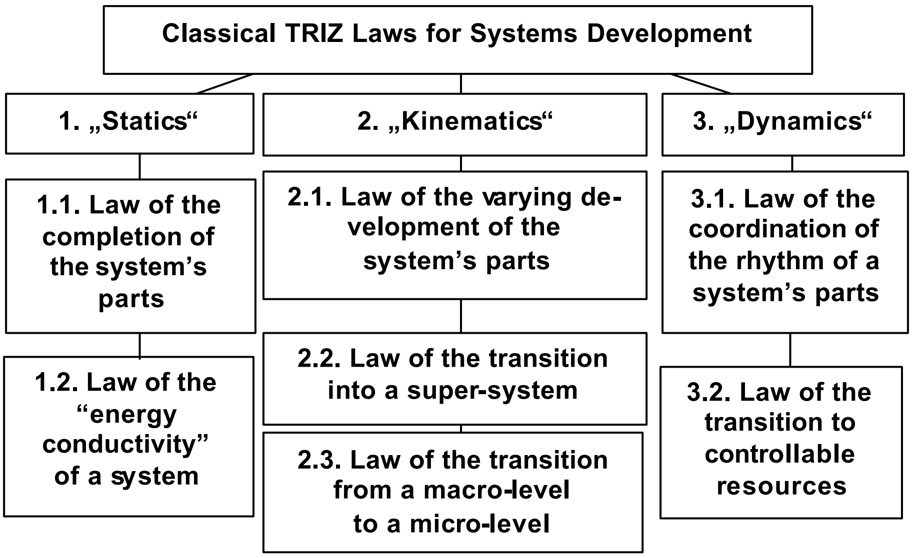

fig. 15.1. Laws of systems development in classical TRIZ

The "Statics" group represents "laws" that determine the beginning of the life cycle of technical systems.

1.1. Law of the completion of a system's parts.

An essential requirement for the existence of technical systems is the presence of the system's main parts and their minimum functional capabilities.

Every technical system needs four main components: drive, transmission, working body, and guidance. An additional component is also important to tie everything together - the construction (see section 8.2 *Resource* and fig. 8.4 *Abstract machine*).

An adequate requirement of the existence of a technical system can be understood as a consequence of this law in the following way (and this is especially useful for beginning inventors): a technical system can only survive when each of its parts both has minimum functional capabilities and ensures the minimum functional capabilities of all of its parts as a unified system. One of the results of this law is extremely important in praxis: the guidance of a system requires that at least one of the parts *must* be controllable.

1.2. Law of the "energy conductivity" of a system.

A necessary requirement of the essential existence of a technical system is the flow of energy through all of the system's parts. Every technical system transforms energy that is transmitted by the transmission mechanism to the working body. An important result of this law is: to make a part of the system controllable, it is necessary to ensure the energy conductivity between this part and the guidance mechanism. We could understand this as information conductivity especially in tasks for measurement or perception, although the task is often understood incorrectly by limiting this conductivity to energy alone. "***Kinematics"*** in TRIZ includes laws that define the development of technical system regardless of concrete technical and physical factors that determine their development.

2.1. Law of the varying development of a system's parts.

The development of a system's parts occurs in different ways and the more complicated a system is, the more the development of its parts varies. The differences in the development of a system's parts cause strong physical-technical contradictions. It is therefore also the reason for inventive tasks. For example, an increase in automobiles in Central Europe is in contradiction to the limited possibilities to build new roads. In addition, extant roads have to constantly be expanded. Large cities suffer catastrophically from the following three problems: air pollution, a lack of parking spaces, and the low speed of traffic caused by constant traffic jams.

2.2. Law of the transition into a super-system.

As soon as a system has exhausted its developmental possibilities, it will be included in a super-system as one of its parts.

Let's examine just one example here: as soon as the bicycle was fitted with an internal combustion motor, it became the moped and motor cycle. But there are still bicycles. As we have already noted, the parallel existence of earlier and current systems that fulfill the same purpose is possible.

2.3. Law of the transition from a macro-level to a micro-level.

The development of the working bodies of technical systems occurs initially at the macro-level, but at the micro-level in a developed system.

In most modern mechanical systems, the working bodies represent macro-details, for example, the propeller of an aircraft or the cutting-tool of a lathe. A plasma beam can function as a cutting-tool. The working body in jet aircraft is an air stream. Here the function occurs at the level of particles, molecules, ions, and atoms instead of macro-details. Nuclear energy is an inexhaustible energy source that can be tapped either by fission or fusion.

A transition from development at the macro-level to development at the micro-level is the essence of the computer revolution.

The laws of "***dynamics***" are incomplete in TRIZ and of rather specialized character. They define the development of modern technical systems in a way that closely relates to concrete technical and physical factors.

3.1. Law of the coordination of the rhythm of a system's parts.

A necessary requirement for the essential existence of technical systems is the coordination of the rhythm, i.e., the frequency of the mechanical or electro-magnetic vibrations and periodicity of function and interaction of all of the system's parts.

3.2. Law of the transition to controllable resources.

The development of technical systems is moving towards the application of resources with a high level of organization with more controllable materials and fields.

This law is closely related to the law of the energy conductivity of systems and the increase of the ideal image. The working body in a linear step-engine is an electro-magnetic field. Information systems, beginning with the first electro-magnetic telegraph constructions, have developed into modern radio and optical systems with highly organized fields as the information channels. When compared to optical microscopes, the electron microscope has completely changed the possibility to investigate the construction of materials.

A device to heat food based on micro-waves led to a revolution in the kitchens of modern households!

Of course it is a simplification to speak of laws isolated from each other. Laws function in their entirety and ensure the real development of systems in this way.

Recognition of these laws together with the evaluation of the parameters of the s-curve for the given type of a system enable us to make a prognosis of the developmental tendencies of virtually every technical system.

15.2 Lines of Technical Systems Development

TRIZ laws are completed and instrumentalized by the so-called "*Lines of technical system development*". These are highly comprehensive meta-models that contain the main tendencies of systems development. The application of these models to solve your problems usually requires extensive preliminary research. This is because all *developmental lines* are based on history and the prognoses for the development of the object to be improved and its system environment.

In this book, we would now like to shortly characterize the following meta-models:

1) Lines of the increase in the degree of an "ideality";
2) Poly-screen;
3) Lines of the replacement of people in the functions of TS's;
4) "Wave of evolution";
5) Kondratyev's long economic waves (cycles);
6) Transitions into super-system or in sub-system;
7) Lines "mono – bi/poly – mono";
8) Lines of resource development.

15.2.1. Meta-model *Lines of the increase in the degree of an "ideality".* There have been very few discoveries and inventions in human history that shook the foundations of human society and gave the development of civilization a tremendous push. For example, this includes the spread of printing, the discovery and application of magnetic fields in a broad range of frequencies and forms, space travel, the development of the computer as a machine for data processing, and bio and gene technology. A historical-technical analysis shows that more or less long periods of slow growth or stagnation in the development of critical functions for humanity preceded these revolutionary changes. We can examine the following examples that heavily influenced Western Europe:

- Train schedules have changed very little in the last decades because the real speeds (not record speeds) and the capacity of rail roads reached its limits a long time ago. To replace extant rails with magnetic train lines would essentially change nothing. This development is a dead end that came several years too late;
- The speed and capacity of high ways is limited and is causing more and more traffic jams that are getting longer and longer. Damages resulting from loss of time in automobile traffic are estimated to be in double-figured billions in Germany alone!
- The effective level of nuclear and thermal power plants has stagnated at 30%, meaning that new energy sources need to be found;
- The productivity of grain cultures, one of humanity's main nutritional sources, has almost reached its limits;
- Nature has just severely limited the intensification of animal farming – violations can lead to the eruption of dangerous animal epidemics.

These and other signs of slowing and stagnation indicate that we can expect great inventions here and now. In every direction we can expect growth in the MPF and with it, other areas or technology related to it. Then the growth of the MPF of these areas will slow down (see fig. 14.3: this area is moving towards the high point of its s-curve in section 1). It is interesting to follow the changes in the quantity 1 and quality (level) 2 of inventions in different areas (fig. 15.2).

Just after a radical invention at the highest level (4 or 5), inventions slow in this area. A real breakthrough occurs in the area (a) as soon as auxiliary inventions are made at a high level (3 or 4) that create acceptable conditions for the industrial production of this product.

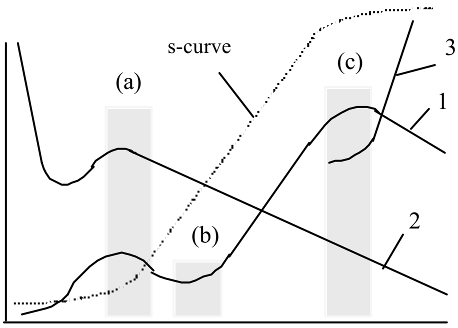

fig. 15.2. Change in the quantity 1 and the level 2 of inventions during the life cycle of the type of system; 3 – development of a new system

At the beginning of production the quality of inventions decreases between the areas (a) and (b) because careful manufacturers wait for the first tests and sales. Success leads to a boom in inventions that is directed towards the improvement of both products and technology. The reduction of the number of patents in area (c) and their direction towards small improvements is a clear sign of the complete development of production and sales.

In area (c), and often even earlier, serious changes in the system of the current type can occur that are directed towards its survival, if alternative systems 3 with the same functions appear. Altogether, this situation is characterized by the lines of growth in the ideal image of a system of the current type as shown in fig. 15.3.

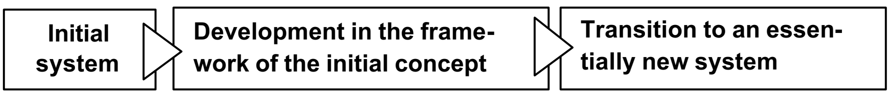

fig. 15.3. Line of growth of the “ideal image”

15.2.2. Meta-model *Poly-screen*. Inventors who are unfamiliar with the developmental laws of technical systems develop a number of different variations of a solution. Only those “mutations” survive that go in the direction of objectively existing laws of development. But, with technology we have the chance to gain experience with “mutations”, to set rules for successful changes, and then implement them consciously. This means that talented thinking can find new structure.

Altshuller colorfully described the possibilities to organize the systems thinking of inventors in a new way. Usually when the word “tree” is mentioned in a task, then people see some kind of tree. Fantasy creates a certain image of the task. As soon as people have read the requirements (represented as **?**), they immediately turn on a mental screen and project an image of solution 1 onto this screen (fig. 15.4).

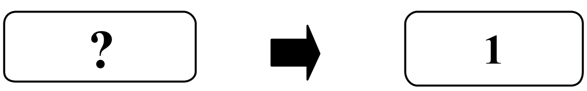

fig. 15.4. Simple “one dimensional” thought screen

A directed selection of variations leads to the possibility that many of these images can appear. The tree gets bigger or smaller but essentially nothing changes. Often an answer is not found and the problem is not solved.

This is normal thinking. A talented fantasy turns on 3 screens simultaneously (fig. 15.5). We see the super-system 2 (tree group), the system 1 (tree), and the sub-system 3 (leaf). Of course, this is a minimum scheme. Other screens up or down are also often included: super-super-system (forest) and sub-sub-system (cell of a leaf).

But, it's more important to see everything as part of its development. Then we need to include temporal screens that show the past and future at every level (fig. 15.6). ***At least nine (!) screens are needed to reflect the systematic and dynamic world seen in the system.***

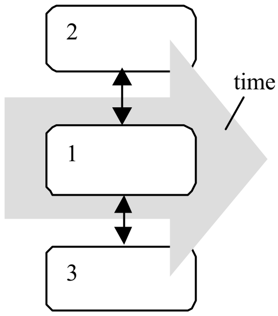

fig. 15.5. "3-part screen": 1 - system; 2 - super-system; 3 - sub-system

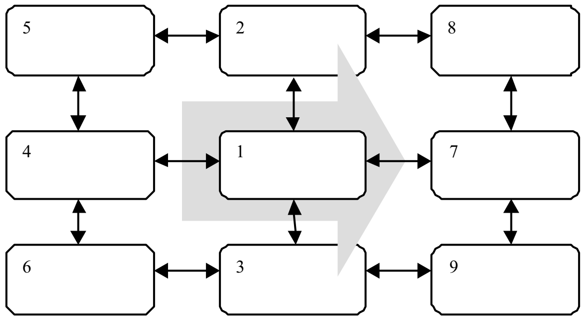

fig. 15.6. "9-part screen": Scheme of talented thinking

Ex. 96. Date palm. A date palm can provide 240 liters of sweet sap per season from which palm sugar can be produced. But, a cut has to be made directly under the crone of the palm in its stem to collect the sap. This is 20 meters high! This assignment was given to a company that produces farm machinery and technology for such machines. The professionals at the firm first tried an "alpine procedure" in which a person climbs up the tree by cutting steps into the tree. This procedure turned out to be unsuitable because the tree dies if there are too many steps and it's hard to climb if there are too few. Then they tried to develop something like a fire truck with a retractable ladder. And then the engineers were amazed when they discovered that farmers in Bangladesh have a secret that enables them to climb palms without any machines.

This task cannot be solved if we only turn on screen 1. But, it is useful to examine screens 1 and 4 together and to recognize just how a solution becomes visible. A small palm is on screen 4. There's not yet any sap, but it's possible to make cuts here – the steps of the future. One or two steps per year don't kill the tree. A couple of cuts can be added the next year. A ladder has formed on the stem by the time the tree has matured and can give off sap.

We get another solution when we turn on screen 2. A ladder has to be placed on a tree. But, when two trees grow next to each other, their stems almost create a ladder by themselves. We only need to add the ropes between them – and we have a rope ladder.

Genrikh Altshuller stressed that this is not yet the most complicated case – 9 screens. Brilliant thinking requires thinking with yet more screens, for example, with 27! Here the *evolution of related and inverted systems* along with their sub and super-systems are considered parallel to the first 9 screens. The goal was set in TRIZ to give the organization of thinking rules that correspond to the scheme of the poly-screen based on the laws of systems development.

Thinking with poly-screens makes it possible to avoid lots of dramatic mistakes. An inventor is normally impatient and tends to think of the mission as finished as soon as the first solution to the problem has been found. This often results in the partial use of a new technical idea, not its comprehensive use.

15.2.3. Meta-model *Line of the replacement of people in the functions of TS's.* One of the main lines of system-technical development is the replacement of people in the functions of TS's (fig. 15.7).

fig. 15.7. Functional replacement of people in the development of technical systems

At the working level, people's hands, legs, and muscular energy were replaced by synthetic instruments, mechanisms, and other sources of energy.

At the control level, this replacement occurred in the development of automatic regulators, copy and processing machines, auto pilots and automatic navigation, etc.

At the information level, it began with instruments to collect information – various sensors and measuring devices with sensitivity, precision, and speed that was somewhat higher than human sense organs. Then people were replaced in sub-systems for information collection and processing and for the preparation and acceptance of solutions.

A paradoxically negative tendency in the development of TS's (a double negative super-effect!) is the replacement of people in nature! The technological sphere developed by people has negative influence on nature and can destroy it, meaning humanity itself would be destroyed.

The latest studies indicate that the earth developed ca. 4 billion years ago. While living organisms developed and adapted to the conditions that existed on the earth at that time, they began to change the environment. These transformations led to the appearance of an atmosphere with oxygen, the ground, the ozone layer, today's geography with its forests, rivers, lakes, swamps, tundra, taiga, and jungles. This is how the biosphere appeared in which millions of kinds of living organisms and the planet they had transformed have adjusted ideally to each other. There was nothing superfluous here.

And then came humanity that could strengthen its muscular power, its sense organs, and its intellect thanks to its reason. It began to develop technology and technological processes.

The industrial power of today's civilization is wholly a logical consequence of a technocratic direction. The expansive development of technical systems has also had a negative effect on nature.

The technosphere needs no ground. This is why there's less and less fertile ground on the earth and more and more wasteland and dead deserts.

The technosphere needs no atmosphere with oxygen. The industry of the USA already uses more oxygen today than green plants on its territory can produce. The USA lives at the expense of the oxygen that is produced in Russia's taiga and in the rainforests of the Amazon. What would happen if every country reached this level of oxygen consumption?

The technosphere needs no ozone layer in the atmosphere. Even if ozone makes up only a tiny portion (1 in 10 million parts) of the atmosphere, it absorbs ca. 4% of the solar energy that falls to the earth. This is one hundred times as much as the thermal energy that is radiated into the atmosphere by today's industry. This means that the influence of the ozone layer on the weather and climate of the earth is much more important than technological influences and also the greenhouse effect.

The technosphere needs no living nature. The number of cancers, allergies, lung, heart, and circulation diseases, and genetic and congenital diseases caused by water, air, and ground pollution is increasing steadily. This is also the case for industrially raised animals that provide human nutrition. The AIDS virus is still extremely dangerous, especially when similar viruses appear. The land is changing irrevocably - ground erosion, deforestation, water pollution, and contamination of drinking water.

The technosphere occupies the same ecological niche as the biosphere altogether: machines, mechanisms, technical facilities on and under the earth, in the water and in the air also actively exchange materials and energy with these elements.

The only consistent way out of this complicated situation is to create a niche for the technosphere, especially for its industrial and energy-producing part, outside of the biosphere! That could ensure the continued existence and development of the biosphere in accordance with the laws that have developed in the course of billions of years of evolution. This could create harmonic interaction between people as biological objects and the biosphere.

There is no such environmental niche. But it exists in outer space where most technological processes also would enjoy ideal conditions: weightlessness, vacuum, extremely high and low temperatures, unlimited energy, space, and even material resources.

Humanity has very little time left to make mass use of outer space. Prognoses predict that in one or two generations (maximum 50 – 80 years) an irrevocable degeneration of the biosphere will begin as a result of technocratic aggression against it. This would start the extinction of humanity, too. The use of outer space nearby is not an invention of fantasy writers. Instead, it is a real plan to save life on earth.

15.2.4. Meta-model *"Wave of evolution"*. Two oppositional processes ensure that the "ideality" of more complex systems is raised.

Escalation – an increase in the quantity and quality of completed functions is ensured by a more complex system;

De-escalation - this is an increase (maintenance) in the quantity and quality of completed functions while simplifying the system.

The simplification can be seen relatively because usually the number of elements is reduced. This means that the "complexity" can only be reduced by increasing the organization of the material and the energy in the parts.

Processes of "*Escalation – De-escalation*" can run back and forth and parallel in different kinds of systems of one and the same type, that is, variously complex systems of one and the same type can exist simultaneously in their niches in the technosphere.

Generally we represent in TRIZ the total effect of processes of complexity-reduction as so-called "waves of evolution" (fig. 15.8). The swings show processes that are important for the corresponding period.

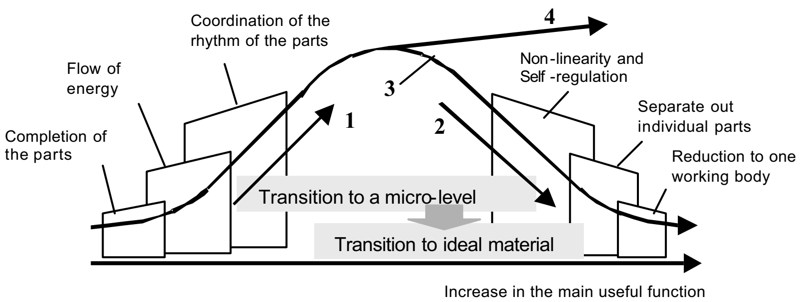

fig. 15.8. Meta-model "Developmental waves" of technical systems*: 1 – escalation; 2 – de-escalation; 3 – Change in the relative complexity of a system; 4 – Integration with other systems

Ex. 97. Electronics and Computers. An excellent example of the variety and progress in which the law of the "*Escalation – De-escalation*" of systems was fully implemented is the computer. You can read in every book about the history of the computer from the middle of the 1940's until the beginning of the year 2002 and you will find the confirmation of this law. We have these comments to the following examples: the first computer with tubes had lower computing performance that any modern multi-functional pocket calculator. It consisted of several metal cases that filled entire rooms. In the last 4 years (since 1998), the tact frequency of computers has grown enormously. This has lead to a tremendous increase in the

* according to "TRIZ: the right solution at the right time" by Y. Salamatov, 1999

productivity of PC's and portable computers from about 200 MHz to 2,000 MHz (2 GHz) with no change in the size of construction. Leading companies also manufacture computer networks that consist of several thousand processors (escalation!). There are lots of examples here, especially if we consider the functional possibilities and integration with control systems.

Many examples of this kind are easily recognizable if you closely follow the changes in radio and TV-sets, audio and video-recorders, and telephones.

The lines of escalation (a) and de-escalation (b) are represented in fig. 15.9.

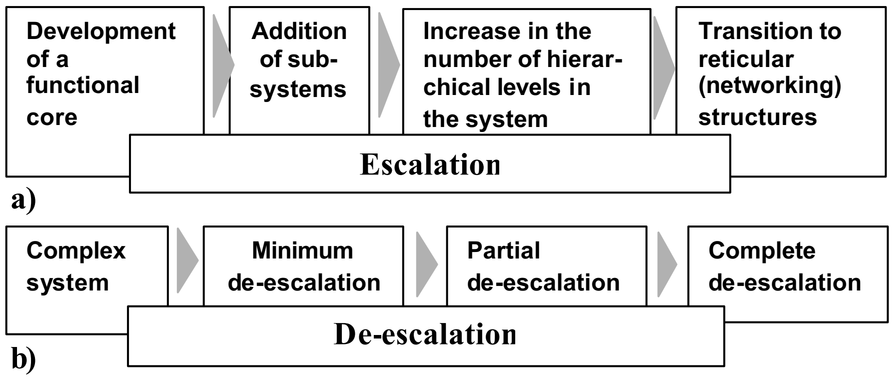

fig. 15.9. Meta-model "*Escalation – De-escalation*" of technical systems

Ex. 98. Micro-processors and RAM. An example of a partial de-escalation is the operative memory of a PC that consists of several constructive micro-chips. A complete de-escalation is to build a micro-processor on a crystal in the form of a single construction element (micro-scheme).

15.2.5. Meta-model "*Kondratyev's long economic waves (cycles)*". The model of the cyclical character of economic development characterized by "waves" is well known by economists. These waves demonstrate the steps growth, prosperity, recession, and depression. The basis for every cycle are the great discoveries and inventions that are usually made in periods of depression. They form the departure point for a new technical reconstruction of civilization and therefore start economic growth again. This model was developed in Russia in 1925 by the economist N. Kondratyev and subsequently recognized in the entire world.

In countries with a very high level of development, these waves deviate and demonstrate special properties. But, the law holds true for all economic systems. In addition, these processes are also characteristic for the world market with its extremely strong economic growth. The waves need to be predicted and kept in mind in strategic planning for the development of new technical systems.

In this way, inventions like the steam engine and the mechanical loom were the basis for the development of the 18th century. The second cycle in the 19th century was connected to the development of metallurgy and railroad traffic. A third cycle occurred in the 20th century that was closely related to developments in the fields of electrical technology, chemistry, and auto construction. A fourth cycle was based on the development of aircraft, macro-molecular petroleum-chemistry, and electronics. A series of prognoses predict that new economic growth will be part of the beginning of the 21st century. The fifth cycle in question is related to an entire complex of fields: biotechnology, laser technology, micro-electronics and nano-technology, communication systems like the Internet, artificial intelligence, and space industries. The quality of road and railroad traffic also needs to be radically changed.

15.2.6. Meta-model *Transition into super-systems or in sub-systems.* This meta-model is closely related to the model of "*Escalation – De-escalation*". However, it demonstrates a few specific properties when the initial system "disappears" even though its functions are still present. They are transferred either to a super-system or to a more complexly developed part of the same system.

We should also remember that many types of systems with similar functions exist parallel to each other temporally and find their own special niches in the technosphere. This procedure enables the new system B to overcome the functional resistance of the "old" system A and the blocking and complicating influence of the manufacturers of A (see scheme 14.1). This means that competition of the new system does not dramatically disappear with the disappearance of the old system. In principle, we can imagine an ideal scenario where large producers of technical systems forget their individual economic interests to work as movers and developers of progressive innovations on a large scale.

The formula for the transition into a super-system is: *a new system B replaces a system A by incorporating it into itself as a sub-system.*

Ex. 99. **Remote check.** These are systems for the remote collection of information from gas, energy, water, heating meters, etc. Here water, gas, and electricity meters can be read without sending a person from the appropriate firm into the customer's apartment. This takes place remotely from a vehicle that makes tours with a radio connected to meters in apartments and other buildings. The function of collecting data is transferred to a super-system. This example can easily be further developed by bringing the meters on-line in the Internet, for example.

The meter becomes part of a super-system because one of the most important functions – the "transfer" of figures was technically connected to a super-system that can then receive these figures. Innovation means escalation in the super-system and de-escalation in the sub-system here.

The formula for the transition into a sub-system is: *a new system B replaces a system A as one of the previous sub-systems and unifies all of its functions in itself.*

Ex. 100. Electric motor-wheel. The first large bulldozers were constructed with the traditional scheme "Diesel engine – electrical generator – electric motor – transmission mechanism to every wheel – wheels".

Later a bulldozer was developed with the scheme "Diesel engine – electrical generator – electric motor-wheels" by mounting an electric motor in every wheel. This simplified the system considerably because control of the performance and revolutions of an electric motor is much easier than mechanical transmission. Mechanical transmissions could be removed completely and their function was taken on by the wheel-motors by making these motors part of the wheel! A super-effect of this de-escalation was that the bulldozers can be controlled much better. Here we see on one hand a de-escalation of the earlier drive system to the wheels and on the other hand a step in the comple xity of the wheels.

15.2.7. Meta-model *Lines "mono – bi/poly – mono".* This model is often confused with the previous one. They really are similar in the way new systems are developed. In the model transition to a sub-system - super-system, the system A is still present either as a part of the structure in the system with higher value (the super-system for data collection incorporates the original meters an information sources) or as part of the system with less value.

The lines "mono – bi/poly – mono" (fig. 15.10) show the possibility of building systems of similar value with different levels of complexity and functionality. Now that we've described this concretely, we can also note that this model can function as a mechanism for a transition to a super or sub-system. But, this is not its main purpose.

The initial technical system (mono-system) is doubled in the construction of a bi-system and multiplied by several factors when several systems are combined into a poly-system. As shown in fig. 15.10, systems with the same functions with differences in their parameters (mixed properties) as well as different or inverse (oppositional) functions unite with each other.

In all of these cases, the main characteristic of an invention is the development of a new system property that was not individually present in the systems that existed previously.

Ex. 101. Knife collection. When we combine a knife as a mono-system with another knife, we get scissors, a device with other properties. When we combine a metal plate with a certain coefficient of linear expansion in parallel with another plate with another coefficient of linear expansion (the same function with another parameter), we get an alloy (bi-metal) plate with a new property: it bends itself when heated or cooled. When we combine plates with another with the same coefficient of linear expansion but in opposite directions (positive and negative), we get a bi-system with a zero coefficient of linear expansion!

Ex. 102. Aircraft wings. Reinventing with the model "mono – bi/poly – mono" is shown in fig. 15.11. Historically, all kind of aircraft wings were developed parallel to each other: mono-planes, bi-planes, and planes with multiple wings (poly-wing). Soon bi-planes reached greater values of effectiveness, although the continuous need to increase the speed of flight lead to the fact that primarily single wings were further developed. Bi-planes that actually place very low requirements on the construction of take-off and landing sites were slowly displaced by faster mono-planes. Planes with multiple wings were totally forgotten by the end of the 1930's because this direction seemed dead. Theories continued to be developed primarily for mono-planes, but also to some degree for bi-planes. Mono-planes have reached super-sonic speeds of 5, 7, and 10 times faster than sound and record altitudes of more than 100 km (only military machines)! Even so, some of the properties of mono-planes cause difficulties: the wings are difficult to manufacture and steer and are heavy.

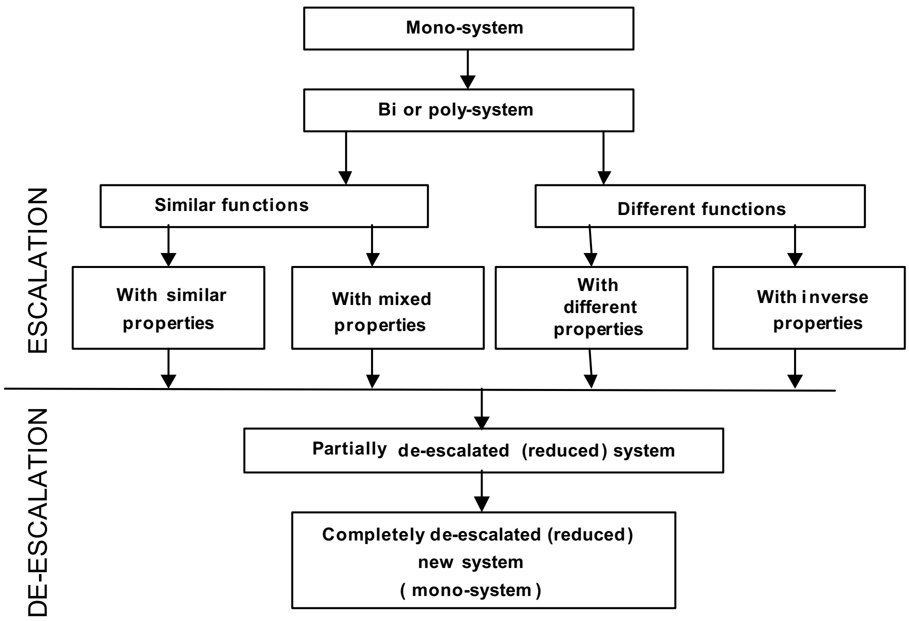

fig. 15.10. Meta-model "mono – bi/poly – mono" for the "*Escalation – De-escalation*" of technical systems

In the middle of the 1950's, a team of enthusiasts formed at the Moscow Aeronautics Institute (MAI) under the leadership of S. Belozerkovski that developed a theory and practical constructions for planes with poly-wings. The rebirth of what was forgotten has led in the last few years to discovery of the excellent properties of poly-wings and to the appearance of a really new developmental direction for aircraft of the future.

With the same lift, the weight of a poly-wing is 4 to 6 times less that the weight of a wing with compact cross cut and 2 to 3 times less than a hollow wing. By making the distance between the wings dynamic, the aircraft has a stabile flight platform at all speeds from its minimum up to super-sonic flight. The installation of poly-wings is considerably simpler than for single wings.

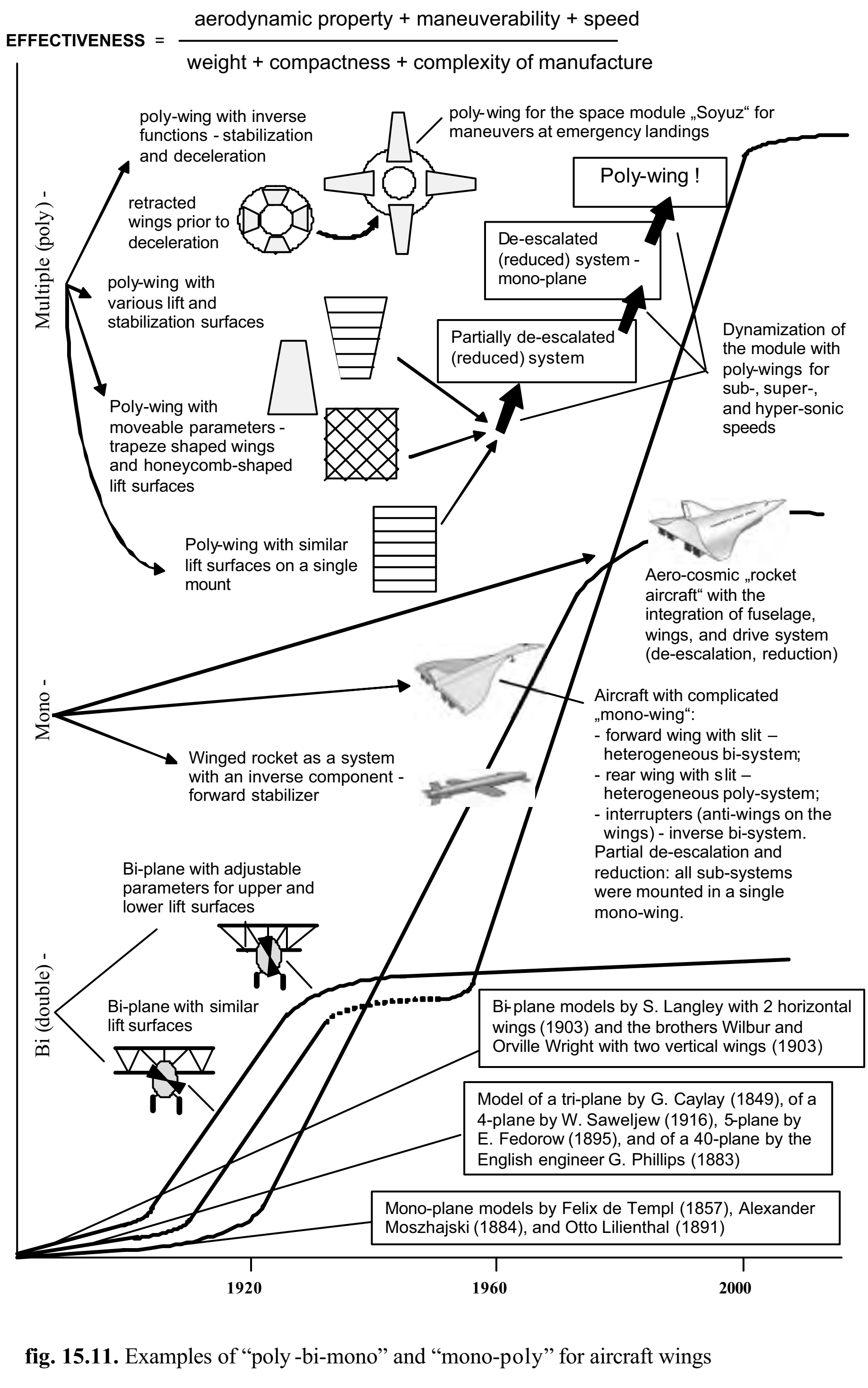

fig. 15.11. Examples of “poly -bi-mono” and “mono-poly” for aircraft wings

Here we can see how it's possible to deal with time, how we can turn back to the past, or better, how we can remember the future. The well-known researcher and discoverer von Daeniken once mentioned a similar phenomenon[55]!

We can conclude that the procedures accumulated in this meta-model show that the transitions don't occur strictly along the axis of "mono – bi/poly – mono". Sometimes they also run "bi/poly – mono – bi/poly" or "mono – bi/poly". We also see again the possibility to verify or reproduce the direction of the procedures that is so characteristic of TRIZ.

15.2.8. Meta-model *Lines of resource development.* The development of systems towards the growth of the ideal image is related to properties such as increasing the level of resource coordination and the application of easily controllable resources. The controllability of a system demonstrates its high level of development.

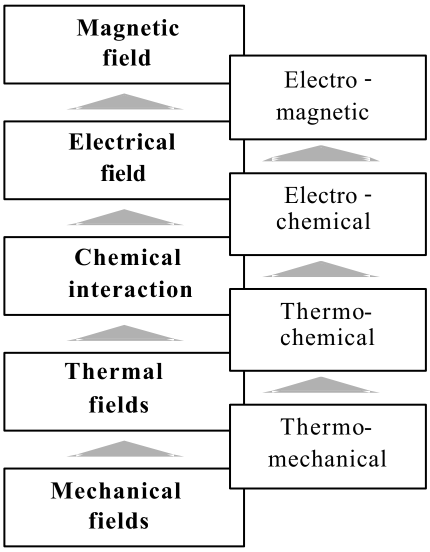

fig. 15.12. Line of transition to easily controllable fields

But, controllability is only possible when the system components to be controlled use dynamic resources with controllable parameters that change in the area needed.

These tendencies are reflected in the developmental lines of the resources. The most important meta-models are discussed further below.

The transition to highly effective fields can be followed using fig.15.12.

Please keep in mind that some of these "fields" should be understood as physical-mathematical concepts.

If we think of all of the mechanical forces that are assigned to an object as a *variety of vectors,* then these vectors create a spatial *field of the effects* of these forces or a *mechanical field.* Acoustic and gravitational fields are considered to be mechanical here. Gravitation causes all bodies on the earth to have weight. But, gravitational fields still have properties that have not yet been completely researched.

Ex. 103. "Pile-hammer". In the course of the one decade, the 1970's, procedures to drive construction piles into the ground were further developed in all the following ways: drop hammers ("gravitation mechanism") – hydraulic hammers – electro-hydraulic shock (like the Yutkin effect) – electro-magnetic hammers (accelerated as a solenoid) – "electro-magnetic piles"; a reduced bi-system "pile-hammer", in which the outer surface layer of the head of the pile is soaked with an

[55] Erich von Daeniken (1935, Switzerland) – well-known researcher of phenomena from ancient civilizations and from visits by extra-terrestrials

electrolyte. The concrete then becomes a conductor and the pile is accelerated instead of a hammer. We should also note that different pneumatic hammers with simple construction were recognized as inventions parallel to the innovations above.

The following three lines are related to making systems dynamic.

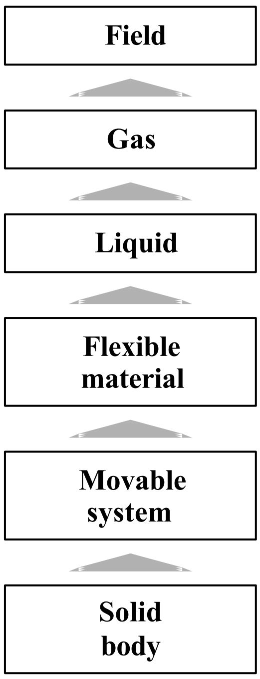

fig. 15.13. Line of the segmentation of an instrument

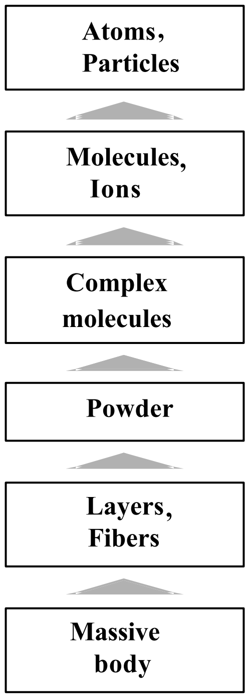

fig. 15.14. Line of the segmentation of a material

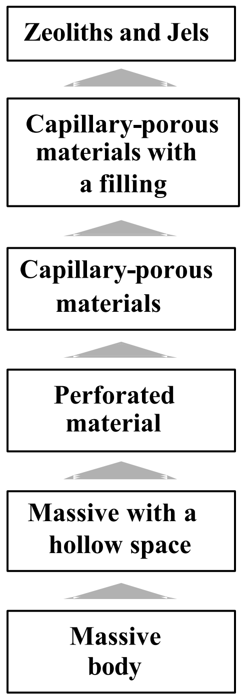

fig. 15.15. Line of the introduction of hollow spaces

Here are some examples of segmenting an instrument (see fig. 15.13):

Ex. 104. Line of segmenting a surgical instrument: Metal scalpel – High-frequency scalpel – Water under pressure – Laser beam.

Ex. 105. Line of segmenting the blade of a lawn mower: a spinning knife made of one piece – a spinning metal chain – a spinning nylon line – spinning water streams under pressure.

These examples illustrate segmenting material (see fig. 15.14):

Ex. 106. Reducing the friction of spinning parts “shaft – mount”: direct contact of the spinning metallic surfaces of the shaft and the mount – hydro-static mount without contact (liquid lubricant) – gas-static mount without contact (gas is provided under pressure by porous plugs) – magnetic high-precision mount.

Ex. 107. Increase in the working life and reliability of contacts (brushes) to transmit electricity to electric motors and from electrical generators: carbon brushes –

hardened carbon fiber brushes – ferro-magnetic powder with a permanent magnetic field – magnetic liquid – ionized gas – discharge in a vacuum.
Here are examples to illustrate the introduction of hollow spaces (see fig. 15.15):
Ex. 108. Use of porous materials in bearings (see ex. 31.1 for A_s-navigator 31).
Ex. 109. Auto tires: compact – with a hollow space for air (with or without chambers) – tires with multiple-walls (multi-chambered tires) – tires made of porous material – tires made of capillary-porous material with cooling chambers – tires filled with porous polymer particles and stored materials.

To conclude this section, we would like to mention a somewhat more complicated meta-model to increase the controllability of fields (fig. 15.16). We can say without exaggeration that the progress of modern radio technology, electronic optics, computer technology, computer tomographies, laser technology, and micro electronics is based totally on this line of development.

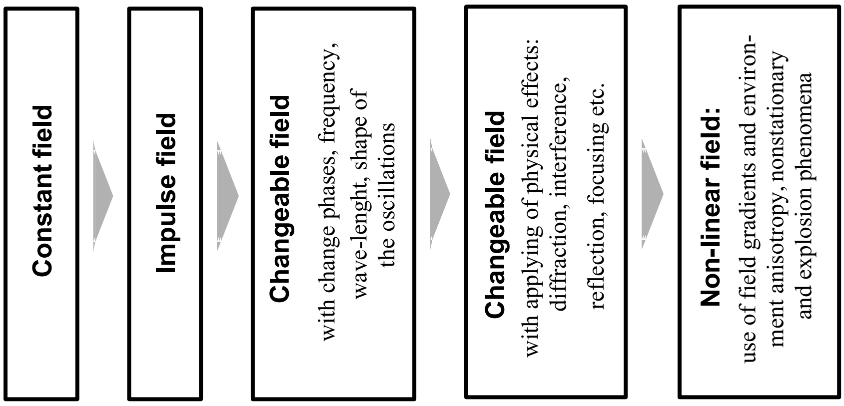

fig. 15.16. Increase in the controllabiliy of fields

15.3 Integration of Alternative Systems

In TRIZ, systems are called *competitive systems* when they fulfill one and the same purpose and have the same main useful function, but when they were implemented differently and therefore are effective in different ways. According to this definition, normal railroads and magnetic trains are competitive systems.

Essentially, it's possible to understand the competition of systems in a more general or more detailed way, too. In a general sense, we can think of competitive systems from different classes (different systems) such as street cars and rail traffic. In a more detailed sense, we can consider the competition of systems similar to each other (of the same type) such as different car models with similar characteristics.

In any case, so-called *alternative systems* with direct oppositional pairs of positive and negative properties are selected for integration.

Ex. 110 (start). Bicycle wheel. The spoke wheel of a bicycle (fig. 15.17a) is light and strong but it is difficult to build. A compact metallic disc wheel (fig. 15.17b) is easy to build but it is either heavier or less robust.

fig. 15.17. Alternative systems: spoke (a) and disc wheel (b)

The method of the integration of alternative systems allows us to consciously construct new systems by uniting alternative systems. Their positive properties make a transition into the new system while the negative properties disappear or are weakened considerably. This means that a higher level of the "ideality" (effectiveness) has been achieved.

This method is especially good for promoting the extended life of extant alternative system of which one (or both) has reached the limits of their development and all perceivable resources for further progress are exhausted. The effectiveness of systems is expressed as a relationship of values that belong to the groups of negative and positive factors, i.e., to the denominator and numerator of the appropriate formula (see section 14.2):

1) numerator: speed, maximum load, precision, etc.;
2) denominator: energy use, fuel use, expenses for usage, complexity of manufacture, ecological damages and compensation for them, etc.

Here the unified systems have alternating pairs of properties. For example, one system is highly productive but expensive and complicated while the other system is less productive, but is also simple and inexpensive. An important point in this unification is the reduction (removal) of the insufficiencies of both systems from the scope of the new system. This should ensure increased complexity and an increase in the useful function that was the reason for the integration.

Let's examine a few examples of the integration of similar alternative systems.

Ex. 110 (finish). Bicycle wheel. The tension of the construction retains the advantages of a spoke wheel that we wanted to transfer to the disc wheel. The wheel is built with two thin diaphragms 2 that are installed under the flanges of the hub 1 and stretch out to the rim under tension (fig. 15.18a). This kind of wheel (fig. 15.18b) is considerably easier to manufacture and steer and is lighter, yet just as stable and strong as a spoke wheel! A further possibility to reduce weight is to cut openings in the diaphragm (fig. 15.18c). This doesn't complicate the manufacturing process as the openings can easily be stamped out. The stamp is more complicated but this has very little effect on the production costs at mass production.

Ex. 111. Bearings. Roller bearings are simple to manufacture, withstand strong radial loads, and work quietly. But, they require lots of energy to be set into motion because at rest the lubricant is squeezed out between bearing and mount meaning that there is virtually dry friction at the start. Swing bearings are an alternative system because they require very little energy to start moving. But, they are much more complicated to manufacture, they're expensive, cannot withstand radial loads, and are very loud.

fig. 15.18. Disc-diaphragm-wheel: construction (a), normal (b) and light-weight (c)

Usually the simpler and less expensive system, in this case the roller bearing, is selected as the basic system. How can we reduce the start energy so that it's like a swing bearing? Perhaps we could add micro-balls to the lubricant. We would then need considerably less initial energy and the usual rolling properties would be retained for normal work.

We can examine the idea of a string transportation system (STS) by A. Unitsky* as an example of the integration of different systems.

Ex. 112. String-transportation system by A. Unitsky. With which means of transportation are we starting into the new millennium? Will people slowly stagnate and be stuck in their psychological inhibitions – without alternative generations of automobiles and aircraft? Will the railroads continue to suck up resources to maintain its morally outdated technostructure? Will we finally understand that today our planet is no more secure than the "Titanic" was with its overestimated security where there were then way too few life boats?!

The car:

1. appeared at the end of the 19th century. Last century more than 10 million km of roads were built and about a billion cars were manufactured. Today a mid-class automobile costs $15-20,000.
2. A modern highway costs 5-10 million $/km, requires ca. 10 acres of land/km and ca. 20 acres/km of infrastructure. The scope of the soil and materials moved exceeds 50 thousand m^3/km. Roads and their infrastructure have made ca. 120 million acres unusable for humanity. And this was certainly not the poorest ground! It corresponds roughly to the surface area of Germany and Great Britain. There are essentially no reserves left for the further construction of roads in Germany.
3. The yearly losses due to idle time spent in traffic jams are several billion dollars in Germany alone. Cars have become the number one cause of human death in the last few decades. According to figures from the WHO, more than 900,000

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* This material was provided by Anatoly E. Unitsky

people die every year world-wide on roads from accidents and the injuries caused, many people live with grave injuries and disabilities, and more than 10 million people are injured.

4. The average speed on roads is 60-80 km/h; a car is parked for at least 90% of its lifecycle. The average length of stretches driven is 10-20 km. It is exhausting and dangerous to drive more that 400 km per day even on a highway in Germany.

5. Cars have become the main source of noise and air pollution in cities. Auto exhaust contains ca. 30 carcinogenic substances and more than 120 toxic bonds. The total energy use of cars exceeds the capacities of all power plants in the world!

6. Systems that supply traffic on roads such as oil wells and pipelines, oil processing and refineries, and asphalt manufacturers have an extremely negative effect on nature.

Railroad traffic:

1. the way we know it today, appeared at the beginning of the 19^{th} century, even though the first stretches with recessed tracks already existed in ancient Rome. More than one million kilometers of railroad tracks have been laid world-wide.

2. Under the conditions that exist today, one kilometer of two-track railroad and its appropriate infrastructure costs $ 3 to 5 million. A passenger car cost ca. $ 1 million and an electric locomotive ca. $ 10 million. The construction requires many different resources: metal (steel, copper), steel reinforced concrete, gravel. The scope of the soil and materials moved is ca. 50 thousand m^3/km on the average. This takes ca. 10 acres per kilometer of ground use and up to 20 acres per kilometer of infrastructure.

3. Special constructions such as bridges, viaducts, overpasses and tunnels have to be built under complicated geographical conditions that make the system more expensive and increase the negative effect on the environment. The average speed on rails is 100-120 km/h.

4. Noise, vibrations, and thermal and electro-magnetic radiation caused by trains influence the life spaces of animals and people who live close to the railroad. Passenger trains cause per kilometer of track per year up to 12 tons of garbage and 250 kg feces.

5. Magnetic trains cannot change the situation meaningfully (perhaps only in Europe). In addition, the construction of such stretches and the disposal and reconstruction of extant sections causes enormous costs that no European country can afford.

Air traffic:

1. is the most dangerous means of transportation environmentally with the highest energy use. The total emission of dangerous substances into the atmosphere reaches 30-40 kg per 100 passenger kilometers flown. The highest amounts of dangerous substances produced by aircraft are concentrated close to airports, i.e., close to large cities, during low flight, and during acceleration. At low and middle altitudes up to 5000-6000 m, air pollution caused by nitrous oxide and carbon monoxide remains for several days. It is washed away by moisture to form acid rain. At high altitudes, air traffic is the only source of air pollution. Dangerous substances remain in the stratosphere much longer - ca. one year. The toxicity of

the emissions from modern jet plane corresponds to 5-8 thousand cars while it uses the same amount of oxygen to burn kerosene as more than 200,000 people use to breath. Several thousand acres of pine forests or an even larger surface area of plankton are needed to reproduce this amount of oxygen in the atmosphere.

2. Due to natural cosmic gamma radiation, every passenger in a flight lasting several hours is subjected to radiation of several thousand micro-roentgen. The radiation level inside an aircraft flying at the normal altitude for passenger flights is 300-400 µR/h as compared to the maximum allowable value of 20 µR /h.

3. Ground is removed for the construction of airports that is comparable to the construction of railroads and roads for auto traffic. However, this land is very close to cities and therefore has much more immediate value.

4. Air traffic is one of the biggest causes of noise, especially around airports. It also causes large electro-magnetic emissions through its use of radio location at radar stations.

5. Air traffic is the most expensive means of transportation. A modern aircraft by Airbus costs ca. $ 100 million, while the costs for a large international airport exceed $ 10 billion.

This short analysis demonstrates beyond a doubt that we need to search for new chances to completely change the nature of traffic. One of these possibilities is an invention by an engineer from Belarus, Anatoly Unitsky. He first published this idea in 1982 in the former USSR but found no official support there. Unitsky was already on the KGB's list of "suspected individuals" before that publication. The attempt had already been made at the end of the 1970's to discredit Unitsky because of his ideas about geo-cosmic industrialization (see section 18.2) that sharply contrasted to the "triumphal politics" of accessing the closest areas of outer space with rocket technology.

Let's now reinvent Unitsky's invention based on the method of the integration of alternative systems. The alternative system 1 has high speed but is not very maneuverable (railroad) while system 2 has lower speed but is much more maneuverable (automobile). Safety and a sufficiently high speed are also important for traffic between cities. Here our basis is therefore the railroad. On the other hand, automobiles are safer when deviating from a structured path because they transport fewer passengers. The most important technical advantages of the automobile are that it can consist of several modules and it is much smaller than a train.

These considerations lead to the first statement: *traffic must be based on modules with a small number of passengers that move at high speeds.*

Of course, there is also the problem of ground use and the construction costs of new lines. High speeds require extremely level and straight structures. Railroad tracks fulfill this requirement best. The high weight of trains means that tracks are built on strong foundations that are not exactly environmentally friendly and that cost a lot. The requirement of a module concept for traffic leads to a second statement: *track structures can be very light constructions above the ground with the advantage that they are extremely level, straight, and relatively independent from the topography of the construction site.*

Module traffic must definitely and without exception have an electric drive (see exercises *14-15*). This leads to the third statement: *If the automobile is to retain a* *place in traffic in the future, then it must be transformed into an electric car and be integrated into a new traffic structure.*

This is the concept of the STS:

The basis for the STS are two special electrified track strings that are isolated from each other and supported at a height of 10-20 meters (or higher, if necessary) by columns. A high speed module - an electric automobile - moves on four wheels along a string. The extremely level and solid construction of the strings means that speeds of up to 250-350 km/h can be reached with the STS and theoretically even 500-600 km/h would be possible, or even 1000 km/h in a vacuum tube. The elements of the strings pull against each other with 300-500 tons of tension and are stabily grounded in anchor supports at a distance of 1-3 kilometers. Columns are separated by 20-100 meters.

The electric modules can carry up to 5000 kg and up to 20 passengers (fig. 15.19, 15.20, 15.22 and 15.23). Power is supplied by the special tracks with an electrified surface in contact with the wheels. With the use of nuclear energy sources, the track surfaces and modules would need no electricity. The lines of the STS can be easily coordinated with special power lines, even with optic fibers to wind and solar power facilities.

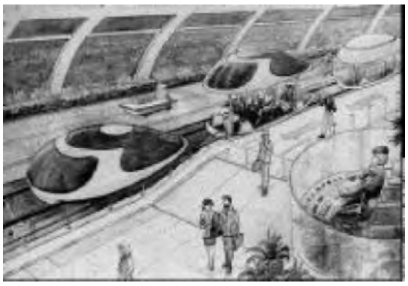

fig. 15.19. Train station of a string transportation system

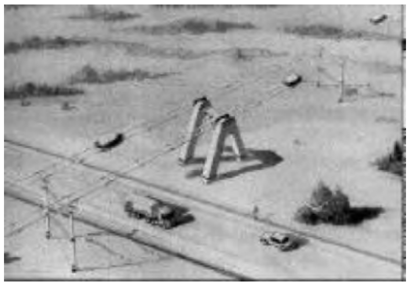

fig. 15.20. STS runs over a highway

The strings of the STS are constructed from high quality steel cables with a diameter of 1-5 mm. These cables are then bundled together and installed with the least possible rounding in the hollow spaces of the tracks (fig. 15.21). The tracks are mounted in such a fashion that the upper surface of the tracks are kept perfectly level with self-hardening materials such as cement or epoxy after the strings have been firmly mounted into the track's hollow spaces. This is how the surface of the track on which the wheels move doesn't sag and has no gaps.

Most of the time, the columns of the STS are spaced 25-100 meters apart. The STS has been projected so that the columns carry only vertical loads. This means that the load is relatively light - 25 tons with a span of 50 meters. The towers of power lines are subjected to a similar load and are therefore similar in the use of materials to the columns of the STS. The maximum horizontal load along the entire line effects only the 2 anchor supports at each end of the stretch: per side 1000 tons for a double track line and 500 tons for a single track.

fig. 15.21. Construction of the string-tracks

The structure of the STS is extremely solid. In a span of 50 meters, the static curve of the track in the middle between two supports is a maximum of 12.5 mm with a concentrated load of 5000 kg/s or 1/4000 of the distance between the supports. As a comparison, bridges are projected today that allow 10 times more sag in the middle - 1/400 of the length of the bridge. The dynamic sag of the STS under moving loads is even less - up to 5 mm or 1/10000 of the distance between supports. This kind of stretch is more level for the wheels of a transport module than the salt lake on which a car reached super-sonic speeds - 1200 km/h - for the first time at the end of the 20th century.

The highest speeds of the STS are not influenced by the levelness or dynamics of vibrations on the track and there are no problems with the friction contact “wheel – track”. Only aerodynamics plays a role. This is why special attention was paid to aerodynamic questions. This produced unique results without analogy in modern high-speed traffic, not even in air traffic. A modern passenger module’s coefficient of aerodynamic resistance was measured in a wind tunnel at C_x=0.075. Measures are planned to reduce this coefficient to C_x=0.05-0.06. Thanks to this low air-resistance, a drive that puts out 80 kW can push a passenger module with 20 seats along at 300-350 km/h, with 200 kW at 400-450 km/h, and with 400 kW at 500-550 km/h. Here the mechanical and electro-mechanical losses are minimal because the degree of effectiveness of the steel wheels is 99% and of the wheel-motor complex 92%.

The reliability of the structure of the stretches and the supports of the STS as well as its building construction is at the level of span bridges with similar construction principles. However, the strings of the STS are much better protected against weather and mechanical influences than the cables of bridges.

Economically speaking, it is estimated that the mass-produced cost of a two track line of the STS with infrastructure (train stations, stations, freight terminals, depots, etc.) in millions of $ per km would be: 1-1.5 on a level surface, 1.5-2-5 in mountains and for lines on water, and 5-8 under water or underground with special tunnels.

The construction of a transportation module is simpler than a car. A mass-produced module would cost $20-40,000 or, in a unit with 20 seats, $1-2,000 per seat. In comparison, other high-speed transportation systems cost per seat: aircraft - $100-200,000, magnetic train - $100-200,000, high-speed trains $20-30,000.

We can now summarize the extremely interesting technical-economic and ecological characteristics of the means of transportation:

1. A lot of land is not needed to construct the string-lines: 150-200 times less than for roads or railroad tracks. It is not necessary to dig trenches or mounds and forests and extant buildings are only slightly influenced or disturbed. This is why it’s easy to integrate the STS into the infrastructure of cities and also into areas with difficult natural conditions: in perma-frost, mountains, swamps, the desert, into areas with water (rivers, lakes, ocean channels, ocean shelves, etc.).

fig. 15.22. Unitsky's STS at the mountains

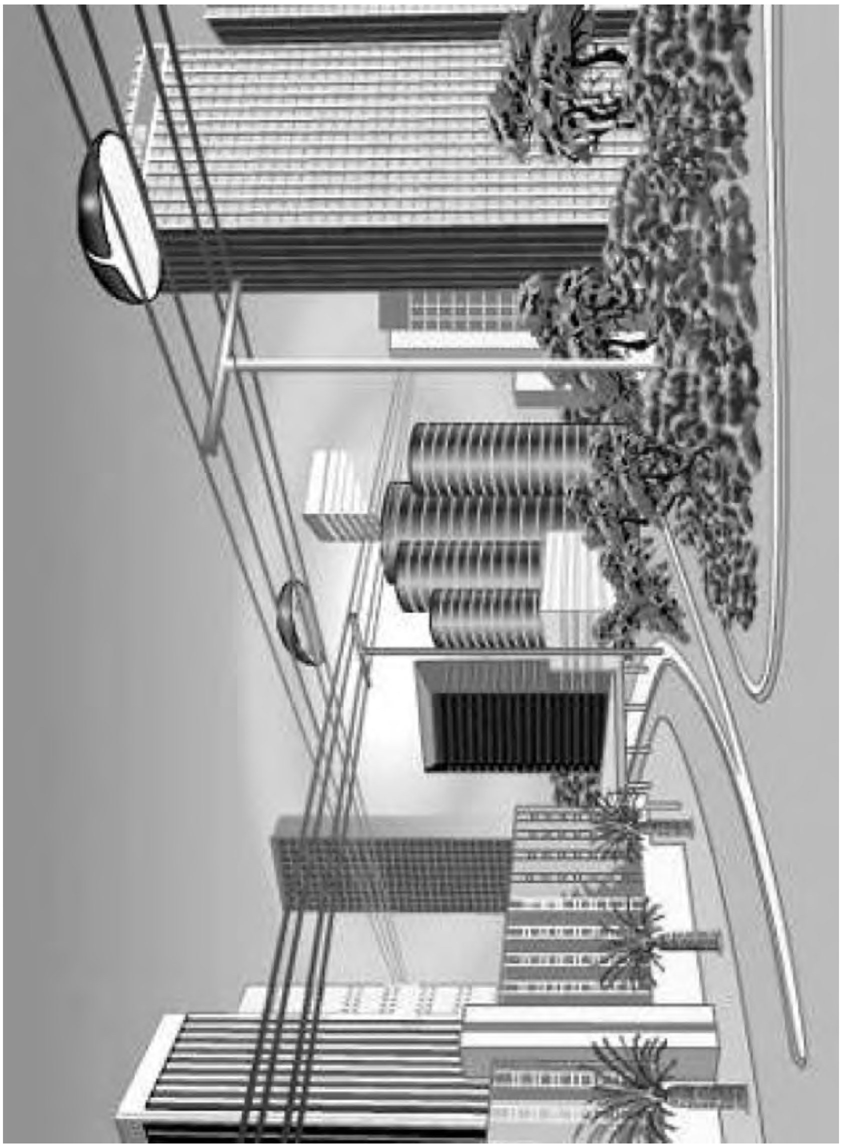

fig. 15.23. Unitsky's STS in the town

2. The stability of the system is increased in natural catastrophes such as earth quakes, avalanches, floods, storms, and under poor weather conditions such as mist, rain, ice, snow, sand storms, high heat and extreme cold, etc.
3. Compared to all other known high-speed transportation systems, the STS is ecologically better, more economical, has better technology, and is safer.
4. The minimal material use and the successful technology of the STS's lines means that it is 2-3 times less expensive and 8-10 times faster than the railroad, 3-4 times faster as a double string or 2-3 times faster as a single string than highways, and 15-20 times less expensive than a magnetic train. Travel with the STS will be extremely inexpensive: $5-8 per 1000 passenger/km and $2-5 per 1000 tons of freight/km.
5. The STS can be built as a technological or special string for freight, passengers, or both. Connecting lines with low maximum speeds (up to 150 km/h), middle-speeds (150-300 km/h), and higher speeds (300 km/h plus) can be built. Up to 500,000 passengers and 1 million tons of freight can be transported daily. The transport capacity exceeds that of a modern oil pipeline, even though STS lines are cheaper. The cost to transport oil with the STS would be 1.5-2 times less than with a pipeline. The STS could be used to transport garbage out of large cities, raw materials from their source to processing plants, coal to power plants, and oil from storage to processing and refining. Hundreds of millions of tons of pure drinking water could be brought to thinly settled regions of the world over distances of 5-10 thousand kilometers, etc.
6. The total cost of an STS line "Paris (London) – Moscow" would be $5.7 billion (the length of the line is 3110 km). The line and infrastructure would require $5.2 billion and the moveable elements would cost $0.5 billion. The line would pay for itself in 5-7 years. The cost of a trip from Moscow to Paris would be $32 per passenger and it would take 7 hours and 10 minutes (at a distance of 2770 km and with an average speed of 400 km/h). In ten years, this line would create revenues of ca. $2 billion per year.

Many variations of the construction of string-lines are possible that could be strategically and geopolitically important for virtually every country in the world.

The STS implements the following TRIZ principles (fig. 15.24).

The application of the STS makes a radical reduction in the number of flights up to 2000 km possible. Aircraft would only be needed for ocean flights longer than 2000 km. The use of roads could be drastically reduced and traffic jams on highways could be eliminated. The railroad could be reconstructed (shortened) completely so that it still handles heavy transports on major lines.

Here we're paying a lot of attention to the development of transportation systems because traffic is one of the most essential current problems that needs to be solved quickly and decisively.

As an exchange (transport) of material and human resources, traffic and communication are necessary conditions for individual and collective well-being. It is a means for human communication in a territorial and intellectual space, a way of life, and one of the most basic cultural values - a criterion for the level of a *life, and one of the most basic cultural values - a criterion for the level of a country's civilization.*

Nr.	Principle	Application
02	Preliminary action	The stations of the STS are in the center of cities as opposed to airports, for example.
03	**Segmentation**	**Small high-speed modules instead of heavy trains with high energy use**
04	**Replacement of mechanical matter**	**Improvement of the mechanical structure – extremely level stretches**
05	**Separation**	**The entire line was separated out above buildings and the ground or down under the ground or water!**
06	Use of mechanical oscillations	The frequency of the string's vibrations is increased to extreme values to reduce the time they require.
08	Periodic action	Freight modules move between the passenger modules.
11	**Inverse action**	**Fast modules on light string-tracks instead of heavy trains and dug up stretches**
12	**Local property**	**The string-track is ideally level; the line can run at an optimal height between connected points.**
19	**Transition into another dimension**	**The line was laid up along higher coordinates.**

fig. 15.24. Application of several TRIZ procedures in the invention of the STS

The unsatisfactory condition of traffic networks leads to disruptions in normal economic functions and in production in mixed economic branches. It leads to enormous temporal and material losses in resources, to higher prices in goods and services, to a reduction in the standard of life of the population, and to problems in the development of education and culture. It causes slow downs in foreign trade and tourism, increases in ecological destruction, problems in dealing with the results of natural catastrophes, and increased death rates in the population.

Exercises 14 – 15

35. Automobile. Use the meta-models "poly-screen" and "mono-bi/poly-mono", the "method of the integration of alternative systems", and "Lines of system technical development".

35.1. Do you know alternative energy sources for cars? Examples are Professor Guliya's swing-wheel, engines with compressed air, hydrogen engines ... Continue with the list.

35.2. Can you suggest a more economical engine that uses other physical-technical effects, such as piezo-electrical ones?

35.3. These are alternatives for the development of the module(s) of Unitsky's STS:

- a cabin to transport passengers or freight;
- a platform to transport cars with passengers;
- an integrated module-automobile that travels independently on the track and then drives off to park like a normal car;
- invent further!

35.4. How would the ideal car look if we use the STS to make it unnecessary to drive for more than 100 km at more than 50 km/h?

36. Railroads and highways. What could change in these modes of transportation if the STS is developed? Would they only be useful to transport loads? Use the meta-models "poly-screen" and the "method of the integration of alternative systems".

37. Air traffic. Safe! Environmentally friendly! Economically sound! Where are the alternatives here? Do we really need super-sonic aircraft to fly at an altitude of 30 km at speeds of 10-12,000 km/h from Moscow to San Francisco or from Paris to Sydney in 2 hours? Or will "Zeppelins" be better for the future?

38. City traffic. What is better, cars for 100–200 people or individual means of transportation? Moving pedestrian zones or light individual flying machines? Which way is best in the city for pedestrians: underground, on the ground, 10-20 m high, or above buildings at heights of 20-100 m? Keep in mind that old and new systems can exist parallel to each other.

39. Oil transport. There are catastrophes with oil tankers and pipelines. We know that there are tankers that transport loads using modules. Is this a solution for the problem of safety and environmental impact? Is the STS the ideal solution to do without above ground pipelines completely? Can we combine the ideas of a module-tanker with the STS's modules?

40. Water. Where can we find unlimited clean, high quality water?

41. Forests. The development of computer technology has increased the use of paper instead of reducing it and has helped drive the destruction of forests – the lungs of our planet. Can we reduce the number and size of the newspapers that are published? Can we stop printing books and using paper for packaging? Or… Use a more constructive spirit to invent further.

42. Electro-energetics. There is so much solar and nuclear fusion energy on the earth. There is so much electrical thermal energy and kinetic energy in the atmosphere and oceans. But, energy sources on the earth are still insufficient. In addition, the earth's atmosphere continues to be polluted and warmed by the burning of fossil fuels, especially oil, just to create energy.

43. Living in the city. In the city there is noise, dust, traffic, and very little connection to nature, and stress with the neighbors. How and where can people shape their living space in the future? Start with the parameter that it shouldn't take more than one hour to travel from the center of a large city 100 km out and back. And it is very important that we live in harmony with nature!

Tactics of Inventing

Machines continue to develop and there will therefore always be something to invent.
The essence of TRIZ is to completely change the technique of producing new technical ideas.
TRIZ recommends thought action that is based on knowledge of the developmental laws of technical systems, instead of the selection of variations.

Genrikh Altshuller

16 Diagnostics of the Problem

16.1 Types of Problem Situations

The determination of and solution to a construction-technological problem with strong physical contradictions always occurs with a specific strategic goal. This can be the goal to resolve defects in the production of a product, to modernize the product itself, to develop competitive ideas with a future, etc. In reality, an engineer is always confronted by more or less complicated tasks that need to be solved quickly but also need to be examined carefully with an eye for the future. When a problem arises, its value, necessary time limits for the solution, acceptable investment in the search for a solution, and an entire series of other questions need to be examined.

We can assume that certain methods and models for the quality analysis of products and technologies are used such as based on the methods of *Total Quality Management* (TQM), Six Sigma or Theory of Constraints (fig.16.1). In addition, we assume that changes will be supported by using means to automate the projection, modeling, and inspection of products. This includes *Computer Aided Engineering* (CAE), certain methods of Systems *Innovation Design Management* (IDM) enhanced with the methods of *TRIZ / CROST technology*. In this case, improvements in the products or production are reached with permanent innovation on the basis of a certain cycle. *TQM show what needs to be improved and IDM shows how to do this.* A short analysis of the problem situation should include "tactical" question to assess the level of difficulty of problem and the selection of solution procedures. When quality analyses of products are not constantly run by a firm, tasks are often set in a somewhat haphazard form and are often not well formulated. This is why, at the very least, the completed form of an initial description and the character of a problem situation must be correctly defined. TRIZ formulates characteristics that can be used to roughly formulate the type of problem situation at hand. The matrix similar to *"Quintilianus' Matrix"* (fig. 4.1) was used to help divide all problems situations into 6 types depending on how exact and completely the characteristics of the situation were described (fig. 16.2).

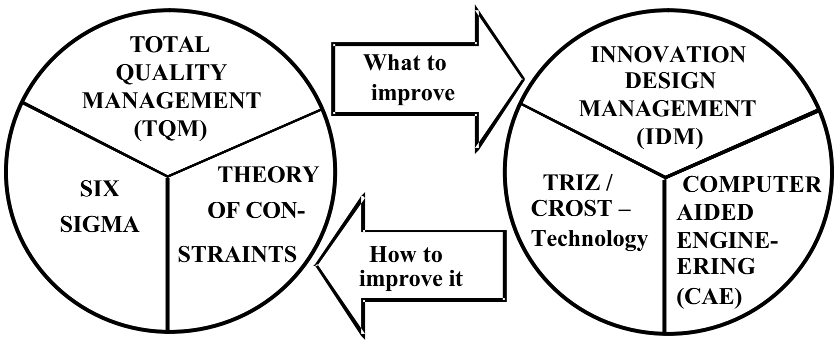

fig. 16.1. Interaction of systems for quality analysis and the control of development

The description of the situation of the *social type* (s) includes economic, planning, control, advertizing, marketing, educational and other problems without really addressing the concrete technical system. Although mainly the subjects of the situation are present in the formulation of the problem, the contradictions in the problem refer to individual persons or groups of people. For example, *suggest measures to increase the creative activity of the employees of a firm.* People often attempt to use economic-social methods to approach such assignments, even when the essentials of the problem are technical, such as those associated with technical equipment at the work site. In the case of social-production type (sp), the location of the contradiction is additionally important and questions of the quality of products, ecology, and labor protection play a role, too.

Ex. 113 (start). *Develop a procedure to clean up the air in the work areas of firms that do thermal processing.* The main property is a conflict between humans and the production system. This statement doesn't even include a reference to the cause of the problem as a technical system. The description of the production-technological type (pt) already includes technical objects and problems in their functions that are result from the fact that technological, use, and physical-chemical parameters of the system do not fulfill the demands on the system (defect, accident, high use of energy and material, appearance of disruptive factors).

Ex. 113 (1st step). *Large amounts of dangerous smoke are caused when large pieces are tempered by dipping them in an oil bath during thermal processing. Make a suggest about how the atmosphere of the work space could be cleaned up.* The main problem in this kind of assignment is that the results are often confused with the causes. There is clearly a purely administrative contradiction here while a technical or physical contradiction is needed for a practical solution to the problem.

A situation of the construction-technical type (ct) includes the problem description of the development of an extant technical system. The characteristic property of this situation is that a clear formulation of the technical contradiction already exists.

Type of Problem Situation / **Characteristics and Contents**			**social** (s)	**social-production** (sp)	**production-technological** (pt)	**construction-technological** (ct)	**construction-scientific** (cs)	**scientific** (sc)
1	**Who?**	**subject**	+	+			(+)	(+)
2	**Where?**	**location**		+	+	+	+	+
3	**What?**	**object**			+	+	+	+
4	**When?**	**time**				+	+	+
5	**How?**	**method**				+	+	+
6	**With what?**	**means**					+	+
7	**Why?**	**goal / cause**						+

fig. 16.2. Types of problem situations

Ex. 113 (2nd step). *Dipping large pieces faster into the tempering oil bath causes less smoke but it disrupts the tempering process.* Here the description clearly describes *where what when happens*, but it is not clear how the problem can be solved. Of course, it is also possible that this information is insufficient to solve the problem. However, this is a very constructive statement that can be used as a basis for attempts to solve the problem at the level of a technical contradiction. Further examination of the conditions that cause the problem is possible, i.e., the physical reasons for the problem can be explained.

A situation of the construction-scientific type (cs) occurs in the problem description – a synthesis of a new system or, if necessary, to understand and research physical process in the OZ of the problem. But, it is still not clear at all with which *means* (resources) *and how* the problem at hand can be solved.

Ex. 113 (3rd step). *The oil in the tempering bath burns when hot pieces are dipped into it. How can we resolve this problem?* This is a physical contradiction that we can describe as follows: the oil has to come into contact with the heated piece to fulfill the requirements of tempering and the oil should not come into contact with the heated piece so that it doesn't reach its burning point. We can also formulate the contradiction like this: the oil may not come into contact with oxygen in the air to prevent burning and the oil has to come into contact with oxygen in the air because the bath is open to facilitate dipping the pieces. Now we can use procedures, standards, and scientific-technical effects to solve the problem.

When the problem can really only be solved after we've collected new knowledge about the nature of physical-chemical processes in technical systems, then this is a situation of the scientific type (sc). The main characteristic is that known (expected) and extant (real) results when implementing a certain physical-chemical process in a technical system contradict each other. For example, *suggest a procedure to temper large pieces without cooling them in an oil bath.* All of these questions naturally include the need to recognize the *causes* and sources of this or that phenomenon and to define the possible *goals* of the applications. Here it is also typical that the problem description in such situations again moves close to the problem situation of the social type because the lack of special knowledge can be attributed to the social system - to the science and research system or the education system.

The triangle in the table in fig. 16.2 shows the area in which the methods of classical TRIZ can primarily be used.

To analyze a problem situation correctly, questions must be answered that lead to the formulation of a technical or physical contradiction. This helps prevent ineffective loss of time and other resources for a solution to the problem situation. Then it's also possible to use TRIZ instruments in their entire broad spectrum.

16.2 Algorithm for the Diagnostics of a Problem Situation

The main goal of diagnostics is the definition of the OZ and the related task assignment. The diagnostics stage must always be completed before assigning a task, even though this simple rule is often ignored or treated haphazardly. Most mistakes occur when we try to approach a solution without a precise formulation of the contradiction. In many cases, the causes of the problem have also not been correctly defined. Another mistake is the attempt to solve a problem that really consists of several tasks related to each other.

It is useful to apply procedures for a non-algorithmic "unraveling" of the problem situation (see section 18-19) before diagnostics. This helps to weaken the normal (imprecise, incomplete, and unreliable) images of the problem and to prepare your thinking for the construction of new ideal function models. The reasons for the problem, contradiction models, and resources in the OZ can be better defined.

It can help to maintain a certain scheme that we'd like to call the ***Algorithm for the Diagnostics of a Problem Situation*** to run the correct diagnostics of the problem situation. This scheme (fig. 16.3) contains a series of procedures that generally increase the quality of the analysis of the initial situation and prepare your thinking to then move to further constructive action with the help of TRIZ instruments. Experienced specialists can do without this or that procedure, but this scheme corresponds generally to the optimal organization of the diagnostics of the problem.

ALGORITHM FOR THE DIAGNOSTICS OF A PROBLEM SITUATION

Term for the Step	Description of Main Procedures
1. Goal	Definition of the developmental goals of the system using a function-cost-analysis and contrasting the developmental laws and lines of systems (section 14-15)
2. System	Construction of a functional system model of the concrete conflict model for the definition of its sources (operative zones – see below in this section)
3. Contradictions and OZ	Definition of a number of technical or physical contradictions and a number of corresponding operative zones
4. Resources	Definition of resources in the operative zones chosen, in the system, and in the system environment
5. Meta-strategy	Selection of a meta-strategy to solve problems in every operative zone (see section 14.1, fig. 14.4)
6. Arrangement of tasks	Arrangement of the operative zones according to the level of difficulty of the problems they contain and the creation of an order for solutions to the tasks (recommendations below in this section)
7. Tasks	Short formulation of one concrete assignment for each operative zone respectively and a transition to the reduction stage

fig. 16.3. Recommended procedures for the diagnostics of a problem situation

In step 1, a general diagnosis of the system is run with the goal of defining, improving, or resolving the components of the system. This is done with a function-cost-analysis, either by contrasting the level of development of the technical system and its components with the developmental laws and lines of systems or by using other procedures to evaluate the effectiveness of components.

Ex. 113 (4th step). Previously the attempt was made to prevent the oil from burning by fitting the basin with cover with an opening that had the exact same size as the manufactured pieces. New shapes always required a new cover. Here it is clear that the solution was based on a static part (cover) in direct contrast to law 3.1 *Coordination of the Rhythm of System Components*, as well as on the lowest level of the development of instruments (fig. 15.13) and of materials (fig. 15.14).

In step 2, so-called functional system models of the conflict can be constructed for complicated parts and of course for the entire system.

The goal of modeling is the definition of components (or functions or effects) that are simultaneously part of the production of positive and negative functions. These kinds of components are called *operative components* and are organized into the appropriate operative zones.

Ex. 113 (5th step). The components that should be considered in the conflict situation described include: the product, oil, smoke, and air. It is always useful to graphically represent the entire system of the interaction of these components (fig. 16.4). Here the oil (inductor 1 - positive) influences the surface of the product (receptor 1) so that it cools. But, the oil burns while influencing the high temperature at the surface of the product and because of the presence of oxygen (inductor 2 -

negative). It gives off smoke (receptor 2). Smoke is a negative inductor for air because it pollutes it.

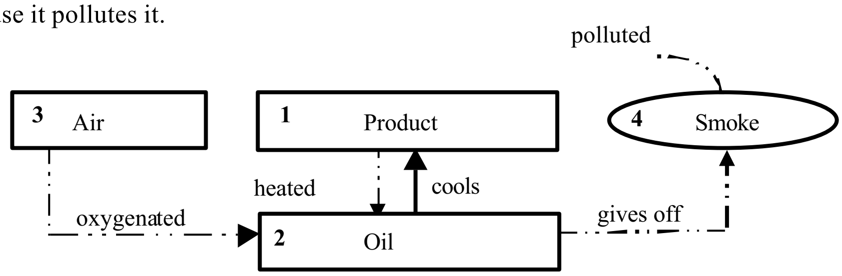

fig. 16.4. Functional system model of the conflict in ex. 113

We can also construct detailed schemes for our diagnostics. For example, we can consider the fact that oil consists of two parts: oil as a whole and a thin layer that comes into immediate contact with the outer surface of the extremely hot piece. It is this layer that heats quickly, burns with oxygen in the air, and gives off smoke.

In step 3, we need to formulate contradictions in the interaction of the components that belong to the functional system model. We have to describe the OZ that is related to the contradiction we've uncovered.

Ex. 113 (6th step). Different processes can be considered and different contradiction models can be constructed in accordance with the level of the physical-chemical investigations of the components. Here we'll stay on the macro-level that is shown in fig. 16.4. For example, we can formulate the following versions of a contradiction for this scheme:

Technical contradiction (variation 1): Oil tempering improves the quality of the product but pollutes the air by giving off smoke.

Technical contradiction (variation 2): Dipping the heated product is necessary for tempering but it causes the oil to burn and results in smoke pollution of the air.

The contradiction models can be represented with different descriptions for one and the same functional system scheme. We have to try to reproduce the positive and negative functional properties in our contradiction models: the *heated* product, the *quality (tempering)* of the product, and the *burning* oil. The second variation is therefore preferable to the first.

Physical contradiction (variation 1): The oil *has to burn* with oxygen present in the air and at high surface temperatures and it *should not burn* because this pollutes the air.

Physical contradiction (variation 2): The oil *has to be heated* to absorb the product's heat and cool it and it *should not be heated* so that nothing is burned.

Physical contradiction (variation 3): Oxygen *has to be* in the air because this is determined by the air's natural composition and oxygen *should not be* in the air so that the oil doesn't burn.

Physical contradiction (variation 4): The smoke *has to be* in the air, because it is a product of the burning oil and the smoke *should not be* in the air so that the air is not polluted.

The physical contradiction has to reflect the physical-chemical processes that connect it with the positive and negative functions in the problem situation at hand. There is no way that we should note the following kind of contradiction: *the product must be heated for tempering and it should not be heated so that the oil doesn't burn.* Actually this model indicates that the tempering procedure needs to be renewed. This would change the task completely in a way that is not acceptable in this situation because we need to retain the principle of oil tempering.

The existence of several alternative models at the diagnostics stage should not be understood as an unacceptable situation. We'll create more precise formulations in the reduction stage. We should not forget that different formulations of contradictions can lead to different ideal functional models and consequently to different directions in the search for solutions.

Ex. 113 (7th step). This simple example demonstrates that, in variation 2, components 1 and 2 are related to the physical contradiction. Variation 3 suggests that components 2 and 3 are related to the physical contradiction and variation 4 points instead to components 3 and 4. Structural models for each OZ are shown in fig. 16.5.

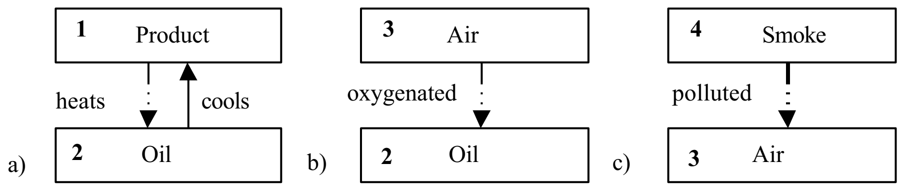

fig. 16.5. Operative zone for the problem situation in ex. 113

In step 4, resources must be evaluated that are present in each of the selected OZ's. This can influence the assessment of the level of difficulty of the problems that need to be solved in the OZ. We can run an analysis based on the table for the selection of resources (section 8.2, fig. 8.7 and 8.8). Here we'd like to do this in simplified form.

The following resources are useful for the OZ **a):** size and speed of the insertion of the pieces, size and shape of the tub, location of the tub at the work site, the chance to move the tub somewhere else.

Resources for the second OZ **b)** are the same as for zone **a)** plus the chance to add supplements to the oil that reduce its oxidation level and the possibility of creating an atmosphere without oxygen or a vacuum in the OZ.

Resources for the third OZ **c)** are the same as for zone **a)**.

In step 5, we need to roughly define the character of the tasks and the preliminary meta-strategy for their solutions.

Ex. 113 (8th step). Clearly, *corrective tasks* with minimum strategies at the middle level of difficulty should be considered for the operative zones **a)** and **b)** because certain resources are present or could be introduced there that could be useful for a potential solution to the problem. A *corrective task* with a minimum strategy at the minimum level of difficulty can be formulated in the OZ **c)** because the procedures of removing polluted air and adding clean air are already well known. But, in no way does the situation **c)** exclude the possibility of developing very good solutions.

In step 6, the level of difficulty of the tasks to be solved in every OZ needs to be evaluated to create a certain order for their solutions.

Ex. 113 (9th step). We've limited ourselves to three different task descriptions in this case due to the results of our diagnostics. It is not easy at all to define in advance which of the variations of the task description provides the best possibility to improve the system as a whole.

Common sense would tell us that a solution with model **c)** doesn't look promising because it doesn't resolve the causes of the oil's burning. On the other hand, a very inexpensive solution could be found here (and even one that has nothing to do with inventing) that corresponds to a minimum strategy such as the installation of effective smoke ventilators. At the same time, we could think without stereotypes and consider the chances to use the "dangerous" smoke to carry out useful functions in this process or at the work site.

The other two variations seem to have the same value although variation **a)** looks somewhat simpler. But, this is only because we can assume that a solution will be found without more intensive investigation of the physical-chemical properties of the burning process, although this could be necessary in OZ **b).** On the other hand, solutions at a material level are generally the most effective with long-term chances and this is also reflected in the developmental lines of instruments and materials.

We recommend the following rules:

1) first the problems with technical contradictions should be solved and then those with physical ones;

2) first the "simpler" problems should be solved and then more difficult ones. "Simple" tasks can help prepare us for solutions to more complex ones because we can then expect to recognize the problem as a whole or uncover hidden complications;

3) first the task should be selected where the solution could resolve several problems at once. We call this kind of task a *key* or *root task.* Modern TRIZ includes recommendations to find such a task.

To clarify this example, let's assume that first the task for OZ **c)** will be solved, then OZ **a),** and finally OZ **b).**

In step 7, concrete task descriptions must be formulated for each OZ.

Ex. 113 (10th step, see also *Exercises 16-17***).** In the system that includes the product, oil, the basin, and air, minimum changes are needed to keep the oil from burning in the following variations of task descriptions:

- for OZ **c):** Smoke that pollutes the air is given off when large heated pieces are dipped in the oil bath for tempering;
- for OZ **a):** When large heated pieces are dipped in the oil bath for tempering, the oil layer that comes into direct contact with the surface of the product is heated to a temperature at which the oil burns;
- for the OZ **b):** The presence of air in the tempering basin causes the oil to burn when it comes into contact with the heated surface of the manufactured piece.

The diagnostic algorithm provides the necessary basis for a transition to the reduction stage, for a precise modeling of the contradictions, for the formulation of the functional ideal model, and a thorough analysis of the resources. A solution can then be constructed by using the stages of Meta-ARIZ. It's possible that individual tasks will require a cyclical repetition of certain procedures or even the entire diagnostic stage.

17 Verification of the Solution

17.1 Effectiveness of the Solution

Verification is a stage with high responsibility that is anything but simple. This is because it is virtually impossible to command so many different kinds of knowledge to predict and assess the quality of a solution and the consequences of its application. How often has the dramatic fate of inventors been associated with the over or under assessment of their ideas? In the first case, inventors fought fanatically for the recognition of an idea that was either poorly constructed and ineffective or sometimes even poorly thought out and not needed. In the second case, inventors simply failed to do further research on their brilliant ideas and couldn't transform them into practical solutions. Often someone else did this later to become a great inventor and successful entrepreneur.

An orientation towards the *ideal final result* and the *functional ideal model (*see section 9.2.) helps prevent ineffective variations and associated searches from the start. Your thinking is immediately focused on areas where *promising*, i.e., *highly effective* solutions exist. However, many technicians and engineers who are not familiar with TRIZ do without solutions to problems with extreme physical-technical contradictions. They are quickly ready to "pay" for the desired function with the high use of energy, material, and information. Often production and use problems as well as negative environmental effects arise, too. Traditional thought is often insufficiently oriented towards the effective use of resources for solutions to technical-technological problems.

It is relatively easy to investigate the consequences of a solution with slight *construction* changes. This is especially the case when good mathematical analogous models exist in CAD systems.

A highly effective solution immediately improves the values for the quality of a system. Negative factors are weakened and positive ones are strengthened (section 14.2 *"Ideal Machine"*). This is different in the development of an *invention*. First, meta-ARIZ dictates that each and every idea up to the completion of the *verification* stage should be viewed only as a hypothesis for the improvement of a technical system. The idea has not yet been processed by construction specialists. In an ideal case, the idea is discussed with construction technicians who are part of the design team. But, in most cases specialists work alone on the search for a solution and often on their own initiative. They certainly don't have the necessary support of other specialists. Second, the application of CAD systems is often impossible because an acceptable mathematical model has to be created for a new solution. This requires time and often additional mathematical research.

A few practical suggestions were worked out in TRIZ for the verification of ideas for a solution that help to prevent serious mistakes when evaluating the quality of a solution. These suggestions include the following essential rules:

Rule of the resolution of the contradiction. A necessary characteristic of an effective solution is the resolution of the contradiction that causes the problem. It is sufficient to check whether this requirement has been fulfilled or not to compare two descriptions with each other: "What it was" and "What it's become". The general question that follows is ***was the contradiction solved*** that was the reason for the existence of the problem ***and in which way***. The check needs to be made for every alternative of the technical contradiction and for every conflicting situation of the physical contradiction.

Rule of the occurrence of super-effects. This rule is concerned with the search for unexpected qualitative or quantitative changes that appear with the new function. When we make changes, we change the properties of components (elements, details, construction groups, sub-systems, systems, products as a whole). The properties of components are expressed as parameters. *Linear* changes in type are more or less characteristic for quantitative changes of a parameter. When the property has a qualitative character, for example, form, color, or user friendliness, or the modifications made change properties, we speak of qualitative changes (*non-linear* ones that change the properties of the object itself). In any case, the object has new properties following qualitative changes, although the disappearance of certain properties in the system also represents the appearance of a new property. When this new property is not the actual goal of the invention, we call it a ***super-effect*** (look again at the definition in section 14.2). Unfortunately, *negative super-effects* are just as possible as positive ones.

In light of the special importance of super effects, a methodology for their search was formulated in the *Algorithm for the verification of the solution* and it will be handled later in section 17.3.

Rule of the doability test. All of the properties of an idea can only be described fully in praxis. Many things can be checked with patterns, models, and with mathematical modeling. But this all happens later after the idea itself has been accepted for a construction-technical test, at the very least. This rule is directed towards the evaluation of ideas for a solution to determine whether any essential physical or technical laws are in conflict. For example, attempts are still being made to discover an "infinite motor" – *perpetuum mobile*.

When you use this rule, hidden problems that make it necessary to find new inventive solutions can come to light earlier.

Rule of the control of usage. This rule attempts to research possibilities about how an idea could be further developed or transmitted to other areas of technology as well as to examine a single concrete application of a new idea. The use of this rule can lead to the appearance of and solutions to new tasks in inventing.

Rule of the background check. This rule foresees a careful check of extant patents and technical literature to determine just how new a solution is. This is definitely necessary if you want to patent an idea for a solution.

Rule of the methods check. This rule recommends that you check whether the procedure for a solution itself is new. If this is true, you can supplement your instruments with a new procedure, add this procedure to the TRIZ tables, or shape it somewhere else in another way.

17.2 Development of the Solution

Different instruments can be used to develop a technical solution and possibilities for its application. The simplest, yet extremely effective instruments are combination tables that resemble morphological matrices (section 4.2, fig. 4.5).

Here we have a "classical" example in the "development of a magnetic filter".

Filters were previously used to clean impurities from heated gas that consisted of several layers of metallic cloth. Gas was supposed to flow easily through the cloth and the impurities were caught in its stitches. A disadvantage was the speed with which the filters were filled with particles and the difficulties in cleaning them with a stream of air in the opposite direction). This is why a magnetic filter was invented (fig. 17.1).

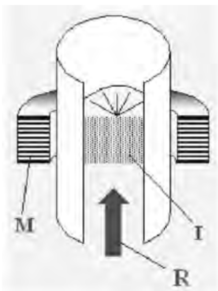

fig. 17.1. Construction of a magnetic filter

Ex. 114. Magnetic filter. In accordance with formula 1 (see further in the table in fig. 17.2) of inventing, ferro-magnetic particles (metal filings) were installed between the poles of a strong electro-magnet. They create a porous mass through which the dirty gas can pass. The impurities (dust) are then caught in these pores. It's simple to clean this kind of filter by turning off the magnet. The ferro-magnetic particles then fall together with the impurities caught into a pan under the filter. Then the magnet is turned on again and the filter "collects" the impurities.

Let's try to reduce the structural model of the filter to a formula.

In the initial version, there is an external magnetic system **M** inside of which is a ferro-magnetic powder (working organ or inductor **I**), with dust inside (the product or receptor **R**) consisting of the stream of sprayed gas. We can fix the structure in the following way: **MIRRIM.** The R was used twice to preserve symmetry.

1st transformation procedure: Scramble the symbols within the structural formula - **1) MIRRIM, 2) IMRRMI, 3) RMIIMR, 4) MRIIRM, 5) IRMMRI, 6) RIMMIR.** Do we now have new filters?? A possibility might be scheme 5 that somehow represents the principle "inversion" when compared to scheme 1. Here the magnet is surrounded by a powder through which the gas flows.

Ex. 115. Development of a magnetic filter. Invention 2 was used to check this procedure: an electro-magnetic filter to clean gases and liquids that contains the source of a magnetic field and filter elements out of a grainy magnetic material. Its special property is that the filter element was installed around the magnetic source to reduce the specific energy use and to increase productivity. This creates an externally closed magnetic shape.

And that corresponds totally to scheme 5. Interestingly enough, this invention was first made 7 years after invention 1!

2nd transformation procedure: Changes in the parameters of components in the structural formula.

Ex. 116. Magnetic valve. What happens when the magnetic field presses the ferro-magnetic powder closer together? Then nothing gets through the filter - neither dust, nor gas, nor liquid. The filter has become a valve! This idea has led to patents to regulate streams of different materials and ***each time by a different inventor at intervals of several years!***

The inventors hadn't worked on developing their solutions further and hadn't noticed that the devices they had developed could use different construction types and applications. These are all inventions.

3rd transformation procedure: Changes in the structure and parameters of the components of an invention. Here it is helpful to use a morphological matrix. For example, we can build a matrix (fig. 17.2) in which all 6 structural components and 5 product states can be examined.

Product state	**Construction scheme**					
	MIRRIM	IMRRMI	RMIIMR	MRIIRM	IRMMRI	RIMMIR
Gas	1	2	3	4	5	6
Liquid	7	8	9	10	11	12
Solid body	13	14	15	16	17	18
Powder	19	20	21	22	23	24
Elastic material	25	26	27	28	29	30

fig. 17.2. Morphologic matrix for the idea of the development of a magnetic filter

The original magnetic filter in invention 1 fits into box 19: scheme MIRRIM, product - dust (this is a powder!). The magnetic valve fits into the boxes 1, 7, and 19. Box 13 is also very interesting: a stream of some kind of solid flows or perhaps is pulled like a wire through a ferro-magnetic powder. The magnetic field presses on the "wire" and makes it thinner. A similar process is also used to produce wire. The initial product is pulled through the openings of a metal plate (pull jets). First the wire is pulled through large, and then smaller and smaller openings until it is processed into thin wire. The jets wear very quickly. Instead of a metal plate, we could use magnetic powder that is pressed together by a field such as in box 13. An invention 3 of this kind has also been made.

Ex. 117. Pulling a wire without a pull jet This procedure for pulling steel wire that reshapes the wire by stretching it has a special property. To manufacture wire with a constant diameter, the necessary reshaping is done by pulling the wire through a ferro-magnetic mass in a magnetic field.

Ex. 118. Stripping procedures. Invention 4 is a procedure to strip surfaces with a device that is shaped like a balloon made from elastic material. It has the special property that ferro-magnetic particles are introduced into the balloon to increase the quality of the processing. Pressure is applied to the device through the influence of an external magnetic field. There's an external magnetic field, a balloon inside with elastic walls, and inside the balloon is a ferro-magnetic powder. This is the scheme MRIIRM, box 28.

Ex. 119. Procedure to spray molten material. Invention 5 is a procedure to reduce molten polymer material to spray by using compressed gas on the flow of molten material. Its special property is that a ferro-magnetic powder is introduced into the material to increase its degree of dispersion. Then the material is directed through an area with an alternating magnetic field. Externally there is a magnetic field, internally a molten polymer material, and inside this material is a powder. This is the scheme MRIIRM, box 10.

Scrambling the components provides 6 schemes for different facilities and changes in the product state allow us to create 5 variations. Altogether, these changes result in 30 combinations (fig. 17.2). All of these schemes arrange the magnetic field and the product linearly with respect to each other. What would happen if we also considered the relative rotation of the components? This kind of invention has also been made.

Ex. 120. Procedure to intensify a process. Invention is a procedure to produce inorganic pigments that is special in that the interaction is carried out in a rotating magnetic field to increase the intensity. Again this is the scheme MRIIRM and it would fit into box 22 in fig. 17.2, if this were not about a rotating field. Actually we need to create this kind of table for a rotating magnetic field, but with the numbers 31-60. Then invention 6 would fit into box 52.

We see that the initial scheme of a magnetic filter can be expanded into 60 (!) different schemes. But almost no one has noticed this so far.

This is why TRIZ recommends the use of Meta-ARIZ to look in some way for possibilities for the further development of an invention in the *verification* stage. We've just examined the simplest procedures.

17.3 Algorithm for the Solution Verification

Essentially all of the properties of a new solution are examined in the search for super effects. This is why the methodology is as general as the *Algorithm of the Solution Verification* (fig. 17.3). Determining super effects has two main goals: to determine possibilities to develop a solution further and to prevent both unnecessary costs for the development of and attempts to implement unacceptable ideas.

Ex. 84. Gas turbine by SIEMENS (finish). A check of the ***necessary conditions*** shows that an essentially correct step was taken towards a complete resolution of the basic physical contradiction. The results of a check of the ***sufficient conditions*** can be found in the table in fig. 17.4 (Siemens controls the exact data).

Exercises 16 - 17

44. Tempering tub. Finish the solution to the three tasks in ex. 113 (10^{th} step at the end of section 14.2).

44.1. Remember to formulate the ideal functional model for every task.
44.2. Check whether there are positive or negative super effects in your solutions.
44.3. Check whether your solutions could also be used in other industrial branches.
44.4. Remember that some ideas can be used for solutions to tasks with different task descriptions. Sometimes solutions appear that can resolve the problem for several task descriptions from the start because the solution makes the completion of other tasks unnecessary.
44.5. Compare all of the solutions found using different criteria such as environmental impact, simplicity of technical implementation, and economic effectiveness.
44.6. Use the method of modeling with small figures from section 18.3 to address any "unsolvable" problems in solutions to tasks in situation a) and b).

ALGORITHM FOR THE SOLUTION VERIFICATION

#	**Procedures**
1	Create a structural scheme of the object suggested
2	Define the components' functions at all levels
3	Define the streams of the most important resources using the structural scheme
4	Demonstrate the interdependencies of the functions of parameters. Define the qualitative and quantitative properties and functions.
5	Show newly introduced components.
6	Start with newly introduced components and *follow the changes in every stream of resources* for an evaluation of the changes in the functions of all levels up to and including the highest (main useful function of the object).
7	Check the character of changes in the functions of the pre-conflict, conflict, and post-conflict phase *in the operative time* with the old solution.
8	Check changes in the *construction resources*
9	Check the new positive functions and properties (*positive super effects*). Assess their influence on the values of the object's effectiveness.
10	Investigate the results of positive super effects. Create an overview of the (positive and negative) changes that result from servicing and usage around the object during its life cycle.
11	Examine the possibilities of improving the solution.
12	Check the new negative functions and properties (*negative super effects*). Assess their influence on the values of the object's effectiveness.
13	Investigate the results of negative super effects. Create an overview of the (positive and negative) changes that result in servicing and usage around the object during its life cycle.
14	Examine ways to remove insufficiencies that appear. If necessary, discard the solution, formulate new problems for inventions, and return to the search for new ideas.

fig. 17.3. Algorithm for the solution verification

45. Gas turbine by SIEMENS. Examine the possibilities of developing the solutions found further. Run diagnostics of the new system with the goal to improve it using the laws and lines of systems development (see also sections 15.1 and 15.2).
46. Highway. Run diagnostics of a highway with the goal to improve it using the laws and lines of systems development. Formulate the contradictions, define several OZ's, and create a task in inventing for each of these OZ's.

#	**Procedures**
5	Refer to the newly introduced components: 24 burners were installed in the functional space around the turbine.
6	Evaluation of the changes in the functions of all levels up to and including the highest (main useful function of the object): The efficiency level increased from 36% to 38,5%. This is a big success!
7	Check the character of changes in the functions of the pre-conflict, conflict, and post-conflict phase *in the operative time* with the old solution: the load on the blades is more even.
8	Check the changes in construction resources: a super effect was discovered in which it's possible to construct smaller turbines with the same level of effectiveness.
9	Check the new positive functions and properties (positive super effects). Assess their influence on the values of the effectiveness of the object: an especially valuable super effect was uncovered - the turbine now has improved repair characteristics because it is no longer necessary to stop the turbine to repair an individual burner!
10	Investigate the consequences of the use of possibilities that result from the appearance of positive super effects. Create an overview of the (positive and negative) changes that result from servicing and usage around the object during its life cycle: 1. Material is saved and the manufacture of the turbine is easier; 2. Room is saved and less fuel is used to run the turbine; 3. The blades last longer with less use of material and work. The economic effect during the life cycle of the turbine is several million €.
11	Investigate the possibilities of improving the solution: 1. We should consider the strategy of distributing contradicting properties in the material of the blades; 2. We should continue with strategy of segmenting the working organ.

fig. 17.4. Example of the solution verification

47. Ideas for entrepreneurial action. Check the possibility to further develop your firm or to sink production costs in storage, transport, and service. Base your analysis on the advantages and disadvantages of the objects that you've chosen. Create tasks for the further development of these objects with the *Algorithm of the diagnostics of a problem situation (section 16.2)*.
48. Your inventions. Check the possibilities for the further development and expansion of inventions you've already made.

Art of Inventing

Good results can only be achieved with a high culture of thinking.
Scientists, builders, and inventors need strong and lively powers of imagination. Unfortunately, many people have very low imaginative potential.
It is possible that the application of laws, procedures, and standards can be diametrically opposed to "flights of fantasy".
The entire apparatus of TRIZ is intended to support strong and easily controllable powers of imagination.

Genrikh Altshuller

18 Pragmatism of Fantasy

18.1 Non-algorithmic TRIZ Methods

"The development of technology, just like every development, follows the laws of dialectics. TRIZ therefore is grounded in the application of dialectical logic for creative solutions to technical problems. But, logic alone is not enough. The special properties of the instruments with which we work must be taken into consideration in every case. This instrument is a very special one - the human brain." This was written 30 years ago by the founder of TRIZ [2].

He stressed that the strong sides of human thinking and character should be maximized in every kind of creativity. These include intuition, powers of imagination, stamina, the ability to work hard, courage, education, etc. But, it's important for creative personalities to also keep the weak sides of thinking in mind to prevent mistakes and loss of time. This is especially true of *psychological difficulties*. Altshuller noted the following two examples:

1) Divers use lead shoes to increase their weight under water and reduce their buoyancy. These shoes were manufactured for more than 100 years in one size only. They were too small for some and too large for others. But it took one hundred years for the development of shoes that can be disassembled. This is a very simple improvement, yet useful!

2) Lenses and eye glasses were well-known ca. 300 years before the invention of the telescope. No one thought of the idea of examining the world through two lenses mounted in line with each other for 300 years! Why? People thought that lenses pass on a distorted image. "Common sense" dictated that two lenses in-

stalled in line with each other would lead to an even stronger distortion. This psychological barrier prevented the discovery of the telescope for more than 300 years! We can hardly think of an invention that has had such a revolutionary effect on the way people see the world. The telescope made the stars accessible to humanity and gave the development of science a tremendous shove forward. We cannot imagine how advanced we would now be if the telescope had been invented 300 years earlier.

The author of TRIZ wrote the following about psychological difficulties [5]: "Inventors construct a series of thought models and experiment with them somehow. Here the thinking of an inventive person has a characteristic quality ... usually an already extant machine is used as an initial model. This kind of initial model has limited possibilities that inhibit the powers of imagination. It is difficult to find a radically new solution under these conditions. When inventors begin with the *definition of the ideal final result*, the initial scheme is ideal – it's extremely simple and has improved properties. Further thought experiments are then no longer bogged down by the weight of the usual forms of construction and a promising direction appears immediately: the inventor tries to find the best results with the fewest means."

Consciousness controls us with images that are embodied by words: "The task description runs using known terms. These terms are not neutral. They strive for the contents that are their own. However, inventing means to give old terms or their entire essence new contents. The cause of the difficulties that are part of technical terminology is above all else difficulties in thinking ..."

Ex. 121. Pipeline for oil. In one of my seminars, we examined an assignment to lay a *pipeline* for oil through a slot. The conditions of the task dictated that it was not possible to install supports or suspension cables. Usually a pipeline distorts into a bow-shape upwards or downwards when oil flows freely. The solution was somewhat trivial: we needed to *increase the cross-cut surface of the pipe.*

The next time we formulated the same task in another way: an *oil pipeline* needs to be moved. The solutions included the following statement: strength and stability depend both on the surface as well as the form of the cross-cut.

A construction shaped like a "double-T" is the most stable form of any cross-cut surface (fig. 18.1a). Another variation (fig. 18.1b) of the double-T can be built from two pipes with a smaller cross-cut that the original pipeline that are mounted one above the other and connected by a solid vertical flange. The result was that the participants replaced a special term to distance themselves from the normal image of a *"pipe with a round cross-cut"* with which the word *pipe* is associated. Then they made new suggestions for a pipeline but no longer with a round cross-cut.

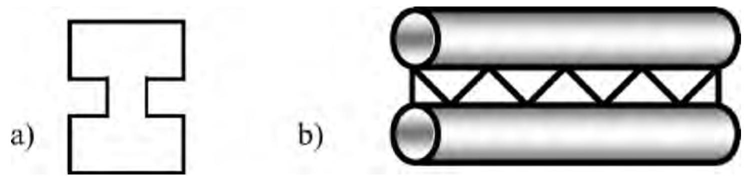

fig. 18.1. Oil pipeline with cross-cut: a) hollow double-T; b) double-T from two pipes

The model of this process can be followed using B. Kedrov's* well-known scheme to overcome cognitive-psychological barriers (fig. 18.2). While searching for a solution, human thoughts move from the facts **F** that describe the initial situation to the determination of something special **S** about these facts in order to create an ***idea*** for a solution. Thoughts move in a specific direction (**α**) until they run into the cognitive-psychological barrier **B**. This barrier means that either sufficient knowledge or the necessary psychological state is not present. Which actions can we associate with the task of removing barriers? We could climb or jump over the barrier, for example. Exactly that was shown as a creative impulse that represents a jumping board that then throws thoughts over the barrier! This kind of jumping board can be a thought that moves towards (**ß**), for example. This can be any association: an object or phenomenon (in the *Method of focal objects),* another idea, even an incorrect one in *brainstorming*, fantasy analogies (in synectics), etc.

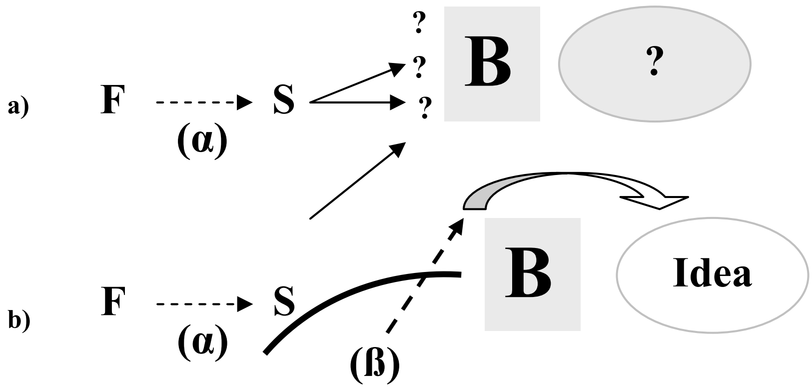

fig. 18.2. Kedrov's model of the invention of an idea

Actually, the same psychological sluggishness is at work here. Ask yourself the question how this barrier really functions? If you just want to see the *idea* behind the barrier, your actions could look completely different! For example, the following associations could work: *go around the barrier, get over the barrier with a ladder or a balloon, pull the barrier down or destroy it, break it up, make a hole or a tunnel through it, etc.* All of these are different images that are so special that they can lead to confusion just like the *terms* in every other problem description. The essence of Kedrov's metaphor is thoughts need the method (**ß**) to take *"non-obvious"* ideas into consideration. In TRIZ, this kind of method is *Functionally ideal modeling* (see section 9.2.). If we want to continue to play with words and thoughts and move to even more fantastic fantasy images, we could say that the functionally ideal modeling makes the barrier transparent! This means that something becomes visible through it.

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* B.M. Kedrov: *Theory of Scientific Inventions*. Anthology "Scientific Creativity", Moscow, 1969 (Russian)

In fig. 18.3, you'll find a comparison of "usual" thinking with *TRIZ thinking*[*]: "Usual thinking is controlled by consciousness. It protects us from illogical modes of action and influences us with a large mass of strictures. But, every invention overcomes normal images of what's possible and what's not."

#	Traditional Thinking	TRIZ Thinking
1	Tends towards making things easy, simplification of the requirements placed on the task	Tends to intensify, more complex requirements placed on the task
2	Tends to avoid "improbable" paths	Strives to follow paths that increase the "improbability"
3	Imprecise visual image of the object tied to its prototype	Precise visual image of the object tied to its ideal final result
4	"flat" image of the object	Image of the object "in its entirety": the object's sub- and super-systems are considered as well as the object itself
5	Image of the object as a "single picture"	The object is understood in its historical movement: yesterday, today, and tomorrow (if the present line of development continues)
6	"Fixed" and hardly changeable image of the object	Image of the object is "flexible" and can be easily changed in time and space
7	Memory provides similar and therefore weak analogies	Memory provides other and therefore strong analogies where information is constantly updated with new principles and procedures
8	"Barrier of specialization" gets stronger with time	"Barrier of specialization" is destroyed with time
9	Controllability of thinking does not increase	Thinking gets more controllable. Inventors view the path of thought from the side, can easily control the process of thinking, and distance themselves from "intrusive" variations

fig. 18.3. Comparison of traditional and TRIZ thinking

The capability for functionally ideal modeling has to be trained. This can also be done by reading science-fiction, detective novels, anecdotes, and even fairy tales, by looking at humorist and fantasy drawings and paintings, and by hearing unusual musical pieces. Altshuller wrote: good results are only possible with a high culture of thinking. Scientists, builders, and inventors need strong and lively powers of imagination. Unfortunately, many people have very low imaginative potential. It is possible that the application of laws, procedures, and standards can be diametrically opposed to "flights of fantasy". The entire apparatus of TRIZ is intended to support strong and easily controllable powers of imagination.

[*] Y. Salamatov: How to become an inventor: 50 Hours of Creativity/ A Book for Teachers. – Moscow, 1990 (Russian)

In addition to the concept of functionally ideal modeling, a series of "non-algorithmic" methods to overcome psychological difficulties were developed in TRIZ:
- "Fantogram",
- modeling with the coordinates "Dimension – Time – Cost" (special shortened form of a "Fantogram"),
- the model "What was - What became",
- " Modeling with Small Figures",
- suggestions about how to avoid logical and psychological mistakes.

Let's now turn to these methods. The first two methods are used to remove psychological difficulties in the initial stages of solutions to tasks in the very first analysis. Two of the following methods are effective "*non-algorithmic*" instruments to generate new ideas.

18.2 The models "Fantogram" and "What was - What became"

The first model is mainly used to "cleanse" thinking of negative stereotypical images of the original problem and the goals of its solutions. Its goal is to perceive (not understood in a strict sense!) the special properties of this object and the limits of its transformation possibilities.

A "Fantogram" is a table (fig. 18.4) that helps to complete express training or express stimulation of the powers of imagination by using the object of the problem to be solved. G. Altshuller had the idea of the fantogram while studying hundreds of science-fiction novels. He approached these books as if he were evaluating inventions for their use and level of newness. In science-fiction, only those texts with new original ideas with fantasy content are generally successful. This requires extra-ordinary powers of imagination and lots of knowledge. It is also very useful for participants in training to try to develop new objects and processes to use "Fantogram" themselves.

"Many people think of science-fiction literature only as entertaining reading, as second-class literature ... No comparable table of predictions and stages for their practical application created by scientists' assessments has the high level of correspondence with reality of an evaluation of the ideas of science-fiction writers. Science-fiction writers look dozens and hundreds of years into the future. Examples are Odoyevski's utopia in «The Year 4338. Petersburg Letters» (1840) – aircraft, electrically driven trains, synthetic materials, moving walkways; Bogdanov's novel «Red Star» 1908) – nuclear engines, automated plants; Nikolski's utopia «In a Thousand Years» (1926) – the direct prediction that the first nuclear bomb will explode in 1945; the first American science-fiction writer Gernsbeck's novel «Ralf 124C41+» (1911) – picture telephone, hypnopedics, microfilms, radio location, rockets*."

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* From Salamatov's text mentioned above

Change: → Object ↓ Procedure	Sphere of existence	Super-system	Purpose of existence	Developm. direction	(Re)production	Change in conditions	Construction (of the sub-system)	Material (chem. or phys. properties)	Energetics
Invert									
Make bigger - smaller									
Dynamic – static									
Accelerate – decelerate									
Universality – specialization									
Segment – connect									
For a time – uninterrupted									
Add – separate out									
Time change									
Bring to life									
Change in relationships									
Change in the laws of nature									

Fig. 18.4. "Fantogram"

Jules Verne[62] once said the following: "Everything that one person can imagine in her or his fantasies can be put into reality by someone else." Altshuller [2] created a table (fig. 18.5) that demonstrates that the "history of science-fiction provides clear examples of the transformation of *the impossible* into *the possible*".

Probably the most astonishing scientific-technical predictions were made by the founder of rocket technology and space travel Konstantin Ziolkovski[63]. Here are some of his ideas that were or could probably be put into practice:

1. Rocket aircraft with wings and standard guidance instruments.
2. Reduction in the size of aircraft wings along with an increase in engine power and in flight speeds.
3. Flight into the far reaches and beyond the limits of the atmosphere, horizontal, gliding take-offs.
4. Establishment of mobile station outside of the atmosphere (artificial Moon).

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[62] Jules Verne (1828-1905) – important French author, founder of the genre science-fiction

[63] Konstantin Ziolkovski (1857 - 1935) – leading Russian scientist, self-educated person, founder of the theory of rocket flight and rocket interplanetary movement

5. Landing on the Moon.
6. Space-suit, also with a liquid filling.
7. Use of solar energy by astronauts first to supply space stations and then for movement in outer space.
8. Increase in the number of space stations, development of space industries (see also Unitsky's project, ex. 124).

Author	**Total number of new ideas**	**Fate of fantasy ideas**					
		Reality		**Essential possibility confirmed**		**proven to be mistaken or implausible**	
		number	%	number	%	number	%
J. Verne	108	64	59	34	32	10	9
H. Wells	86	57	66	20	23	9	11
A. Belyayev[64]	50	21	42	26	52	3	6

fig. 18.5. "Table of success" of the predictions of science-fiction authors

However, it's not possible to reduce the mechanism of the influence of fantasy on science to the formula "It was created by fantasy and put to use by science". A portion of the prognoses turn out to be wrong or socially unacceptable.

A special part of the "Fantogram" has become an independent TRIZ instrument as the "Dimension - Time - Cost" or DTC model. The DTC model is intended to work against standard images of the object, just like the "fantogram". The purpose of this model is to transform "the usual" into "extraordinary". This model is used to successively take changes in the conditions of the task into consideration that depend on three parameters: geometric dimensions – D, time – T, cost – C. D can also mean changes in various parameters such as temperature, stability, brightness, etc. A special table (fig. 18.6) developed by G. Altshuller is used for DTC modeling.

Each parameter must be changed in the largest area possible where its limit is only the loss of the physical purpose of the task. The value of the parameters needs to be changed in steps so that we can understand and check the physical contents of the task under new conditions.

Ex. 122. DTC modeling. Assume that you have the assignment to find the places where liquid is leaking from an aggregate refrigerator. The results of DTC modeling are in fig. 18.6.

DTC modeling can produce lots of different results. This depends on the fantasy, knowledge, experience, and individual qualities of the user. **But, the goal of the original task should not be changed!** For example, you may not write the following in the last line: the quality of the aggregate should be improved, although of course it makes more sense in praxis to prevent leaks in advance instead of fixing them later.

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[64] Alexander Belyayev (1884-1942) – one of the first Russian science-fiction authors

Limits		Real value	How can the solution look?	Possible solution principle
D	0	Length of the detail < 1 m	The amount of material lost is slight. It should be made easy to find.	Some kind of micro-supplements, that can be detected even in the smallest amounts
	∞	Length of the detail >100km	Remote location – radio location, optical location, heat location.	Location in standard or infra-red rays, radio location
T	0	Discovery has to occur in 0,001 s	Mechanical and chemical procedures are not allowable; electro-magnetic including optical remain	Electro-magnetic radiation
	∞	Discovery must occur in 10 years	Flowing liquid reacts with the pipe's material and changes their appearance	The material of the pipes serves as an indicator
C	0	Discovery costs 0	This is possible when the liquid „communicates" well about itself	Smell, color, quantity
	∞	Let discovery cost $100,000	Add something expensive to the liquid that is easy to find	Supplements of easily accessible materials in micro-doses

fig. 18.6. Table and examples of DTC modeling (G. Altshuller)

We can also quickly note about ***costs*** that a change in this parameter towards an increase only means that we accept the hypothetical possibility of a change regardless of the costs. We have to answer the following question: which changes does this cause regarding the problem? How can it then be solved and why?

DTC modeling is often accompanied by illustrations. We recommend that you make drawings that are as precise and as careful as possible. **Usually a poor drawing means that a task was poorly understood.** The minimum number of drawings is two: "**What was**" (or "**Is**") and "**What became**" (or "**Should be**"). Sometimes it is helpful to make both drawings in the same scale, compare them, and mark the differences with color.

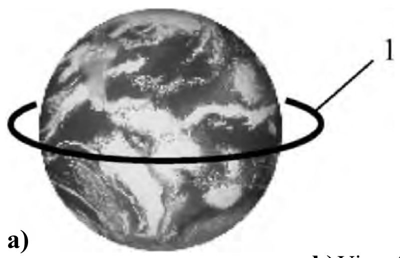
Here are two examples.

Ex. 123. Ring around the earth. This is also an entertaining learning task. It can be easily formulated and has a simple answer. It's important that this training task is solved in 20 seconds! Use a watch with second hand and don't read the requirements until after the assignment.

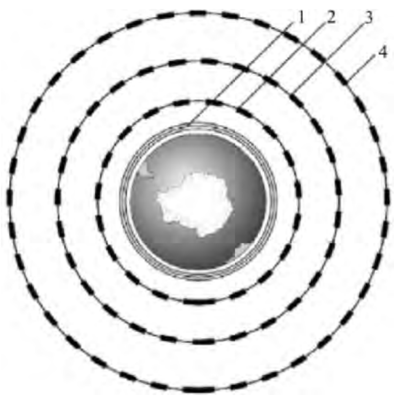
It's clear that our possibilities to absorb and process and to intellectually evaluate the conditions of a task are not constant and that they depend on several factors. More specifically, when we say in a seminar that a complicated problem should be solved in 20 seconds the percentage of correctly and punctually completed tasks sinks drastically!

Let's assume that a thin movable ring were laid on an "ideally round" earth. You should move this ring so that on one side the distance between it and the earth's surface is ca. 0.5 m so that you can crawl through. By how many kilometers should you increase the size of the ring?

Ex. 124. Cosmic transportation and industry systems by Unitsky. An excellent example of DTC modeling are the investigations of an unbelievable invention - that is still plausible according to the laws of physics - by the inventor Anotoli Unitsky whom we already know from section 15.3. This time he invented a wheel! This is not just any wheel, but a ball as large as the earth! Unitsky has proposed a ring around the equator that can then become a means for space transportation: in fig. 18.7a "What was = ring", in fig.18.7b "What became = **CTS (Cosmic Transportation System)**". The fantasy element in this project exceeds even Baron Muenchhausen's dreams who pulled himself and his horse out of a swamp using his hair. But the same is true with the CTS – **it transports itself up to the outer space**!



a)



b) View from a point over the south pole

fig. 18.7. Unitsky's Cosmic Transportation System

The ring 1 (fig. 18.7a) represents the rotor of a motor with magnetic mounts. The stator of the motor is mounted in a casing with the rotor and includes the earth, too. The rotor hangs in the casing on a magnetic mount without touching it in any way. The size of the rotor can be 20 – 40 cm. Materials for the construction of plants or facilities in space or raw materials for space industries can be stored inside the rotor. When the rotor is accelerated to speeds above the 1st cosmic speed of 10 km/s, it becomes weightless! Then the magnetic mount is turned off and the rotor boosts into outer space! The casing is discarded at an altitude 10 km (position 2 in fig. 18.7b) and it floats with parachutes back to earth. The rotor then climbs to the altitude desired, position 3 in fig. 18.7b, for example. Here the altitude could be something like 100 km and in position 4 – 1000 km.

The rotor is shaped from sections that are held together with telescopic connectors. It can therefore easily increase its diameter and overall size. At the equator, the earth's diameter of 12756 km corresponds to an overall size of ca. 40,000 km. This is the size of the rotor at take-off. At an altitude of 100 km, its size increases only by about 628 km or 1.6%, but at 1000 km it increases by 6280 km or 15.7%. Compare these figures with the parameters in the previous problem and take into consideration the fact that there the ring lies on the earth on one side and is separated from the earth on the other!

When braking, the rotor starts to get smaller and it can then come back to earth. Here it's possible to recover a large amount of energy!

If only 1% of the construction elements produced today or 50% of the energy produced today were produced in outer space, geocosmic freight transportation would encompass at least 10 million tons per year. To put loads of this kind into orbit by 2020 using space transporters like the *shuttle* with 60 flights per year, we would have to have started earlier with this plan than with the construction of the Cheops pyramid in Ancient Egypt! It is completely unrealistic to transport these kinds of loads into space in one year.

An additional point is that today rocket transportation is already approaching the limits of the economic, technical, and ecological development of its potential. It was computed that the burned rocket fuel from 100 shuttle flights one after another alone would lead to the catastrophic and irreversible destruction of the earth's ozone layer.

The CTS has the capability to transport 1 to 5 million tons of freight in one flight into outer space or from the industrial ring back to earth. Dozens of take-offs and landings can be made per year all of which have essentially no impact on the environment! *The cost of freight transport with the CTS is less than one dollar per kilogram or a thousand times less than rocket transportation!*

The table in fig. 18.8 shows a short overview of the procedures for inventing that Unitsky put into praxis with the CTS.

At the start of the III. millennium, the use of this kind of cosmic transportation system is ***the most practical of all true fantasy ideas*** to create a geocosmic industrial civilization.

In conclusion, here's another optimistic word by G. Altshuller: "The use of fantasy techniques has absolutely nothing to do with memorizing patterned texts. Depending on the personality of a concrete person, one and the same exercise can be done in different ways. Here it's like in music in that *technical procedures help to uncover individual qualities* and, interestingly enough, sometimes an exercise is aesthetically just as pleasurable as well played music."

18.3 Method of "Modeling with Small Figures"

The first example of the use of TRIZ on itself to promote its own further development was probably the development of the *Method of Modeling with Small Figures (MSF).* G. Altshuller investigated the *contradictions* of the procedure empathy (put yourself in the place of the object to be changed) from Gordon's synectics. Its strengths are the use of fantasy and sense organs to stimulate the powers of imagination and its weaknesses include the essential limits of the method in certain frequent transformations such as segmentation, cutting, dissolving, turning, fragmenting or condensing, pressing parts together, heating, etc. Empathy should be present, but it should also not be relevant! An ideal solution is often the principle of copying. This is how we can model actions and influences but with a model figure designed for the situation, not with ourselves as inventors. Or we can formulate this method better as modeling with as large group of small figures as needed and with all possible unexpected and fantastic properties!

Procedure	Application
03 Segmentation	Split the rotor into sections
04 Replacement of the mechanical environment	Use of magnetic mounts and linear electro-motors
05 Separate out	The only property needed for the development of the CTS was outlined – a rotor that lifts itself
07 Make dynamic	The rotor's body changes its size
11 Inversion	Increase the loads that can be transported into outer space a million times (!) instead of reducing them
16 Partial or excess effect	It 100 space shuttle flights a year are not possible, could we then transport the necessary loads with just one flight?
18 Mediator	The rotor is the mediator that transports loads in the CTS!
19 Transition into another dimension	The CTS moves horizontally and rotates in a circle while it changes in a radial fashion (the rotor spreads or shrinks)
21 Transform damage into use	The high weight of the CTS has become its useful freight!
26 Use of phase transitions	This means especially the change of the rotor's weight when accelerating to the 1st cosmic speed!
29 Self-servicing	The CTS is the only means of transportation that carries itself!
32 Counter-weight	Centrifugal forces compensate for the rotor's weight when accelerating!
34 Matryoschka	The CTS is a construction with parts inside each other at different levels: load–rotor–casing–stator (moving mechanism)
37 Equivalent potential	Installation of the CTS with equivalent potential on the surface of the equator instead of the vertical take-off of a rocket

fig. 18.8. Reinventing Unitsky's cosmic transportation system

Well-known examples from the history of creative solutions can serve as analogies for this idea. The chemist Kekulé[65] first imagined that the structure of the benzol (C_6H_6) molecule is a ring of apes that hold the bars of their cage with their hands and feet at the same time. One of Maxwell's[66] thought instruments led to the desire to transport highly charged particles from a container filled with gas into another container. Maxwell connected the containers in his head with a tube

[65] Kekulé von Stradonitz, F.A. (1829-1896) - German chemist who discovered the formula of benzol

[66] Maxwell, J.C. (1831-1879) - Scottish physicist who found the theoretical basis of electro-magnetic fields

with a small “door” opened for the fast highly charged particles and closed for the slower particles by “small demons”.

Historians of creativity have usually referred to Kekulé’s story only to illustrate the role of chance in discoveries or inventions. Maxwell’s experiences were used to make the point that a scientist’s powers of imagination are very important. But G. Altschuller was the first person to transform this chance into a method. He called it the *Method of Modeling with Small Persons*. I changed this image of small “persons” into the more schematic and emotionally neutral image of “small figures”. This is because some or all of the “persons” are destroyed in certain situations and that leads to psychological stress that prevents a creative solution to a problem. This uncomfortable feeling disappears with the image of “small figures”. “Small figures” can fulfill all of our fantasies, they can be active and still be absolutely abstract objects similar to chess pieces or caricatures. “Small figures” are not alive and have no emotions. They are *symbols* like letter, commas, points, and parentheses that can be deleted if necessary and replaced with other *symbols*.

The “figures” should be selected situationally and not reduced to molecules or microbes. It’s important for thought modeling that the particles can “see”, “understand”, and “act” in the team. Inventors also feel empathy when using MSF, but not themselves! The figures do this. Inventors are then puppet masters or painters who guide the figures and follow their actions themselves. The strengths of empathy were retained while the weaknesses were removed. The rules for MSF are shown in the table in fig. 18.9.

This is one of the first examples that demonstrated MSF:

Ex. 125. Adjustable polishing disc. Standard polishing discs are not intended for polishing complicated surfaces because thick discs cannot reach into small grooves in the product and thin discs reduce productivity. The application of MSF can be described as follows.

Step 1. The rules of TRIZ dictate that the instrument needs to be changed. Let us imagine a polishing disc out of two parts where one undergoes a transformation. This is clearly the part that comes into contact with the product (left side in fig. 18.10a).

Steps and Thought Operations	
1	Separate the part of the object that cannot fulfill the contradictory requirements needed. Represent this part as a large number of small figures.
2	Divide this number of small figures into groups who act situationally. Here you should write down the situation as “what was” or “what is”.
3	Analyze the initial situation and rebuild the model of the object so that it corresponds to the ideal function needed and the original contradictions are resolved. Here you should write down “what became” or “what should be”.
4	Move to a technical interpretation and search for means to put it into praxis.

fig. 18.9. Method of modeling with small figures

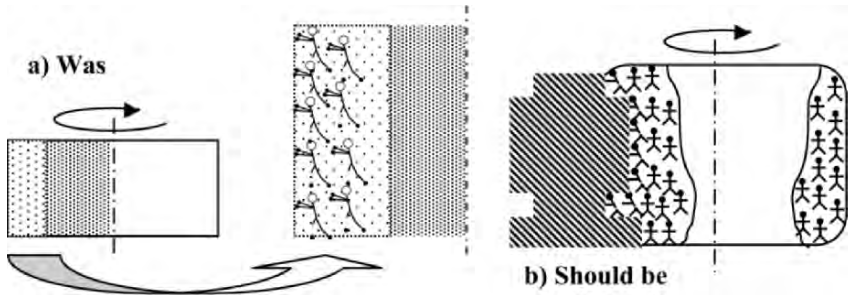


fig. 18.10. Example of the application of MSF

Step 2. We can now draw a number of figures who are trying to change the cylindrical surface of the disc (right side of fig. 18.10a)! Or even better, some of the figures could polish the product themselves and the others could hold those figures steady who are polishing!

Step 3. Let's assume this is a product with a complicated form (fig. 18.10b). When the disc spins, only the figures press against the product at those points where there is contact. After their contact with the product, the figures meet in a group and return the disc to its original shape.

Everything corresponds to the maximum ideal model: the *disc itself* takes on the form of the product!

Step 4. It's clear that the disc should be constructed so that its external surface is dynamic and adjusts to the profile of the outer surface of the product. The first technical possibility is a disc with several layers. This idea seems illusory due to the unequal wear of the layers and it's certainly possible that it wouldn't achieve the results desired. The second possibility is to build a disc where the external dynamic part consists of a magnetic abrasive powder and the core is a magnet. Then the magnetic abrasive particles are dynamic just like the small figures and as a group they can take on the form of the product. But, they are individually hard and they can therefore polish the product. In those areas that are not active, they assume a position during rotation that is determined by the structure of the magnetic field that shapes them.

The MSF reduces the psychological difficulties related to the visual perception and resulting image of an object. It's therefore important to make a large scale drawing of the object. This helps to represent the forces that the object is supposed to model in large groups of figures. They are not limited by the lines of a small drawing and can work in an ideal way.

19 Integration of TRIZ into Professional Activity

19.1 Motivation and Development of the Personality

One of the most embarrassing phenomena at the beginning of the III. millennium is the wide-spread attitude towards inventors that they ... are very strange people. A person who discovers or invents something and of course would like to inform the world about this is quickly labeled strange, heretic, or psychologically disturbed. The bigger and “stranger” in invention is, the higher the probability that people will laugh at it or even refuse to accept it. The attitude towards inventions still runs through the same unfortunate stages:
- in the first stage, these kinds of remarks are typical: “Impossible!!”, “Completely absurd!”, “The theory is wrong”, etc;
- in the second stage, we hear expressions like: “Well, it works, but who needs it?”, “We can’t put it into praxis”, or “It’s too early”;
- in the third stage, the same big-mouths say as loudly as possible: “What’s new here – everyone knows that!”, “I always thought this would be promising!”, “This is not only X’s idea. We all participated ...”, etc.

The TRIZ school differentiates between three kinds of creative action:
1. Application of a known idea for a known purpose;
2. Development of a new idea for a known purpose;
3. Development of a new idea and an idea about how it can be achieved.

Look again at the table *Levels of Inventing* (fig. 3.2). Creative action of the first type means solutions at the 1st and 2nd level; creative action of the second type – solutions at the 3rd and 4th level.

The 3rd type of creative action refers to the 5th level and also to the 6th level that is not included in the table. It’s a system of discoveries and inventions at the 5th level.

The stages of creativity are different not only in the level of the task description and of the solution to the problem. They also differ in their stimuli, in their motivation for creativity itself. They also differ in their characteristic reaction to inventive people and their products, as mentioned above. Too many inventors and creative thinkers who produced milestones in human history had a dramatic and tragic fate.

Under Altshuller’s direction, the fates of thousands of leading creative personalities were researched. We need to stress that no “inventive” criminals, amoral, and other asocial persons were included. This research led to the construction of theoretical models [6] that a creative person can use to counteract negative effects caused by external conditions. However, short principles of this kind had already been published 10 years prior the work by Altshuller and his followers mentioned above. These principles can help a creative person in the struggle against old images and in the attempt to “take a punch” like boxers say.

The “Creative Complex” encompasses 6 necessary properties.

1. You need a worthy goal – an important, socially useful, and new one that’s not yet been achieved. We can speak of the selection of a goal in the sense of social progress, a goal in the sense of the humanistic development of civilization for the level of creativity of the third type (see section *Strategy and Tactics of Inventing*).

2. You need a complex of real working plans and regular self-checks of the fulfillment of these plans in order to reach a goal. The goal will be a nebulous dream if you don’t work out an entire package of plans, for example, for one, 5, or 10 years. The fulfillment of these plans must also be questioned every month or even daily. In most cases, these plans also include the accumulation of new knowledge and capabilities such as a foreign language so that you can read necessary texts in the original language.

3. High investment of energy in the fulfillment of the plans made. Collect and systematize auxiliary information. For example, Jules Verne left behind drawings and notes in 20,000 (!) notebooks.

4. Good technique for solutions to problems. August Piccard‘s[67] biographers have written that his invention of the bathyscaph (deep-sea submarine) differs completely from a number of similar inventions that have often been made by chance and in every case intuitively. Piccard achieved his inventions only with a systematic, well-prepared search for a solution. The developer of the stratostat and the bathyscaph could recognize technical contradictions and had access to a large number of inventing procedures even from the perspective of modern TRIZ.

5. The ability to defend your ideas –the ability “to take a punch”. It took 40 years from the dream to reach the maximum depths of the ocean floor to the first start of the first bathyscaph. Piccard had to be patient about a lot of things during that time: lack of means, the ridicule of journalists, the resistance of oceanographers. Piccard was 70 years old and gave the pilot’s seat to his son Jaques.

6. Production of results. If the first properties are present, then positive partial results must be reached on the way to the goal.

TRIZ is related to only four of the properties in this complex. But, the properties make up a system in which you cannot expect high values in one point if the others tend toward zero.

Each of these kinds of creativity is important for the development of society. When life is connected to actions of the first type, things are good. When this is the case with the second or third type, it’s almost always difficult and sometimes even dramatic.

If creativity of the first type directly produces progress, then activities of the second or third kind determines its tactical and strategic direction and creates and solves tasks from the far future that is inexorably bearing down on us. This crea-

[67] Piccard, A. (1884-1962) - Swiss physicist, engineer, and scientist

tivity is therefore much more important for society generally. TRIZ recommends that you develop both creative capabilities and motivation for this reason. These can be achieved using exercises, by collecting experience in solutions to problems in inventing, and by perfecting techniques for solutions on the basis of TRIZ. Studying leading creative personalities and creative solutions in art, literature, film, politics, economics, psychology, and other areas of human activity can also help achieve this goal.

19.2 Adaptation of TRIZ Knowledge for Your Profession

The primary goal of TRIZ is to help thinking become talented and intuition become controllable, structured, and functioned well.

You will note when working with this book that you now have access to many new tools for solutions to problems.

At the same time it is necessary to focus and train your use of TRIZ to apply it in your professional area. The following remarks explain why.

First, reading professional literature from you professional area means that you interpret new knowledge by collecting only the facts that you believe you can immediately apply to your work. You select and systematize information. In contrast, TRIZ is universal and far-reaching. It should therefore be learned as a whole. This is exactly the opposite of everything we have gotten used to in our long years of professional activity.

Second, every activity requires experience. It is clear that every doctor completes comprehensive training and works as an assistant for more experienced doctors before he or she treats patents. Doctors cannot stop collecting and analyzing experiences during their professional career. Why then do many engineers maintain that they know all of the fine details of their profession? Why do some managers think this, too?

Third, are we surprised when we observe people of different ages doing aerobics through a window where we can't hear the music and the voice of the instructor? They jump, spread their arms, and make unified rhythmic movements. We then know that athletes or perhaps just health-conscious people are doing aerobics. This kind of training has already become a standard element of our modern society. Why then are recommendations for training mental capabilities understood as an affront or as a justification for a tired smile or astonishment? Does this come from the fact that the culture of thinking has not yet been developed enough in modern society to understand that the constant training of thinking is an absolutely necessary procedure? Only this kind of training can effectively shape thinking even into old age.

And finally, how many people who think of themselves as civilized still hang onto the ideas about their own health we've already mentioned? This simple recipe is found in the book "How to become a genius" and other sources where people dream of being healthy – no alcohol, no smoking, don't listen to music that's too loud, especially not with headphones, regular healthy nutrition, and lots of action in fresh air. Actually it's very simple. But, do many people actually pursue this "simple" life? This is undoubtedly about maintaining good health. What can we say about creativity if its nature dictates that it provides truly destructive "pleasures" everywhere as alternatives? And what about if health itself is not perceived to be a pleasure?

These are concrete suggestions.

1. Don't expect to be able to solve any and every creative problem immediately after reading this book. As a comparison, ask yourself whether you would step into a boxing ring after reading an introduction into boxing without the slightest idea whom you will meet there? And who knows which "super-heavyweight" really is waiting for you in the "intellectual ring"?

2. Work regularly with this book and similar books. Always try to follow the solution to a task in your thoughts and look less and less at the answers provided in this textbook.

3. Follow the principle of the procedure, not the corresponding example. The entire power of a procedure is in its principle, and in your fantasies, in the ability to interpret a procedure with respect to the task to be solved.

4. Replace things! This is a "golden" rule in TRIZ! You should learn to describe every problem so that a student - at least at a higher level - can understand it. The fact that you cannot describe a problem with other generally understandable words often means that you have not understood the task correctly.

5. Create your own tables for procedures and original ideas for solutions from patents, technical literature, science-fiction, detective stories, and all possible intellectual sources.

6. Make notes! This is also a "golden" rule in TRIZ! First, we feel much more responsible for written text than for spoken words. Second, the visualization and use of purely mechanical forces additional neuron fields and associations that can then be applied for solutions to the problem. Third, if you know that you won't forget your often short-term thoughts because you've written them down, you'll create more space in your "operative memory" for new ideas!

7. Use TRIZ software. These products are described in section 21 *CAI: Computer Aided Innovation / Invention.* One of the advantages of TRIZ software is the different examples of the application of TRIZ instruments. The second advantage, especially in the system *Idea Navigator* (section 21.3), is the chance to include the user's own examples directly into the software's tables and navigation systems. This function of the software *Idea Navigator* was specially designed to adapt to the systems in individual professional activities. It allows a branch-specific orientation with individual specialization and personal interests in mind.

8. Train your powers of observation and your feeling for the brilliance of a solution.

It's possible that you will not be able to develop an idea in the process of a search for solutions, although you have used the procedures and other recommendations. It is certainly possible that you are then dealing with a task that requires new knowledge and scientific investigations. This is precisely the boundary between the possibility and impossibility to develop and put a new technical idea into praxis. If we had given the most talented scientists in the middle of the 19^{th} century the assignment to look through a metal product, they would simply have shrugged their shoulders. Today, we use X-rays, gamma rays, and high-frequency sound for this purpose.

Inventors need sufficient knowledge of the history of many associated areas as well as their own specialty in order to evaluate a given situation correctly.

But, what can you do when it seems that nothing works? It can help in this case to search for other ways by making use of human psychological resources.

Rule 1. This rule can be formulated with two questions: "***Why*** **was it like that, and** ***why*** **does it now have to be different?**" Experienced inventors never approach a task without first clarifying in which direction technology is developing (see section *Strategy and Tactics of Inventing*).

Rule 2. Here the formulation is new: "**Let's see what happens!**" Imagine that a technical contradiction has already caused a negative effect. Consider whether this effect *is not actually natural for the system involved* and whether the ideas were simply incorrectly implemented. A firm once undertook considerable effort to develop a clamping device for steel plates to be transported with a crane. The size and weight of the pieces grew continuously and they sometimes fell. A search was started for a new construction for the clamping mechanism.

Then the firm went in a totally new direction. May "chance become the rule" - the pieces could stay closer to the ground and then they didn't need to be lifted any more. Simple cars were used on tracks that made it possible to move steel pieces of essentially any weight.

Rule 3. This rule reflects the most important psychological discovery in the methodology of creativity. It's about *how to rely on the main contradiction and the ideal result:* "The more difficult it is to precisely formulate the primary contradiction, the closer we are to a solution!" I formulate this rule very simply: **"The more difficult, the better!"**

At the end of the 19^{th} century, the Swedish inventor Laval[68] ran into an almost impossible problem while trying to improve a steam turbine. The turbine's rotor rotated almost 30,000 times per minute. Such speeds dictated that the rotor maintained perfect balance, but this seemed impossible. *The difficulties grew continuously!* The inventor increased the diameter of the shaft and made it more solid, but there were always vibrations that deformed it. After it was no longer possible to make the shaft more solid, Laval decided to try the opposite approach: an experiment was made with a massive wood disc mounted on a reed stem. It was the

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[68] Laval, C.G.P. (1845-1913) - Swedish engineer and physicist

principle “inversion” and the rule “Let’s see what happens”. And suddenly it was clear that a “flexible shaft” finds its own balance when rotating!

Rule 4. When this rule functions, it’s very useful. It’s easy to remember when formulated so: “**Minus times minus equals plus!**” or “**Kill two birds with one stone!**” This means you should try to resolve a negative effect with another negative effect from one and the same system.

For example, the shutter was installed either directly in front of or behind the lens in the first cameras with simple lenses. In the first case, the image looked somewhat “blown up” and in the second, rather squashed. This phenomenon (distortion) could not be resolved for quite a while. The solution was to install two shutters, one in front of and one behind the lens! The rays were first expanded and then reduced. One distortion compensated for the other one.

Generally, you should remember that TRIZ can be useful for everyone, just like every theory. Clearly it functions especially well in talented hands. A chess theory arose as a result of collecting and analyzing a large number of real chess moves. TRIZ has already gone this route and will do it again. But, if the records of chess moves reflect the players‘ thought processes in a certain way, descriptions of inventions will be fixated just on the results. We need to reinvent in order to reconstruct the inventor’s thought processes. TRIZ teaches you how to do this by teaching you how to solve new problems.

The desire to understand the difference between the games of a great master and a chess lay person is the impulse for a chess analysis. ***Only someone who can play in a similar way can understand the master!*** TRIZ provides you with the strongest “moves” that were played in millions of “invention moves”. It shows the secrets of a master’s game to everyone who wants to find them.

19.3 Ten Typical Mistakes

Many typical mistakes occur in the praxis of inventing (fig. 19.1). These mistakes are all of differing nature, but they all cause problems when searching for solutions with or without TRIZ.

In any case TRIZ helps to eliminate these mistakes due to equipping user with the clear understanding an initial situation, all the stages of problem solving and idea generating on the base of Meta-Algorithm of Invention, effective navigators with their patterns from data bases etc.

TRIZ makes the *“impossible”* and *“unsolvable”* situation as *“possible”* and *“solvable”*!

More that TRIZ enables users to get the most effective solutions due to transforming only the operative zone during operative time, due to using the operative resources with minimal bringing the resources from the outside.

TRIZ prevents and protect everyone from serious or fatal errors!

And fortunately this is not a commercial advertisement, but the convincing conclusion from the many decades of TRIZ practice.

#	Term and Explanation
1	**Dead end**: The problem description is constructed from the start in such a way that it moves in an unpromising direction. This is a typical mistake when attempting to improve systems with virtually exhausted developmental resources.
2	**Exaggeratedly concrete:** This is a too narrow problem description that is characteristic of professional technicians.
3	**Projection:** An extremely complex problem is addressed instead of a concrete one.
4	**Mess**: Here an entire mountain of tasks hides behind a single assignment.
5	**Flood of information**: A specialist who assigns a task provides mounds of information in which the most important points are lost. The attempt to make the task easier has made it more difficult.
6	**Lack of information**: A specialist who assigns a task neglects important information, perhaps about extant resources. The specialist thinks this information is either unimportant or self-evident. This is typical when a task is assigned with second-hand information where concrete facts are not known.
7	**Limits are too strict**: Here it's typical to demand that a problem has to be solved with a certain pattern with "no changes", for example.
8	**Secondary explanation**: A specialist explains this or the other effect, fact, or property of a system with incorrect, yet typical reasons instead of real ones.
9	**"Short-sighted" tasks:** The task description does not take changes into account that can occur while solving the problem and before the "new" system is ready. This can cause problems with the requirements placed on the system and mistakes in the evaluation of production and sales measures.
10	**Correction task:** Instead of trying to optimize the technological operations in which mistakes occurred, it seems more plausible to improve a technological section that was developed to clean up bugs that already exist.

fig. 19.1. Table of "typical mistakes" in inventing

19.4 Practical Examples Reinventing

Below we give two practical examples that demonstrate application of TRIZ in solving to the "unsolvable" real problems.

Ex. 126. Holding the big thin glass sheet in vacuum chamber

General description of the task

One company in South Korea produces the machines for liquid crystal screens manufacturing. Special technology of manufacturing uses two very thin (with thickness of less than 1 millimeters), flexible, being easily broken, glass sheets with size of every side to 2 meter.

Many screens could be resulted from this pair of glass sheets.

A robot transfers to and places the first (lower) glass sheet on the lower platform. After that it transfers the first (upper) glass sheet to upper platform and the upper glass is chucked by vacuum suckers (that pass through the holes in upper platform) and is drawn to upper platform.

Each of sheets must be held by some forces evenly along entire surface and tightly chucked against the appropriate platform. And during the operation under vacuum the sheets are chucked by electrostatic field. But the problems are: a huge energy consuming and too wide duration of electrostatic field transition in high level for chucking and low level for releasing the sheets.

Special requirement: chucking and further operations must be realized by the horizontal orientation of sheets.

The liquid crystal spots are regularly drawn on the surface of the lower sheet according to the sizes of screens to be.

The epoxy glue lines are drawn on the lower surface of the upper glass according the contours of the screens to be.

The chucked sheets are aligned in the plan and drawn nearer to the very small distance each from other, and after this they are pressed each to other.

The schemes at the fig. 19.2 explain the initial situation.

Problem lies in the fact that the chucking must be realized *in vacuum chamber*.

Comprehensive set of solutions were developed by author of this book. And some of them he has a legal right to represent here.

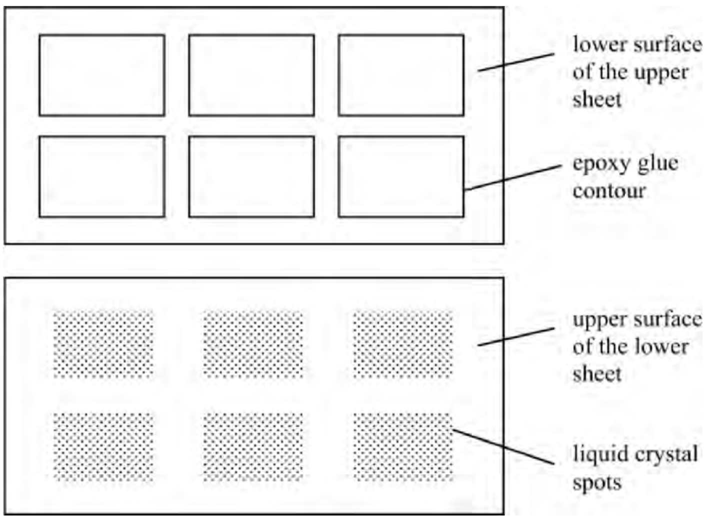

fig. 19.2. Glass sheets for manufacturing the liquid crystal screens

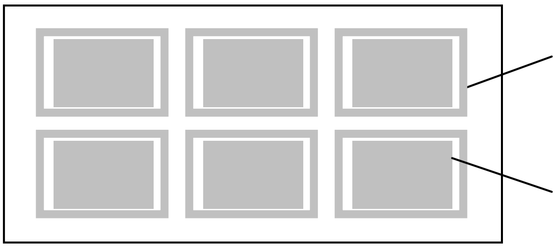

fig. 19.3. Location of epoxy glue contours and liquid crystal layers (not spots!) after the alignment and pressing the sheets

DIAGNOSTICS

Problem situation

Sheets are preliminarily chucked by vacuum suckers.

Under the vacuum conditions the sheets are chucked by electrostatic field.

Though the electrostatic method of chucking is more progressive according the lines of resources development and could be efficiently improved, the customer required removing the electrostatic method of chucking.

Problem extraction from initial situation

Lower sheet lies on the platform, and it only must be kept from the horizontal displacement.

Upper sheet must be chucked completely, but this is a problem.

The force of gravity pulls upper sheet downward, and this sheet must be tightly, accurately and evenly chucked by upper platform.

How could it be done?

Strategy of the solution depends on the determination of operative zone, resources and operative time.

The following versions are possible:

1) working only with the upper sheet on the operative time;

2) working with two sheets on the operative time;

3) joint studying pre-operative, operative and post-operative times;

4) combined studying of possibilities.

REDUCTION

Operative zone and the resources

Upper surface of the upper sheet (to hold!); space between this sheet and the platform; the surface of the platform above the sheet; gravity (weight of sheet); low vacuum.

The material of sheet (glass) and the material of platform (aluminum) must be taken in the attention.

Inductor and receptor

Inductor - platform. Receptor - sheet.

Technical contradiction

Platform S2 must chuck a sheet S1, but there are no effective interaction between platform and upper sheet. In other words: platform must hold the sheet, but gravitational field counteracts this goal.

Nr. TC	Effect, Condition, Object						
	holding the upper sheet						
	(+) - factor			**(-) - factor**			
1	to hold in vacuum	09	ease of manufacture	harm action of gravitational field	13	external damaging factors	05, 18
2	to hold in vacuum	09	ease of manufacture	expensive energy consumption for electrostatic chucking	37	energy use by the moving object	03, 04, 10, 13
3	large surface of the sheet	17	surface of the movable object	harm action of gravitational field	32	weight of the movable object	04, 05, 14, 19

fig. 19.4. Selected technical contradictions for problem modeling

Physical contradiction

Platform S2 must chuck a sheet S1 to perform the main positive function, and platform S2 must not chuck a sheet S1 because of there are no visible resources (fields, forces).

Ideal Functional Result

Macro-FIM: X-resource, without producing the inadmissible effects and without complicating a system, ensures together with other existing resources

[*the reliable chucking an upper sheet (in high vacuum)*].

Detailed modeling (fig. 19.5)

The constructed model is incomplete, since there are two substances: S1 - receptor and S2 - inductor, and the field of interaction Fm between them is absent (!). There is also the harmful gravitational field Fg, which moves S1 away from S2.

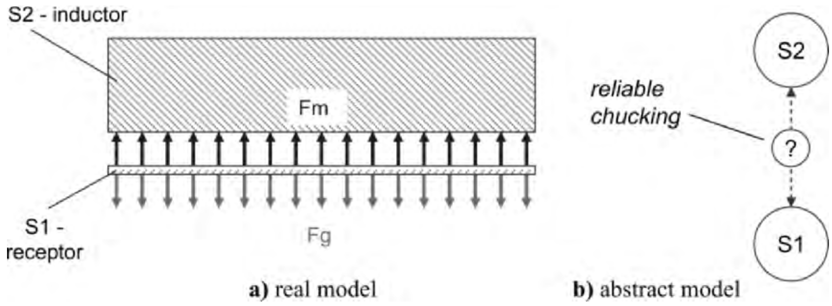

fig. 19.5. Substance and fields (forces) in operative zone

TRANSFORMATION

Solution to technical contradictions

From the table (fig. 19.4) we could extract ranged set of the navigators: 03, 04^2, 05^2, 10, 13, 14, 18 and 19.

The composition "portrait" of a solution to be:

03 segmentation – disassemble an object into individual parts;

04 replacement of mechanical matter – c) replacement of static fields with dynamic ones, from temporally fixed to flexible fields, from un-structured fields to fields with a specific structure; d) use of fields in connection with ferric-magnetic particles;

05 separation – separate the "incompatible part" ("incompatible property") from the object or - turned completely around - separate the only really necessary part (necessary property);

10 copying – a) use a simplified and inexpensive copy instead of an inaccessible, complicated, expensive, inappropriate, or fragile object;

13 inexpensive short-life object as a replacement for expensive long-life one – replace an expensive object with a group of inexpensive objects without certain properties, for example, long life;

14 use of pneumatic or hydraulic constructions – use gaseous or fluid parts instead of fixed parts in an object: parts that can be blown up or filled with hydraulic fluid, air-cushions, hydrostatic or hydro-reactive parts;

18 mediator – a) use another object to transfer or transmit an action; b) temporarily connect an object with another (easily separable) object;

19 transition into another dimension – b) do construction on several floors; tip or turn the object on its side; use the back of the space in question.

The possible solutions could be formed on the base of navigators 10, 13, 18 and 19: to use some copy of the sheet like mediator with a feature to hold the sheet on the whole upper surface ("a back") and to be held to a lower surface of the upper platform.

Other solutions could be considered on the base of navigators 05 and 14: to use vacuum – or in contrary, atmospheric pressure – effects for holding the sheets.

Solution to physical contradiction in general form

In this case it is necessary to find and to use new physical-technical effects for obtaining the field Fm (fig. 19.5, b), with enough force for chucking the sheet by the upper platform under the conditions of high vacuum.

Ideas of technical solutions

According to mentioned above models the many different solutions could be generated. We show some of them.

Concept 01. Higher vacuum

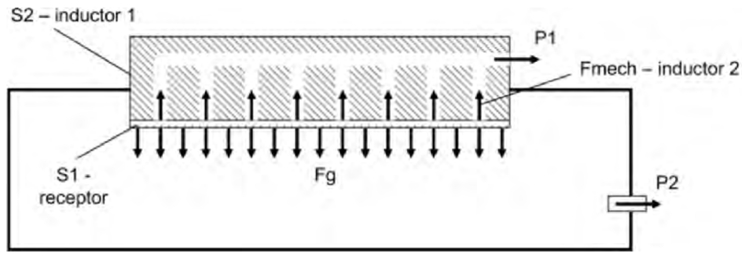

fig. 19.6. Solution on the base of creating a higher vacuum in suckers for chucking the sheet

Upper glass is chucked by suckers with the parameter of pressure P1 < P2, where P2 is a parameter of air pressure in the vacuum chamber.

Concept 02. Glue

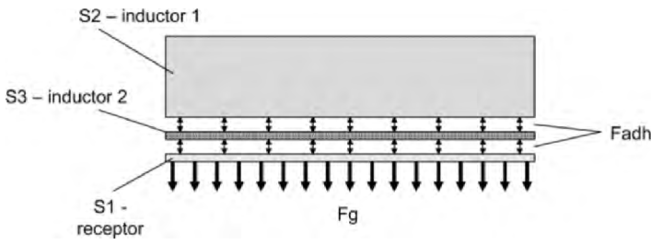

fig. 19.7. Solution on the base of creating a temporal glue layer between the sheet and platform

Upper glass is chucked by glue S3.

Glue can be temporarely brought on the glass out of the machine or enter from the capillaries in the upper platform.

Glue can be brought not along entire surface.

Glue could be removed back through the capillaries in the upper platform.

Concept 03. Two-side adhesive mediating film or thin/thick plate

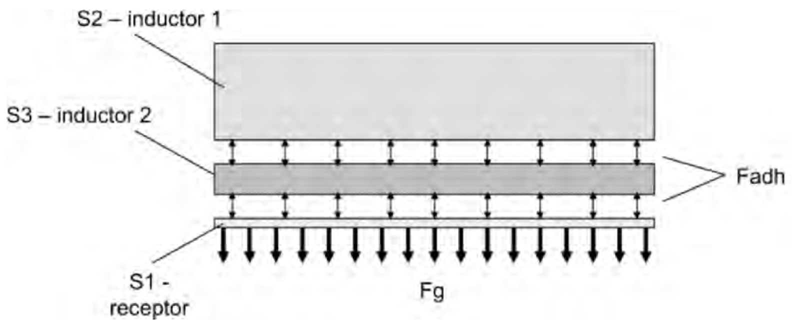

fig. 19.8. Solution on the base of creating a temporal two-sided adhesive layer from thin film or plate between the sheet and platform

Concept 04. Adhesive mediating film or plate with ferromagnetic particles

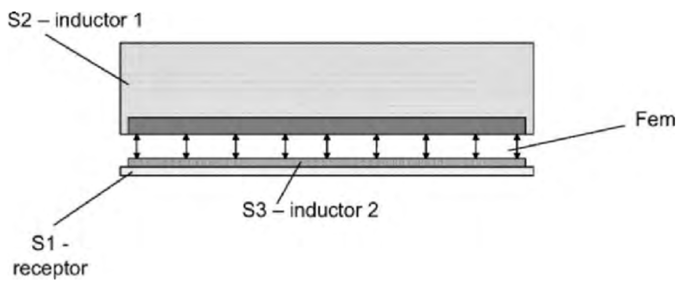

fig. 19.9. Solution on the base of a temporal one-sided adhesive layer with ferromagnetic particles

There are the electromagnets in the upper platform. A temporal one-sided adhesive layer S3 with the ferromagnetic particles is brought to upper glass. After switching on of the electromagnets, ferromagnetic layer are attracted to the platform and chuck the glass against platform.

Concept 05. Adhesive ferromagnetic layer under the sheet

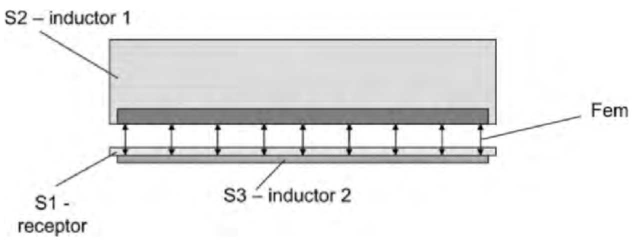

fig. 19.10. Another solution on the base of a temporal one-sided adhesive layer with ferromagnetic particles

Disputable variant of “ideal” solution: ferromagnetic particles are added to the used epoxy glue S3.

Concept 06. Double magnetic fields

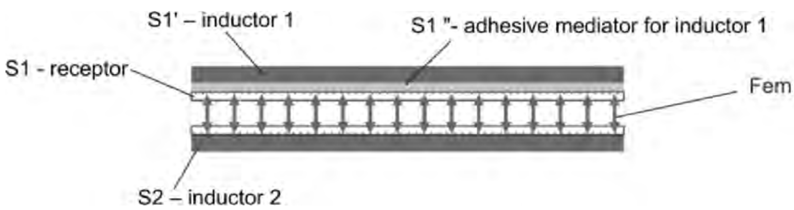

fig. 19.11. Another solution on the base of double magnetic fields in the upper sheet and in lower platform

The plate with the controlled electromagnets S1' is fastened to the upper sheet on the basis of adhesion.

There are electromagnets S2 in the lower platform also, which create the field of the same polarity, as upper magnets. Due this effect, upper glass will hang (levitate) above the lower one.

After the creation of vacuum the parameters of the currents of electromagnets change so that upper sheet would accurately descend to lower one.

Then with the aid of the same magnets and with changed polarity of one of them, the sheets are pressed in vacuum.

VERIFICATION

Economic efficiency of the change of the former electrostatic method of chucking with one of new methods (we do not pointed here with which one) is estimated as about 800 000 USD for one machine. An exploiting of new method during 3 till 5 years will additionally bring more than 1 Mio USD with saving energy consuming*.

---

* Additionally to these examples several most effective solutions of this problem were developed by the author, but not patented and have a status know-how.

Ex. 127. FITBONE®

General description[*] of the task

To stretch out the bone during the treatment after a fracture, the very difficult constructions (fig. 19.12) were used, which pained the patient and sometimes not guarantied getting right shape. What could be done?

Here we reinvent this invention to extract from it the logic of applying the MAI and TRIZ navigators according to work[**] where MAI-structure and TRIZ tools were efficiently applied.

This is one of the solutions where the TRIZ models are shown up very clear.

For educational purpose we use here some additional interpretations and models as usual for every reinventing.

fig. 19.12. Well known Ilizarov holder to stretch the bone

DIAGNOSTICS

The initial construction of bone holder and stretcher consists from the rods connected in single whole with a help of the rings which are adjusted to correct state while the rods are little by little made longer.

The gaps in the bone after the fracture are fulfilled with the regenerative bone fragments taken from patient.

Though this method had been the most effective for the decades, some problems were occurred.

Because of complexity of construction the holder is difficult adjusted. It leads to some mistakes which in their turn lead to incorrect form of the bone after the stretching.

The complexity leads also to long time of treatment while the open wound could cause infection.

In any case this construction pains and prevents to patient to wash, to walk etc.

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[*] Registered mark, pictures and initial materials are the property of the Wittenstein intens® (Intelligent Encapsulated Systems) Ltd. and were put by proprietor to the author for publishing in this book in the notation used here.

[**] Dr. T.Bayer: TRIZ in der WITTENSTEIN AG. – 4th European TRIZ-Congress, 2005; additional sources: magazine “DER SPIEGEL”, No. 30, June 2005 and www.fitbone.de.

REDUCTION

Operative zone and the resources

OZ: the bone. **OT:** time for stretching.

Inductor and receptor

Inductor - rod stretching construction. **Receptor** - the bone.

Technical contradictions for method CICO

The problem is very difficult and could be described with a group of different contradictions. After that we could apply the method CICO.

Nr. TC	**Effect, Condition, Object**						
	holding the bone for stretching						
	(+) - factor			**(-) - factor**			
1	infections; movement restriction and sleep disturbance	14	internal damaging factors	long time with open wound	23	functional time of the moveable object	07, 21, 31, 38
2	infections; movement restriction and sleep disturbance	14	internal damaging factors	applying the sizeable strengths	30	force	01, 03, 04, 17
3	to accelerate the treatment	01	productivity	to simplify the adjustment	10	ease of use	03, 04, 08, 34
4	infections; movement restriction and sleep disturbance	13	external damaging factors	to keep the construction in working state	23	functional time of the moveable object	04, 07, 21, 38
CICO ranking: 04^3, 03^2, 07^2, 21^2, 38^2, 01, 08, 17, 31, 34							

fig. 19.13. Selected technical contradictions for problem modeling according to CICO

Physical contradiction

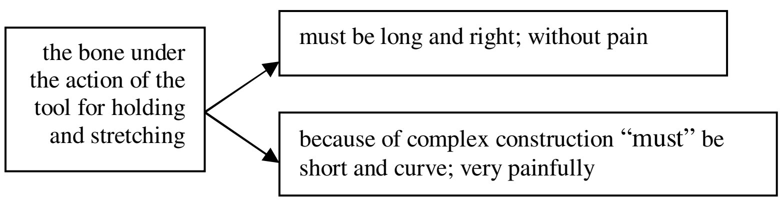

fig. 19.14. Graphic model of physical contradiction for problem

Ideal Functional Result

Macro-FIM: X-resource, without producing the inadmissible effects and without complicating a system, ensures together with other existing resources

[*the right shaping the bone (with less pain, restrictions and disturbance)*].

TRANSFORMATION

We could see that the spatial resources are the most interested here. Let us consider additionally the combination of fundamental transformations with specialized ones.

fundamental transfor-mation	connection to As-navigators
1 separation of the conflicting properties in **space**	**05 separation:** remove the disruptive part, emphasize the part needed. **10 copying:** use of simplified and inexpensive copies. **19 transition into another dimension:** increase the freedom of an object, use construction in several layers, use lateral and other surfaces. **22 spherical-shape:** transition to curved surfaces and shapes, use of wheels, balls, or springs. **24 asymmetry:** transition to asymmetrical shapes, increase asymmetry. **25 use of flexible covers and thin layers:** use flexible covers and thin layers instead of normal constructions. **34 matryoshka:** store an object in another one in stages, place an object in the hollow space of another one.

fig. 19.15. Combination of fundamental transformations with specialized ones.

Analysis of navigators and idea generating could be made as following.

According to navigator 05 it is possible to apply new X-resource as more close to bone (operative zone) as possible due to eliminating old difficult solution (long-distance positioning) and inventing new one (short-distance positioning).

According to navigator 10 it is possible to apply some X-resource like copy of bone in operative zone (?).

Navigator 19 could be interpreted like recommendation to consider not only outside but also inside surfaces of bone (operative space! How is it possible?).

From remaining navigators the navigator *34 matryoshka* looks very suitable to develop new construction due the possible idea to put some stretching X-resource just in the bone hole (!?).

In a similar manner let us study the selected navigators from resulting cluster of CICO. The composition “portrait” of a solution to be:

04 replacement of mechanical matter – Yes! We have to use electrical, magnetic, or electromagnetic fields for control new X-resource in operative zone near or inside the bone!;

07 dynamization – Yes! We have to use the characteristics of an X-resource (inductor) and the bone (receptor) changeable to optimize increasing the length of bone during stretching!

08 periodic action – OK! May be we could use transition from a continuous function to a periodic one (impulse) to get opportunity of little by little increasing the bone without intolerable pain?

17 use of composite materials – Yes, we have to think about materials which are compatible with an organism;

31 use of porous materials – Interesting! It looks like recommendation to use supplementary porous elements (inserts, coverings, etc.) to set new X-resource into the bone; and it is very similar to matryoshka-navigator;

34 matryoshka (nested doll) – Really, it is an idea for solution! X-resource could be a construction inside the bone!

Taking in account the table on fig. 19.15 we could see that navigator *34 matryoshka* is very promising.

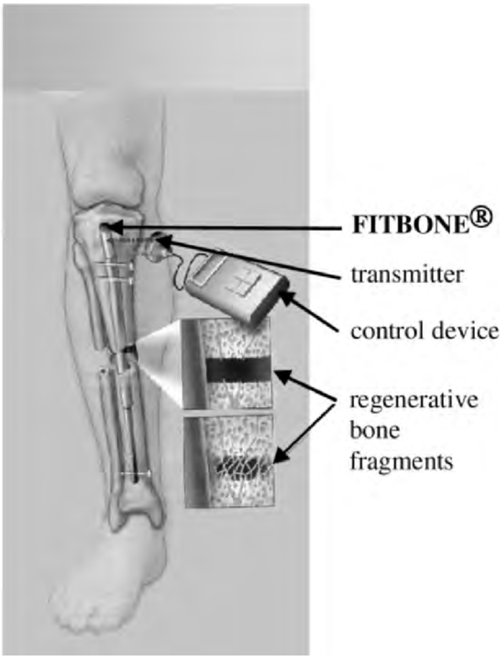

fig. 19.16. New solution on the base of navigators 04, 07 and 34

Together with this the navigators 04, 07 and 31 look as very perspective to generate radical new ideas based on the making the construction inside the bone!

Main resulting idea (fig. 19.16): to realize the stretching construction like special controlled rod (marked at the picture as FITBONE®), put into the bone and growing on the length due the embedded micro-motor and miniature transmission.

VERIFICATION

Both technical contradiction and physical contradiction are eliminated.

The strong super-effects: painless, very reliable stretching and shaping.

From materials of the authors we know that the growth of the bone could be increased by 1mm a day. The patient in short period could work, wash and sleep.

To finish this part author has to say that the very special knowledge is necessary for solving to any difficult problems. To solve first problem author had co-operated with the specialists of the Korean company produced the machines for liquid crystal screen manufacturing. To solve second problem inventors and bio-mechanical engineers had co-operated with the doctors who are specialists in surgery and prosthesis.

Exercises 18 – 19

49. "See" what's invisible. Can you imagine how a doctor adjusts an X-ray machine to display only the necessary part of the body? The light-sensitive film is in a container behind a synthetic wall on which the rough position of the body was drawn in relationship to the relatively invisible film. Which procedures were used here?

50. Allow the "impossible". Let's assume that the geocosmic industrial complex uses Unitsky's Cosmic Transportation System (CTS). The industrial ring is at an altitude of 1000 km, for example. The CTS moves between the ring and the earth.

Would it be possible for several industrial rings and several CTS's to function properly? Try to draw this situation. Questions:

1. Could we install a transient ring between the extant rings at the start of the CTS from the earth?
2. Could we start a transient CTS on earth?
3. How could we bring about an exchange of material and energy between the earth and the next industrial ring with several transient CTS's?
4. How could neighboring and not neighboring industrial rings enact a material and energy exchange with CTS?
5. Which problems would have to be solved for the technical reliability, safety, and long-life of the CTS and the industrial rings?

51. Understand the "inexplicable". We know that spiral stairwells were developed to save space in towers and castles, for example. They are usually narrow and steep. It's difficult to move by people coming from the other direction. Is it possible to double a spiral staircase's ability to let people pass without doubling its diameter?

Development of TRIZ

Progress is driven by creativity and depends on the concentration of talented people in every generation. A creative person has to have the ability to solve the most complex problems ...

Today, the time is ripe for TRIZ.
The first generation worked out the basics, even though it didn't yet have the freedom necessary for real research.

We need a second generation of TRIZ developers. In this new stage of development, researchers are free to determine what's important and valuable with the courage to reject what's not.
Today, theory has already exceeded its name but in the name of tradition it hasn't yet been expanded accordingly.

Onward into a new stage of TRIZ!!

Genrikh Altshuller

20 Choice of a Strategy: Human or Computer?

20.1 TRIZ Knowledge: Strategies of Development and Application

The best aspect of TRIZ as a system of knowledge is the fact that its main principles don't age! They are timeless and constant. There's no doubt that the main discovery of TRIZ - the principle of contradiction in the development of systems and as the solution to the main contradiction in problems in inventing - does not age. There is no doubt about the primary laws and procedures of TRIZ. The meta-algorithm of inventing also stays constant. Only the examples of inventions can age because they are more closely connected to the concrete level of technical development and more generally with science and the historical level of the development of technical systems. Math is constant regardless of whether we're calculating the time needed to drive with a car to work or to fly to Mars. Fig. 20.1 shows an evaluation of the speed at which various kinds of knowledge age.

The problem is to define in which direction TRIZ knowledge can and must develop. We can mention the following strategic tendencies:

1) *orientation on human inventing;*
2) *orientation on the formal synthesis of solutions with computers.*

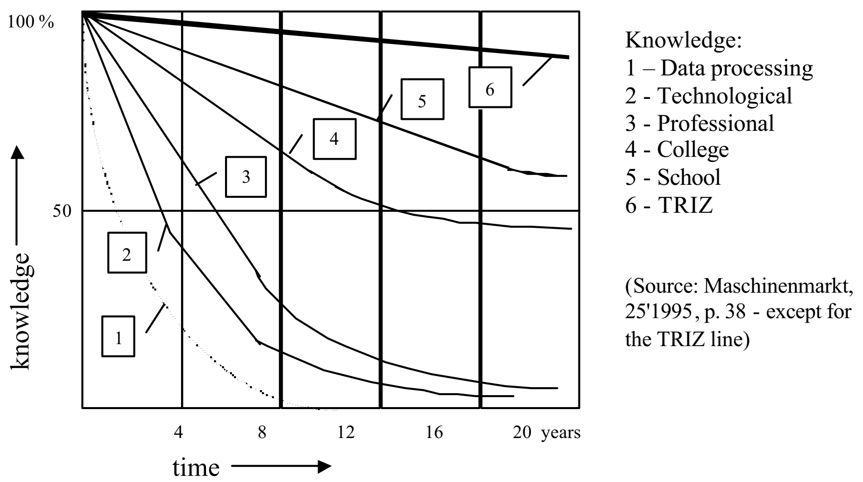

fig. 20.1. Evaluation of the aging of knowledge

The second direction is based completely on the formalization of procedures for the synthesis of innovations by the human intellect. A series of mathematical models, more specifically models to perceive patterns and models of optimization with multiple criteria promise to be able to complete the process of a computer synthesis of well founded and effective ideas.

However, we can note at least two unsolved problems with a computer synthesis:

1) *automatic formulation of the functionally ideal model as a goal of innovation and transformation;*
2) *automatic formulation and consideration of aspects that are socially (ethically, ecologically, aesthetically, and otherwise) important.*

In other words, a machine has not yet accomplished what's most important – to create a socially valuable image of the future. So far, only the human intellect can do this.

Altshuller made the following comment: "Simple tasks can be solved literally by addressing the physical contradiction, for example, by separating the contradictory properties in time or space. The solution to more complex problems often requires a change in the purpose of the task by removing the psychological limitations that the researchers originally placed on themselves and that seemed logical until the problem was solved. To understand the task, you have to solve it first: inventive tasks cannot be formulated immediately. The solution process is also a process that corrects the assignment." Only humans can rethink the content of a task.

Does this mean that strategies for the further development of TRIZ knowledge should be oriented towards producing methods that are based exclusively on the use of human intellectual and psychological resources?

The author's experience with systems for artificial intelligence, the development of this kind of systems for CAD/CAM, and experience gained in the application and production of TRIZ models and software show clearly that *the focus of research should be on the first direction: support for the synthesis of human ideas.* Here we should stress that computer systems are an irreplaceable instrument of human creativity. This is the most effective procedure of TRIZ – the integration of alternative systems with positive system super effects.

Computers can free people from routine and time consuming work such as the search for analogies in patents or access to facts from certain areas of knowledge that can be found in encyclopedias. Access procedures need to describe goals and criteria as well as the methods of the search that ensure the effective selection of facts and the extraction of the necessary knowledge appropriate for the goals of a new idea.

To this point (2006), the development of computer systems for the psychological support of creative processes and especially for innovative and inventive creativity has hardly been researched and certainly not productively.

We can therefore allude to the following essential directions of the development of TRIZ knowledge that concentrate on supporting innovative human activity with intelligent computer systems.

1) *development of systems to process knowledge for innovative and inventive activities;*
2) *development of universal and specialized applied systems based on TRIZ;*
3) *integration of TRIZ systems with other systems that support human activity such as education, projection, control, and research systems;*
4) *development of systems for the psychological support of innovative and inventive activity;*
5) *development of systems to support human social value orientation with the laws, limitations, and goals of ecological and social progress in mind.*

An especially important direction is the *movement of the TRIZ transfer into art, management, and general education.* TRIZ can play a leading social role in building a broad movement that promotes the development of creative personalities. This process should start in childhood. I would like to quote G. Altshuller here to underscore this psychologically and pedagogically [6]: "Usually we live according to a three-point scheme: *work – money – enjoyment*. A creative lifestyle foresees a reduction of the middle link that is superfluous in the scheme *creative work – enjoyment*. The process of work itself brings satisfaction.

Creativity is the chance to express oneself, to perceive oneself and the environment, and to make the world a bit better. Creativity is a trip into a dream world. But, can dreams be bought with money?

People look for creative work on their own. You can't voluntarily do something for 15 hours a day that you don't like. This would be unimaginably stressful. You can change to a creative life rhythm only when work becomes a need. Then 15 hours of work seem like 15 hours of enjoyment because they are a reward.

... What do we really want generally and in the future? Human progress depends on the concentration of talented people in every generation. The greater the percentage of creative personalities in a generation is, the better and better developed society is. This is a primary parameter for a society that defines its areas, business, possibilities, and perspectives. When Einstein is busy with his work, he doesn't get into arguments in the stairwell. This costs too much time. Of course, there are exceptions in the sense of negative or destructive creativity, but progress is still driven by creativity..."

20.2 *Homo Inventor*: the Inventive Human

Here our focus is on investigations that are strategically oriented towards intellectual and psychological human activity in the solution of problems and the creation of innovative ideas. This is why we would like to briefly explain the relationship here between the creative methodologies that have been developed and TRIZ.

The question of the selection of a creative method is being discussed just as much at the beginning of the 3rd millennium as it was in the time before Christ.

But, what exists between the *brainstorming* that belongs to "pure" art and, let's say the *morphological analysis* that's a part of "pure" science? Both methods demonstrate simplicity and universality in application. They both lose their advantages when used for difficult tasks. *Brainstorming's* random (!) search and the uninterrupted selection of a *morphological analysis* lose their advantages that otherwise seem so clear.

TRIZ was developed by Altschuller's school as a direct alternative to the method of *trial and error* that included almost everything that was not part of TRIZ. A multiplication function from the dimension of changing factors in an assignment was used to evaluate its level of difficulty. For example, if a solution requires a search in an area with 5 factors where each can have 10 meanings, the field for the search contains 100,000 combinations. The example of Edison's method is often used that he applied to develop a battery where 50,000 experiments were required.

> *Many other examples that are just as well known also demonstrate that astonishing solutions can be found under circumstances that are unimaginably complex. This shows that the human brain can also use mechanisms that are much more effective than simple selection procedures.*

These arguments seem to make an explanation of this contrast in the style of TRIZ rather philosophical because it *unifies alternative procedures*.

The goal here is the integration of methods of creativity with each other that previously were considered incompatible, even oppositional. The basis for this integration is an understanding of the nature of thinking. This is at least so in the way in which the integral and supportive functions of the left and right hemispheres of the brain and in their neuro-physiological activity work as well as in the forebrain's integration of new ideas.

A generalization of these ideas made it possible for the author of this textbook to construct three schemes of "creative thinking" at the beginning of the 1990's that will function here as a basis for the practical development and evaluation of these schemes themselves. The results of the application of this procedure and new facts about the brain's functions have confirmed the correctness and usefulness of these schemes.

The first scheme in fig. 20.2 reflects the fundamental difference in thinking with the right and left hemisphere. It allows us to place requirements on theoretical and applied investigations of this topic:

1) *time:* consideration of the macro-rhythms of thinking and the micro-rhythms of the brain's functions;
2) *space:* integration of logical-algorithmic, emotional-imaginative, and metaphoric models;
3) *emotions:* consideration of the individual psychological-physiological qualities of concrete personalities – motivation, psychological resources, health, education level.

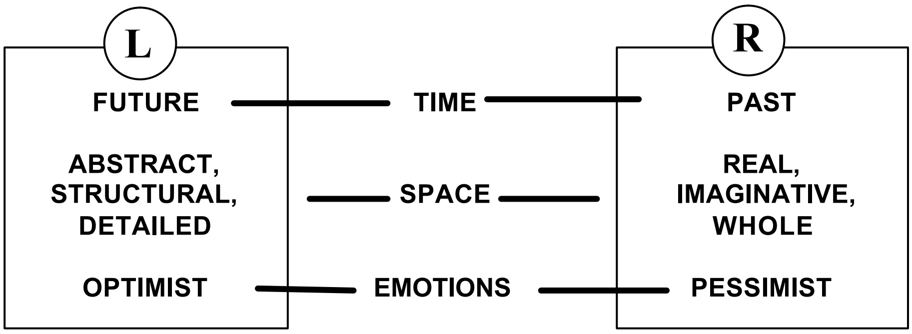

fig. 20.2. Functional-structural model of the asymmetrical brain

The results of research on the brain's activity, especially that was done by the Russian school of neuro-physiologists, became the basis for our "topological models of the birth of ideas" (see fig. 20.3).

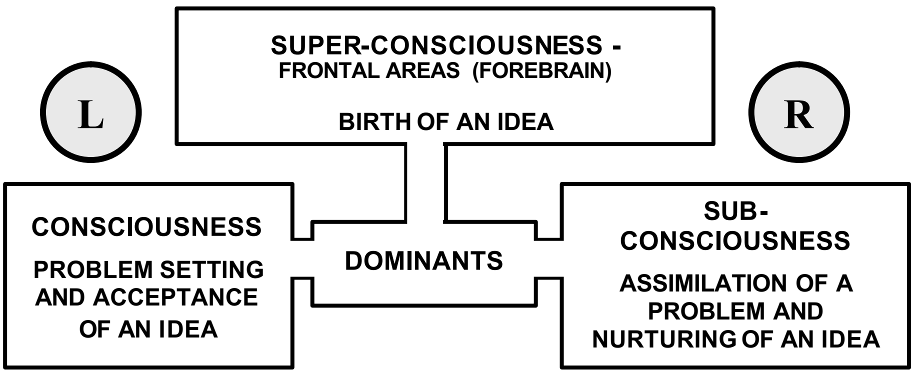

fig. 20.3. Topological model of the birth of an idea

Finally, the third scheme shows an image of emotional-temporal phenomena that need to be considered in new studies (fig. 20.4).

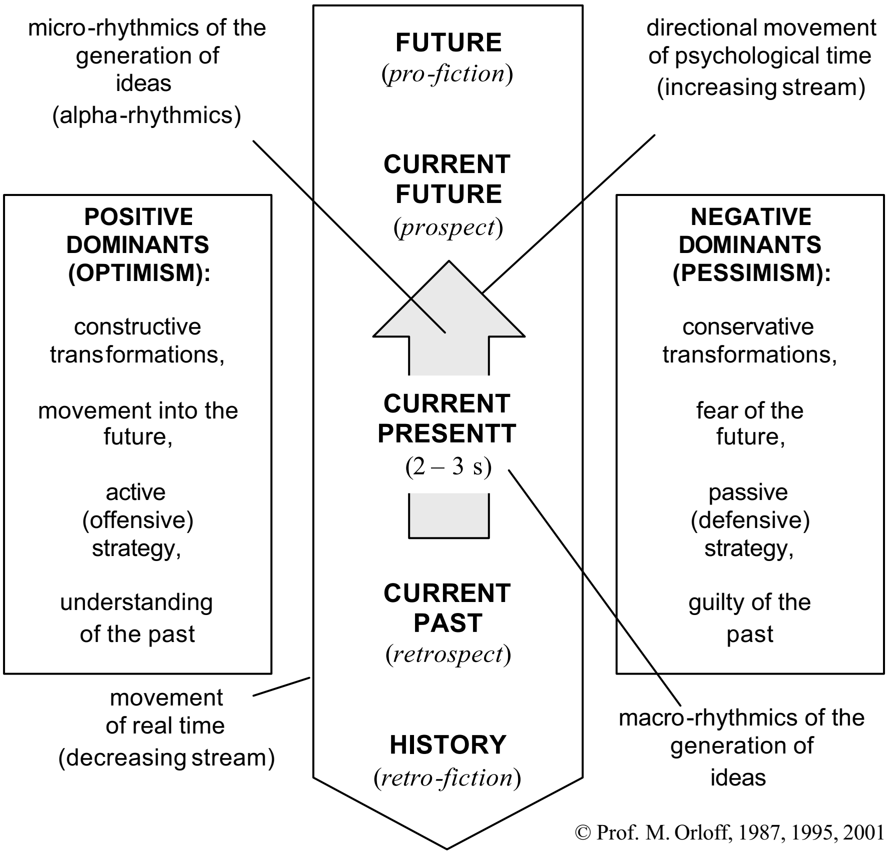

fig. 20.4. Emotional-intellectual dynamics of creative thinking

20.3 CROST: Five Main Cores of Creativity

The integration of several procedures is therefore justified psychologically and harmony and pragmatism are clearly shown here. The beginning of this kind of integration goes back to the 1980's when the author of this book started its development with the term **CROST™** – *Constructive Result & Resource Oriented Strategy of Thinking & Transforming*.

CROST integrates the following components with each other:

Constructive – the basis of this direction is TRIZ as a theory and constructive instrument package for the controlled synthesis of ideas and the focused transformation of the object to be improved;

Result & Resource Oriented – the procedure is oriented towards the highly effective result by searching and application of a minimum quantity of necessary and most easily accessible resources in operative zone (in the system) and human intellectual-psychological resources;

Strategy of Thinking & Transforming – the procedure disciplines and organizes thinking towards constructive and improved transformations that are appropriate for the content and strategic goals of the assignment.

The entire scope of knowledge that is related to the motives, goals, and procedures of human creativity cannot be easily shown in a single scheme. But, the scheme developed by the author below is dear and constructive. This scheme clearly demonstrates concrete steps in the development of the methods of creativity and the relationship of this development to the historical evolution of society and nature. The scheme rationally differentiates knowledge from creativity. It is especially important that this shows possibilities for the future of a *guided* development of this knowledge.

This scheme was metaphorically called *PentaCORE* in the development of our new software. Five main areas of *PentaCORE* provide the strategic basis for a constructive analysis and synthesis of technologies of creativity for the practical contrast and integrated application of "old" and new methods.

The five symbols that we used in *PentaCORE* were derived from the concepts that correspond to the appropriate visual components of *PentaCORE*.

Now we can construct *PentaCORE* together. Let's start with the second letter – "B" – that stands for the key concepts brainstorming and brainwave.

It seems appropriate for our purposes to call all methods based on expectations, free associations, fantasy, and free analogies "*brainstorming" that results in brainwaves.*

These are essentially methods *of artistic thinking with the right hemisphere*. Regardless of its concrete versions, brainstorming is often described as a method of trial and error. But the majority of inventions made in human history were made with this "experimental-creative method". Wouldn't it be better to call it a method of *"trial and success"*! In any case, we can reduce all of these procedures to a B-concept (fig. 20.5).

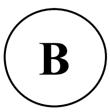

fig. 20.5

Of course, it is also possible to relate the symbol ***B*** to the name of the psychologist and teacher, scientist, and author *Edward de Bono* who developed this kind of method for more than 30 years. He gave this method its reputation as rational search and as a nuance of playing and joking.

De Bono's ideas, just like the Genrikh Altshuller's ideas are not finished yet, but we won't use them in the context of the B core concept. This concept is closely related to the core of the scientific knowledge that has led to constructive results in the last 30-40 years. This core has accumulated knowledge about the psyche and human psychology. We've chosen the concept *dominant (dominance)* that also gives the concept the name D concept.

Intuitively we think that all leading thinkers of all known epochs of human history were aware of this. On the other hand, we have to ask which constructive, practical, and effective recommendations we have received from this concept. These kinds of recommendations were for the most part philosophical interpretations and primarily contemplative and imaginative descriptions of a process and of individual examples of creative acts. However, the development of the concept of dominants and of the role and organization of the combined effect of different parts of the brain in the last few decades has helped create the essentials for the production of instruments to shape and support creative action.

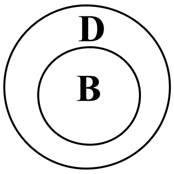

fig. 20.6

At this point we would like to refer to the clearly hierarchical and interactive relationship of these concepts (fig. 20.6) that have developed together in an inseparable way for more than 1000 years. These "old" methods of the B concept and really the D-concept were plagued by the following problems: the haphazard and unguided character of the search for new ideas and the impossibility of passing on collected knowledge.

The incredible progress of technology and the enormous growth of knowledge since the middle of the 20th century have made it necessary to develop appropriate methods for creation. These methods are based on the laws of the evolution of technical systems and of the development of inventions at the highest level. This kind of approach was presented in TRIZ as it is based on systematic investigations of the knowledge accumulated in patents from all over the world. This conception was constructive in that it then helped construct methods and theories of inventing, concrete procedures and rules, models and resources, conditions and limits that then led to the creation of highly effective inventions. This is essentially about ***methods of thinking with the left hemisphere, with logical thinking.*** Altshuller called his primary method ***"Algorithm of Inventive Problem Solving".*** This name and Altshuller's name itself gave us the term for the core-concept of *algorithmic (algorithm)* thinking - A concept.

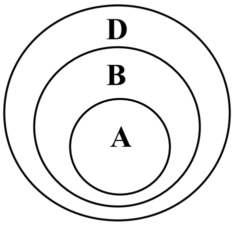

fig. 20.7

Clearly this approach is very similar to methods for systematic construction and methods for the mathematical (computer supported) synthesis of technical solutions in CAD. Generally speaking, this is a new class of methods that provides a method for the controlled search for solutions and operates with logical models. This is a new core of methods using primarily thinking with the left hemisphere.

It is precisely the methods of the A core concept that become the critical point for and need to therefore be integrated into all of the other core concepts. In the second half of the 20th century, the problems of maintaining the natural environment, of ensuring harmonic and humanistic human development, of stopping wars and terrorism, of preventing crime, and of integrating the development of different regions of the world have intensified immensely.

Problems of the positive evolution of civilization have always been a central issue for leading thinkers at every point in human history. But, these problems have taken on the kind of character at the beginning of the 3rd millennium that seems to prohibit any solution.

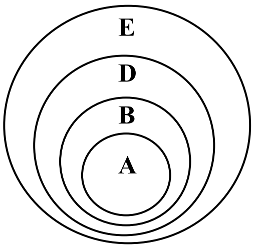

fig. 20.8

These global problems can only be solved on the basis of new inventions and discoveries. We examine methods and models with the E core concept (fig. 20.8) that are concerned with creativity and are aimed directly at the evolution of nature and civilization. The key concepts here are *evolution* and *ecology.* At the end of the 1980's, we developed the concept of the integration of the A and B core concepts as mutually enhancing instruments. This approach corresponds to one of TRIZ's most constructive procedures - the *integration of alternative systems*. This is how we use the procedures of TRIZ for its own further development. But, the rational and coordinated application of methods from different core concepts needs more development including experimental tests of special models and algorithms.

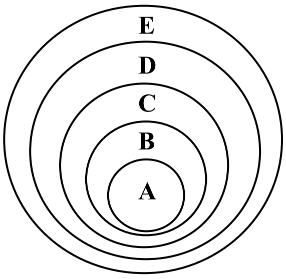

fig. 20.9

Instrumental models and methods need to be developed to effectively use the modern knowledge of the D and E core concepts. The methods should consider progressive goals (*challenges*) and the categorical limits of evolution. They should provide positive personal motivation and increase creative possibilities for people. We believe that many new inventors will dedicate themselves to these problems in the future. PentaCORE therefore has one more core concept, the C concept with *constructive* models and with *challenges* (fig. 20.9). The key ideas here are *challenge* and *constructivism*. We have connected combined positive and creative models and procedures to each other in this concept that are opposed to destructive tendencies that are found in society and quite often in the human psyche. Here we've also included our desire for the discovery of something new that's also extremely useful, that's constructive in the most essential use of the word. It's like in the origins of Russian artistic and architectural constructivism in the first half of the 20th century that arose along with *European Constructivism* and later led to creations by many internationally known painters, authors, composers, engineers, and architects.

So, we now have access to systems at the end of this section that correspond to the brain's asymmetry (fig. 20.10).

The important parts of this textbook are dedicated to the analysis and systematization of the methods of the A core concept and where necessary also to the methods of the C concept (in the sections "Meta-Algorithm of Inventing" and "Strategy and Tactics of Inventing"). The methods of the B concept are treated more abstractly in the sections "Methods of Creativity" and "Art of Inventing". This is because quite a bit has already been published about the B concept. Although only the limited number of publications about this topic that we needed for our work are included in our bibliography, this list will help you find more relevant publications. The methods and ideas of the D and E concepts are fragmentarily represented to the degree in which they come into contact with the methods of the A, B, and C core concepts. The limited scope of the book does not allow us to pay the attention to these models that they deserve.

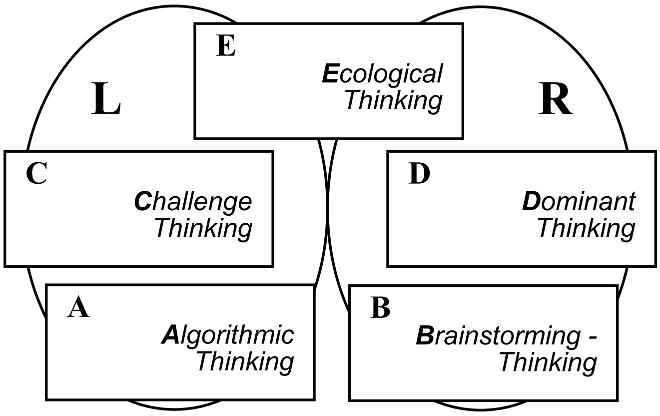

fig. 20.10. Relationship of the PentaCORE-model of the creative studios with the brain's asymmetry

21 CAI: Computer Aided Innovation / Invention

21.1 From *Invention Machine* to *Co-Brain and Goldfire*

In Minsk (the capital of Belarus, one of the republics of the former Soviet Union), the innovative software ***Invention Machine*** was developed at the end of the 1980's after 7 years of experimental work. It was initiated by a group led by Dr. Valery Tsurikov, a specialist in TRIZ and a scientist in the field of artificial intelligence. By 1991, more than 2000 examples of this software were sold. The work of the self-financed firm "*Invention Machine Laboratory*" became extremely complicated when the Soviet Union imploded. Valery Tsuricov immigrated to the USA and founded the company Invention Machine Corp. in 1992 while the development of a new Windows version continued in Minsk. 1995 was extremely successful for the company. Contracts were signed with Motorola for 3 million dollars. In 1996, Mitsubishi bought the rights to the Invention Machine for 18 million dollars.

An expanded version of the TRIZ software *Invention Machine* appeared with the name *TechOptimizer* in 1997. The wide distribution of *TechOptimizer* made TRIZ a well-known in the whole world and Invention Machine Corp. the leader of the field **CAI – Computer Aided Innovation / Invention**.

At the beginning of the year 2001, the ***TechOptimizer 3.5*** was the best system that is based on TRIZ. Four sub-systems based on TRIZ models comprise the instrumental part of the system: the "Principles Module" implements the A-matrix and the A-table, the "Prediction Module" enacts the TRIZ laws of systems development and original models for transformations that detail and further develop the models of the type "Standards"; the "Effects Module" contains a data bank with technical effects, and the "Feature Transfer Module" – puts the *Method of the Integration of alternative Systems* into praxis.

The sub-system "Effects Module" is especially valuable. There were accumulated more than 4,400 (!) effects from different areas of knowledge.

The sub-systems "Product Analysis Module" and "Process Analysis Module" are based on models of the function-cost-analysis and help to formulate the problem correctly.

Finally, the sub-system "Internet Assistant Module with Patent Analyzer" enables us to directly access patents for the first time in the Internet from TRIZ.

This text book will undoubtedly help you to work with the TechOptimizer 3.5 in the following ways:

1. You need certain knowledge of TRIZ to work with the software *TechOptimizer 3.5*. In this regard, the textbook provides the necessary facts for work with the TRIZ sub-systems "Principles Module", "Prediction Module", "Effects Module", and "Feature Transfer Module";
2. Meta-ARIZ and its strategies for a directed solution to problems in innovation can offer meaningful help to users of the software *TechOptimizer 3.5* because it doesn't contain this kind of general navigator;
3. Knowledge about the diagnostics of problems, strategy and tactics of inventing and TRIZ laws for the development of systems help users when working both with the sub-systems "Product Analysis Module" and "Process Analysis Module" as well as with TRIZ sub-systems.

At the end of this section, we would like to note that the firm Invention Machine Corp. has developed three ***pioneer systems*** – ***Knowledgist, CoBrain*** and ***Goldfire Intelligence***. All systems are strong semantic processors that help with the search for knowledge in patents and other electronic sources of information. The system *Knowledgist* helps the user to work with the data from the "Effects Module" in a natural language. The system displays the most appropriate sections and examples to the user using synonym interpretation. The systems *CoBrain and Goldfire Intelligence* are extremely promising both for a quick overview and analysis of patents when looking for analogies as well as for prognoses about the development of an area or for the evaluation of the competitiveness of products.

In other words, the software produced by the firm is oriented towards the first and second fundamental directions of TRIZ knowledge – the development of processing systems for *knowledge in innovative and inventive activities, especially for integration with systems that support projection, control, and scientific research.*

Knowledge of TRIZ laws and the developmental models of systems like in the section "Strategy and Tactics of Inventing", the method of reinventing, and models to structure the OZ help you to find the goal orientation needed to work with the systems *Knowledgist, CoBrain* and *Goldfire Intelligence.*

21.2 From *Problem-Formulator* to *Innovation Workbench*

Boris Zlotin, an outstanding TRIZ theorist, engineer, TRIZ teacher, and TRIZ author wandered a long path of creativity along with the founder of TRIZ Genrikh Altshuller. The same reasons already mentioned in the previous section lead in 1992 to Zlotin's emigration with his school to the USA where the firm Ideation International Inc. was founded with his help.

Zlotin's consulting activities quickly made TRIZ well known in the USA and, together with Tsuricov and his firm, he has become an important catalyst both for TRIZ applications and for the rapid growth of TRIZ consulting and teaching companies. An entire series of TRIZ specialists from Russia took part in the rebirth of the *TRIZ Journal* in the USA in 1996. This was previously the only TRIZ newspaper in the USSR that had appeared since 1990 one or two times a year. As a comparison, it is now published every month in the USA!

Since the middle of the 1990's, the firm Ideation International Inc. has introduced several software systems on the market, including ***Problem Formulator, Innovation Situation Questionnaire, Ideator, Improver, Anticipatory Failure Determination (AFD), Knowledge Wizard,*** and ***Innovation Workbench***. All systems in Ideation International's family ***TRIZ-Soft*** are based in one way or another on classical TRIZ models of transformation, although they also contain other original instruments. This is especially true of the system *AFD* that is meant for the analysis and prevention of phenomena caused by systems defects. The firm's software targets the second, and to some degree also the third and fourth fundamental developmental direction of TRIZ knowledge – *the development of universal and special applied systems based on TRIZ.*

Using this textbook to learn the basics of classical TRIZ and especially the Meta-ARIZ and models for systems development will help you to quickly become familiar with most of the systems mentioned by Ideation International, if necessary.

21.3 *Idea Navigator*: Integration of Intellects

The software mentioned above are oriented to large companies that could organize a continuous training in TRIZ of their employees. But application of both these software by the small and medium-sized enterprises is not so easy because of requirement of long time preliminary educating in TRIZ before the effective use of software. They require comprehensive knowledge both of TRIZ basics and of a large number of various system-technical methods and models that lie beyond the limits of TRIZ. No one of the products mentioned above contains a unified navigation system to search for innovative solutions and inventive ideas. They also provide no psychological support for thought processes.

To meet the needs of small and medium-sized enterprises, not long ago we started a program to develop the simplest software as possible. And till now several versions of the software under the common title ***Idea Navigator*** were developed.

All versions are based on the structure of Meta-Algorithm of Invention (MAI) and they use a standardized form of MAI for the educating the users from the patterns accumulated in data base of software as well as for the process of idea generating.

We represent here two simple versions of software ***Idea Navigator*** and its advanced perspective version.

21.3.1. Idea Navigator™ EasyTRIZ™.

This software was developed on the base of the simplest version of the MAI under the name of ***Simplest Meta-Algorithm of Resourceful Thinking (SMART)***.

This algorithm (fig. 21.1) has used under the name of SMART-2000 for many years (from the end of 1990th like SMART) in our trainings and problem solving projects like "computer-free" technique. Just this experience has served us as a clench to start developing software **Idea Navigator™ EasyTRIZ™**.

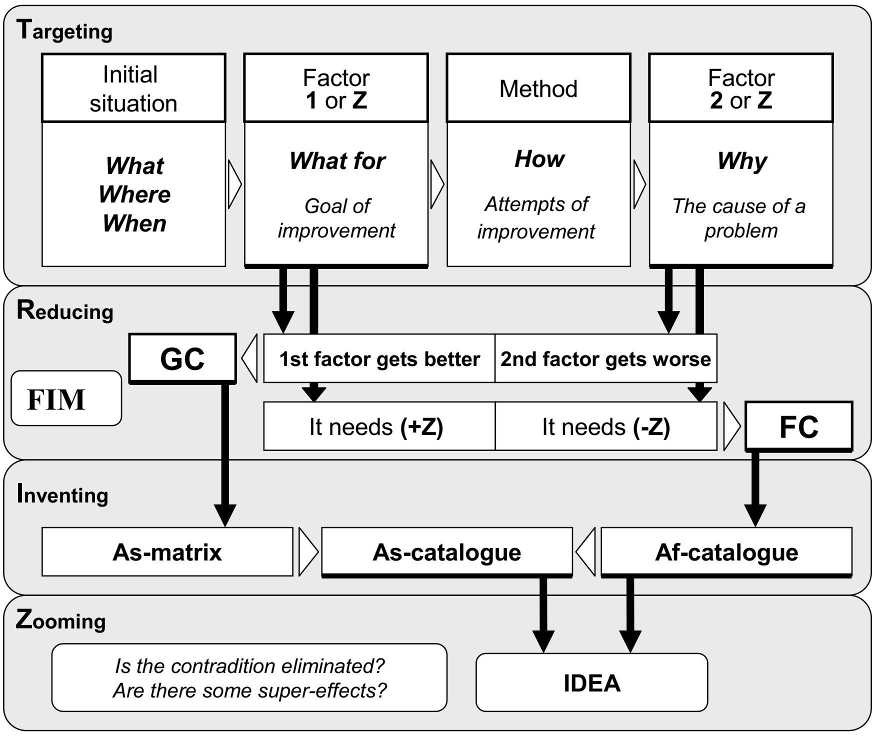

fig. 21.1. SMART-2000 "TRIZ": the Simplest Meta-Algorithm of Resource Thinking "Targeting – Reducing – Inventing – Zooming"

The first stage of MAI "Diagnostics" was named in SMART-2000 as "**Targeting**". Really the simplest idea of this stage is to define a target of system developing and problem solving.

The second stage was named as "**Reducing**" that is very close to MAI and does not need additional commentaries.

The third stage was named as "**Inventing**" that is clear taking in account the purpose and content of this stage.

The fourth stage was named as "**Zooming**" that could be effectively explained and interpreted like studying the invented idea in different scales and different surrounding likewise studying the geographical place on the maps of different scales or likewise aiming through the view finder of camera or camcorder. Studying the details level we could easily interpret like "zooming in" and studying the surrounding or super-system level we could interpret like "zooming out".

This algorithm was tested for many years at the trainings for beginners in "computer-free" form (fig. 21.2). But one may say that some times this form has been very useful for skilled users also during express problem solving especially without software that just means working "computer-free".

Considering all the stages together we could get the very symbolical abbreviation "TRIZ"! It is very easy remembered by every trainee-beginner especially by school teenager.

Next idea for **EasyTRIZ™** was developing it like "one-screen software"!

It could be the simplest TRIZ-software with only single screen to solve all the problems – and no one more!

This software is supported by special textbook based on the idea to train the very beginners as simple as possible. Title of textbook for beginners also includes the name **EasyTRIZ**[*]**.**

A screen-shot of the "one-screen" software **Idea Navigator™ EasyTRIZ™** is shown at the fig. 21.3.

SMART also uses the special designation for previous well known notions "Technical contradiction" and "Physical contradiction". These both contradictions are not exact convenient for many practical situation that are not from technical areas. Quite the contrary use of the new designations "General contradiction" and "Fundamental contradiction" accordingly is free of confusing for any situation.

In fact it is easy to see that the *General contradiction* very well reflects the incompatibility between any two aspects of system problem situation. Similarly the *Fundamental contradiction* reflects the incompatible requirements to one and the same aspect of system problem situation.

New notation makes much easier widening the use of these fundamental TRIZ terms for any practical application.

Preparing and type-out of the data of problem solving process is realized in form close to SMART-form shown at fig. 21.2.

Some other versions of simplest software ***Idea Navigator*** also use the SMART "TRIZ".

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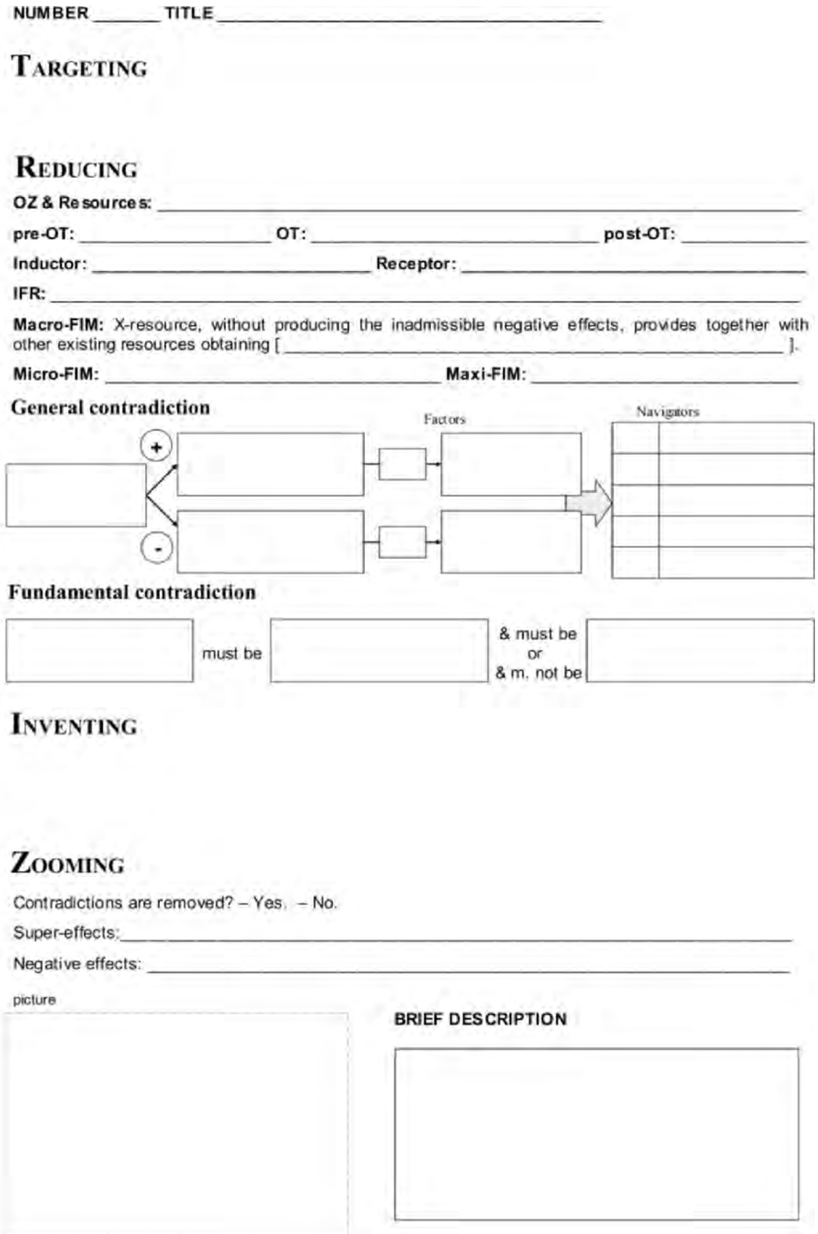
[*] Visit please our web-site www.easytriz.com



NUMBER ______ TITLE ____________________________________

TARGETING

REDUCING

OZ & Resources: ____________________________________

pre-OT: ________________ **OT:** ________________ **post-OT:** ____________

Inductor: ________________ **Receptor:** ________________

IFR: ____________________________________

Macro-FIM: X-resource, without producing the inadmissible negative effects, provides together with other existing resources obtaining [____________________].

Micro-FIM: ________________ **Maxi-FIM:** ________________

General contradiction

Fundamental contradiction

must be

& must be
or
& m. not be

INVENTING

ZOOMING

Contradictions are removed? – Yes. – No.

Super-effects: ____________________________________

Negative effects: ____________________________________

picture

BRIEF DESCRIPTION

fig. 21.2. Form for “computer-free” working with SMART-2000 “TRIZ”

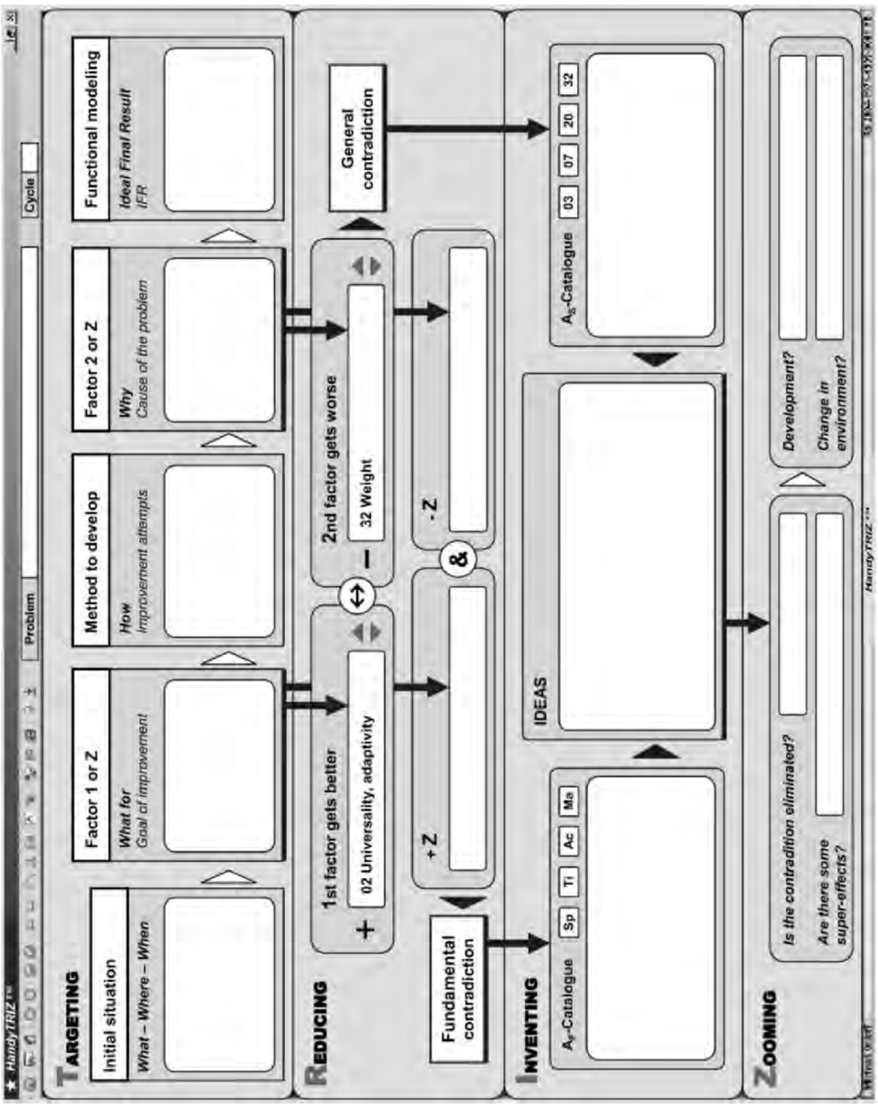


fig. 21.3. Screen-shot of the "one-screen" software **Idea Navigator™ EasyTRIZ™** on the base of SMART-2000 "TRIZ"

21.3.2. Idea Navigator™ HandyTRIZ™.

This software[*] has also developed on the SMART-2000 base.

In contrast to EasyTRIZ™ software **Idea Navigator™ HandyTRIZ™** includes tools of three studios – A, B and C (fig. 21.4). This software is oriented on the professional use by any engineer or researcher.

Every studio uses the same Meta-Algorithm of Invention (Meta-ARIZ) structure but with the tools of corresponding studio.

Studio A includes all main A-navigators. Additionally there are some new tools developed by author recently on the base of A-matrix.

Studio B includes the method Dimension-Time-Cost and matrix for Brainstorming.

Studio C includes the most popular tools on the base of resource development lines.

Working at any studio is supported by a Project-navigator (fig. 21.5) that automatically records all information created by user during problem solving process. Registration of any data is realized on the same standard MAI-structure.

Every example has the same MAI-format (Ex. 128 and Ex. 129). It gives standard frame for thinking to both for newcomer by education and for skilled professional by problem solving.

There are specialized pop-up windows for notes and for ideas recording. All the windows could be rolled in line if not used temporarily (look at the pop-up window "Ideas" rolled up into line at fig. 21.5).

The main window is SMART-navigator that could be called from behind the right side of screen (fig. 21.6). It helps user to be oriented in his location on the stage and tool of MAI and problem solving process. If it is not necessary to get the SMART-navigator on the screen it could be rolled in line or removed behind the screen.

The pop-up window "Dominator" (fig. 21.5) represents one of the simplest tools from D-studio namely for psychological supporting with color stimulating. At this window a user could set the color that corresponds with his preferable feeling and need to be stimulated with some color.

In this case one could say that the "dynamization" of the well known method Six Hats was realized here as in contrast to initial fixed setting all 6 colors to 6 thinking operations it is possible setting free any color to any operation. During working it is possible to set temporarily the preferable color on the full screen.

It is very important to use the same standard structure MAI for navigating in every version of software. Due this user could go on easily to the next version after gaining experience in the previous one.

Combining the tools of three studios gives user sizable freedom in control of problem solving process.

Software **Idea Navigator™ HandyTRIZ™** occupies an intermediate position between software **EasyTRIZ™** and advanced version **TRIZ PentaCORE™** that will be described below.

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[*] Visit please our web-site www.handytriz.com

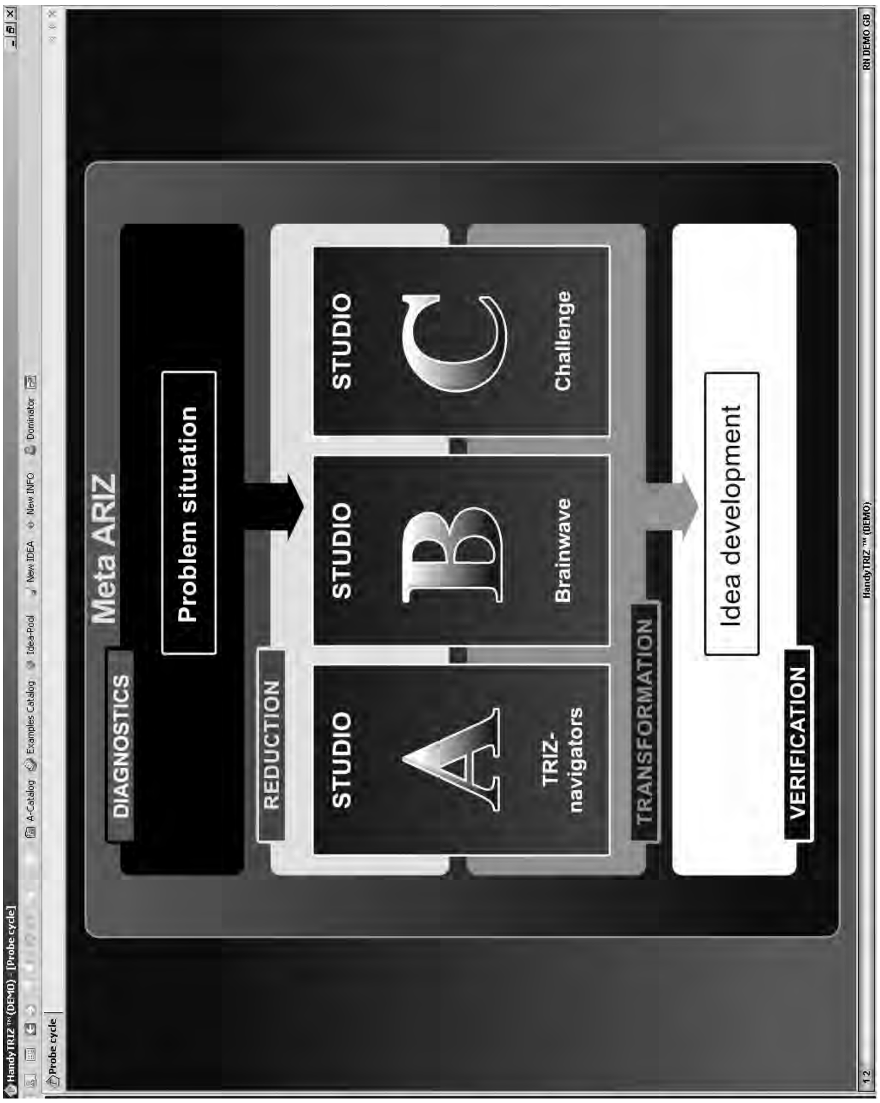


fig. 21.4. Screen-shot of the screen "Meta-ARIZ" of software **Idea Navigator™ HandyTRIZ™**

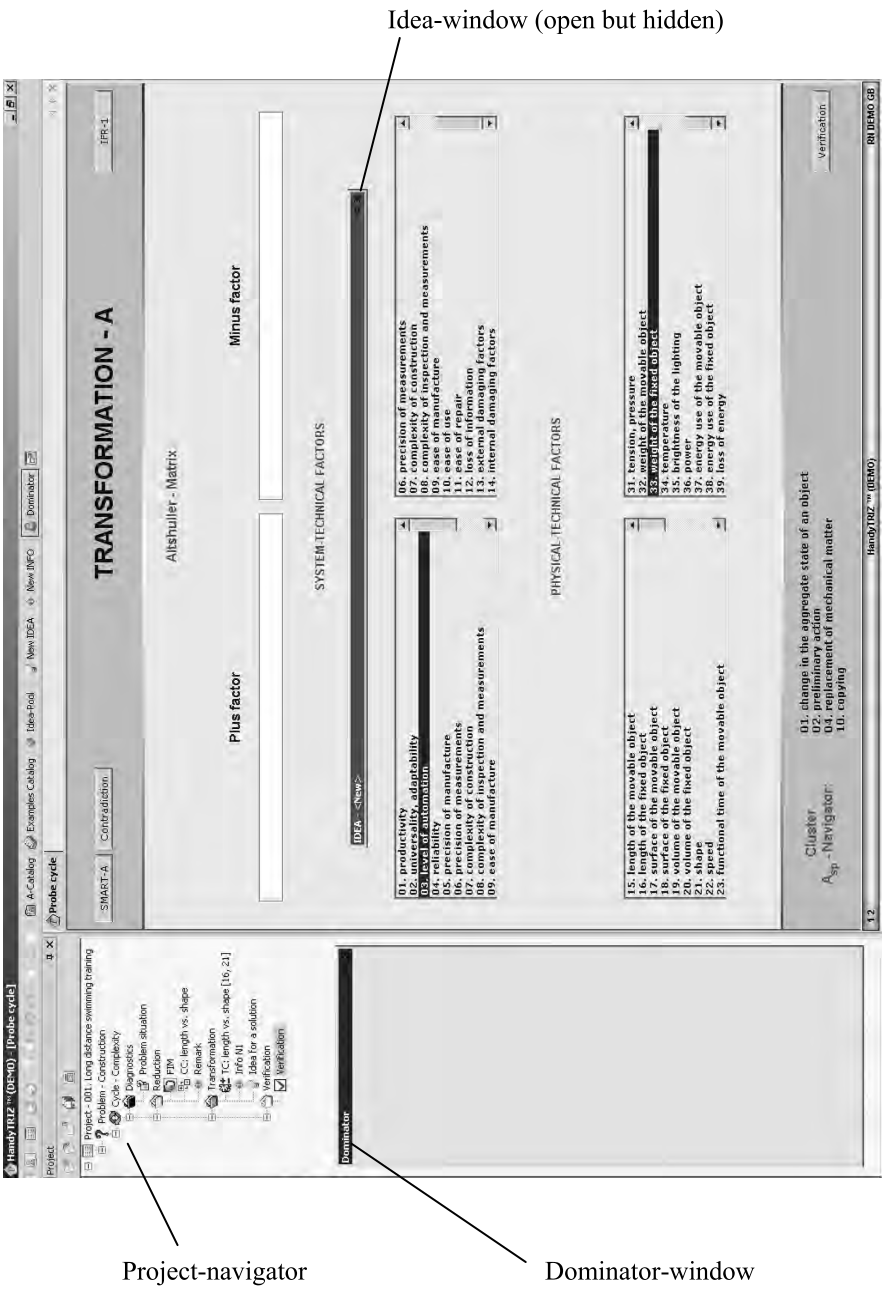


fig. 21.5. Screen-shot of the screen “Transformation-A” of software **Idea Navigator™ HandyTRIZ™**

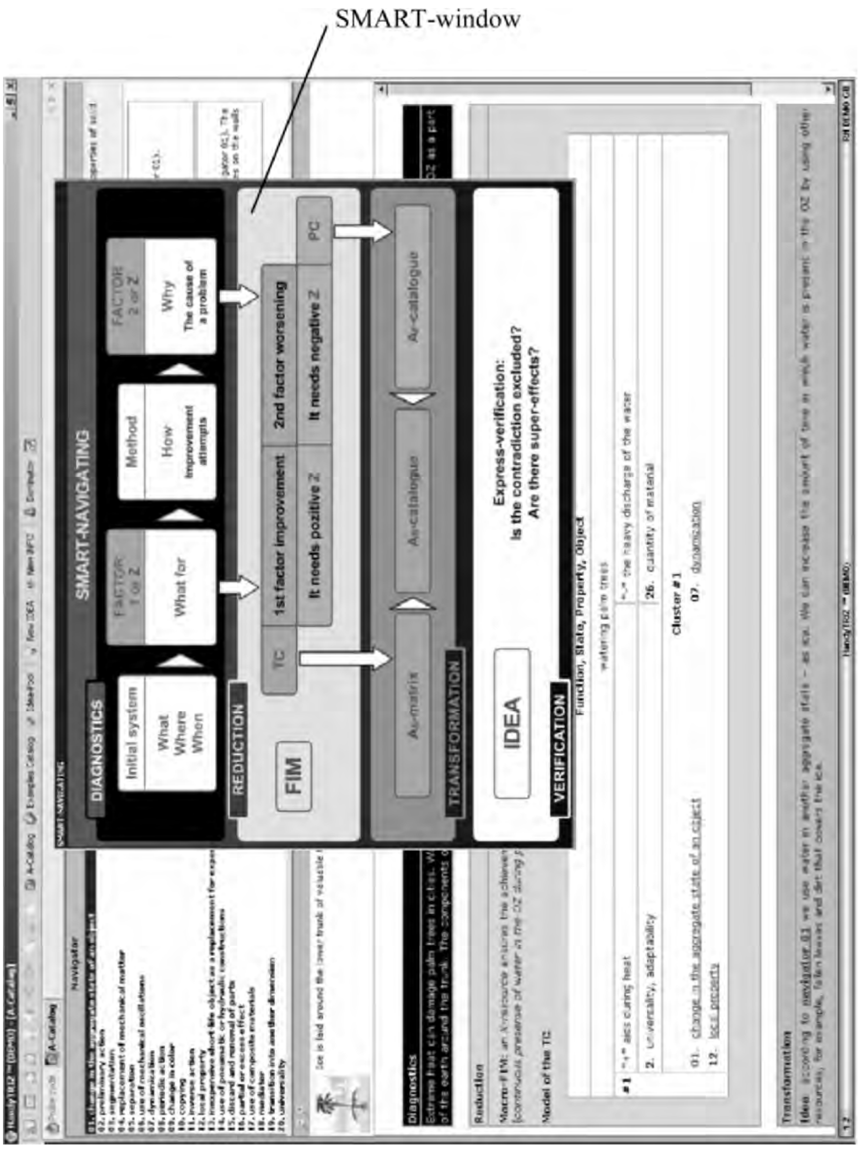


fig. 21.6. Screen-shot of the screen “A-Catalogue” of software
Idea Navigator™ HandyTRIZ™ with a pop-up window SMART

21.3.3. Idea Navigator™ TRIZ PentaCORE ™.

We'd now like to present the general structure of the software **Idea Navigator™ TRIZ PentaCORE ™** (fig. 21.7 and 21.8) that has been developed under the direction of the author of this textbook and that offers the user maximum effectiveness when creatively solving technical problems.

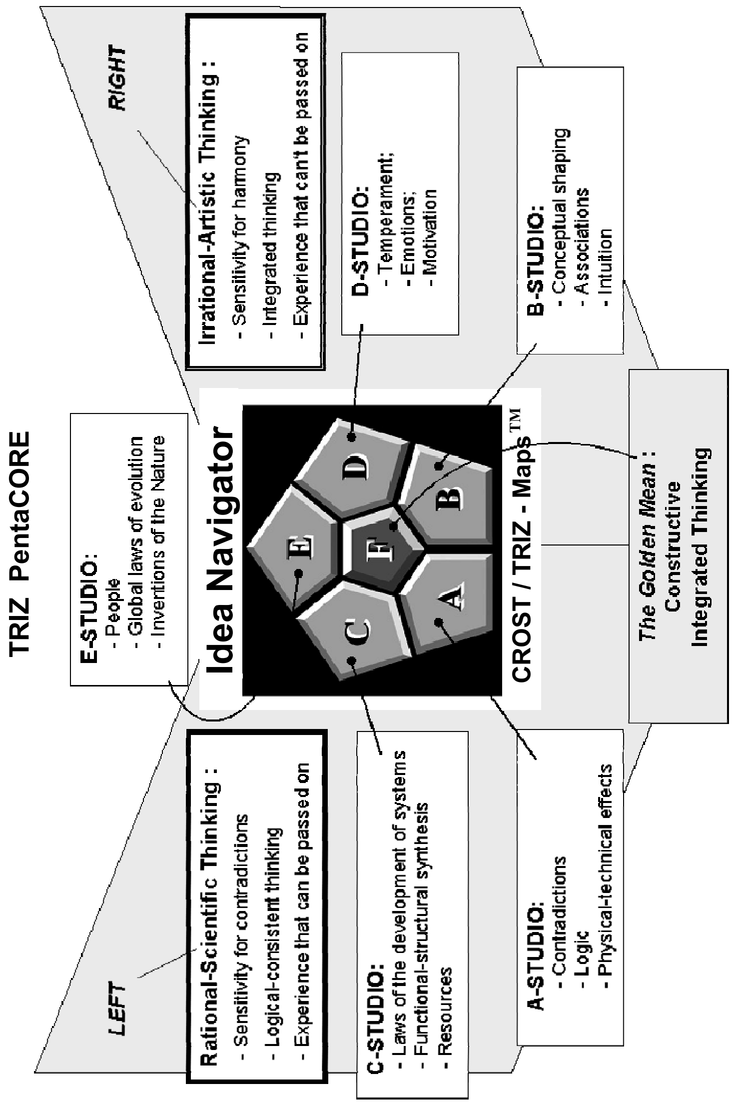


fig. 21.7. Structure of the **Idea Navigator™ TRIZ PentaCORE ™** creative studios.

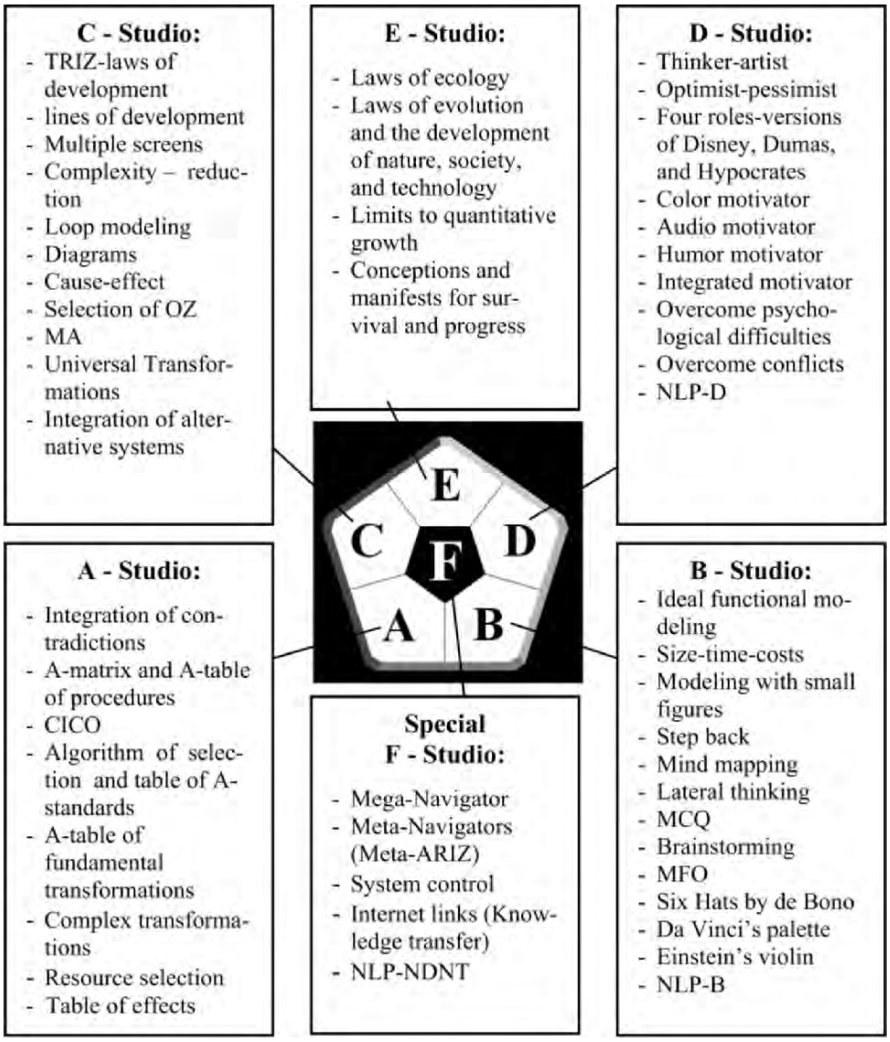


fig. 21.8. Main navigators of the software **Idea Navigator™ TRIZ PentaCORE ™.**

This effectiveness results from the integration of the best and most proven theories and methods.

> The entire scope of its functional properties and the level of its system integration mean that *Idea Navigator* is completely new and radical software without previous analogies integrated by so structured and comprehensive way.

The software *Idea Navigator* is based on the fundamental **idea of the integration of the rational-logical intellect with the emotional intellect**. *Idea Navigator* encompasses five parts of *PentaCORE-model* and a central navigation module for the system in general (see also fig 21.9).

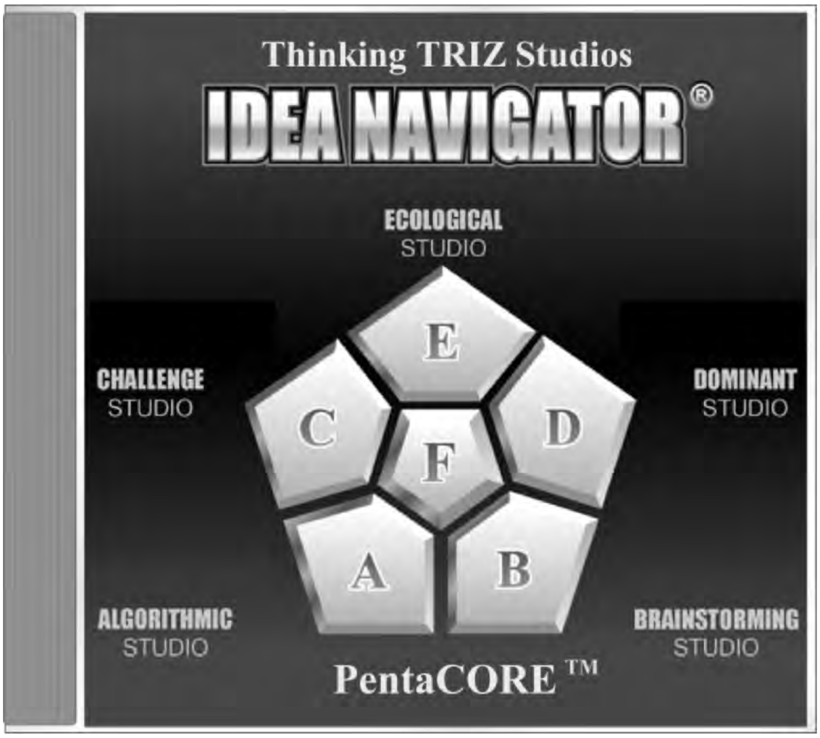


fig. 21.9. Composition of the **Idea Navigator™ TRIZ PentaCORE ™** studios.

The modules are called ***studios*** and correspond to models and instruments that people select and apply in creative activities.

The most important models and instruments in the studios are shown in fig. 21.8. In *Idea Navigator,* they are called ***navigators*** (see section 6 *From Praxis to Theory*).

Some of the key navigators require special know how and they can therefore not be explained here.

Two navigators from the control module F play an important role in the integration of intellects: ***Mega-Navigator*** and ***Meta-Navigator***.

The term ***F*** for the module stems from a direct relationship to the essential concept of abstract algebra and constructive mathematics ***Functor*** and from the definition ***Frontal.*** The former is a complex transformation that directly corresponds to Meta-ARIZ. The later is associated with a connection to the frontal areas of the brain responsible for generating ideas (see fig. 20.2, 20.3 and 20.10).

The *Mega-Navigator* is based on the table for the selection of strategies and thinking stile (shortened in fig. 21.10).

Strategic Level of Thinking	**Strategic Style of Thinking**		
	Scientific - Rational Intellect	***Constructive Engineering Intellect - The Golden Mean***	***Artistic - Emotional Intellect***
Operator	***A***	***AB***	***B***
Tactician	***AC***	***ABCD***	***BD***
Strategist	***ACE***	***ABCDE***	***BDE***
Master	Composite Neuro-Dynamical Navigator of Thinking **(C-NDNT)**		
Genius	Personal Neuro-Dynamical Navigator of Thinking **(P-NDNT)**		

fig. 21.10. Structure of Mega-navigation for the integration of rational-logical and emotional intellects

The Meta-Navigator implements the function of Meta-ARIZ (see section 7.2 *Meta-Algorithm of Inventing*). De Bono's idea of the navigation of thinking is included with the term "*Six Thinking Hats"* in fig. 21.11. The basis for this idea is the control of the emotional intellect during the search for a solution to a problem.

The Meta-Navigator does not change, meaning it has an easily recognizable structure for all studios of *Idea Navigator*. The meta-navigator of each and every studio is supported in diagnostics and reduction phases by models and recommendations of classical TRIZ that are discussed in this textbook.

Idea Navigator is a universal system based on TRIZ that integrates methods for the psychological support of innovative and inventive activities and models of the laws, limits, and goals of ecological and social progress. *Idea Navigator* contains mechanisms to integrate other systems and to support human activities such as with education, projection, control, and research systems.

A short demonstration of the main stages of *Idea Navigator* work includes two examples from A-studio. Because of absence of color on the pictures there is only grey scale on three first stages "*diagnostics*", "*reduction*", and "*transformation*".

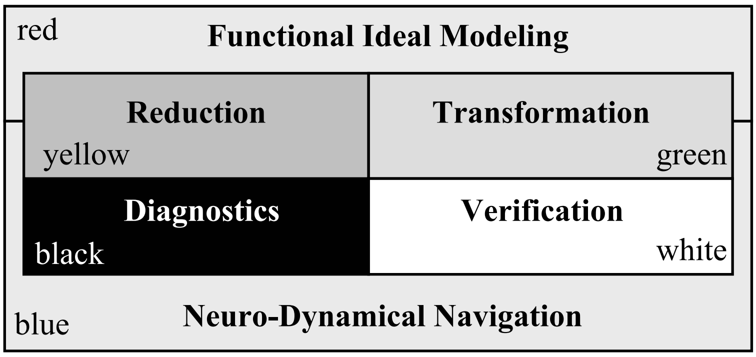


fig. 21.11. Structure of Meta-Navigation based on Meta-ARIZ and psychological color support

These examples use re-inventing for specialized A-navigator 05 *separation*. You could imagine that you are solving some problem with technical contradiction that leads to A-navigator 05. In this case you could study one or more examples from full list for A-navigator.

These examples could be added by navigators from other studios to solve the problem with preliminary destroying of psychological inertia or with well-timed help for imagination and inspiration.

Ex. 128. Excursion submarine

05-3 Diagnostics
The development of a self-contained excursion submarine requires lots of money and has to deal with extensive problems in security and reliability. This is why the idea was extremely costly and was not very popular. The administrative contradiction is to find a way to make an under water trip attractive for leisure, sports, or scientific purposes?

05-3 Reduction
We need to change the administrative contradiction into a technical one.
1^{st} TC: An excursion submarine has to be simple to use but external conditions can also make it unreliable and dangerous.
2^{nd} TC: The use of the submarine has to be inexpensive, meaning its production needs to be uncomplicated.
OZ and leading operative resources: The functional properties of the system conflict with each other.
Macro-FIM: an *X-resource* that does not complicate the system in any way and that causes no negative super effects, but that ensures the following together with other resources:
[*inexpensive, secure, and simple excursion submarine*].

Models TC:

Nr. TC	Effect, Condition, Object						
	excursion submarine						
	(+) - factor			**(-) - factor**			
1	user friendly	10	easy to use	has to be secure	13	external damaging factors	04, **05**, 23, 29
2	user friendly	10	easy to use	has to be inex-pensive	07 09	ease of production	**05**, 35, 37

Navigator 05 separation is clearly demonstrated here.

05-3 Transformation
The idea according to *navigator 05* is to retain the useful primary function (*presence under water)* in the body of the submarine and to transfer the guidance, forward movement, and security to another system, i.e., a ship that pulls the submarine (*X-resource)*. The submarine can be uncovered so that the passengers wear light diving suits.

05-3 Verification
Both TC's were resolved.

05-3 Short description

The goal is to develop an inexpensive and simple excursion submarine. The useful primary function (to be under water) is still part (*navigator 05*) of the construction of the submarine and guidance, forward movement, and security were transferred out of the system to a ship that pulls the submarine (fig. 21.12).

fig. 21.12. Excursion submarine

Ex. 129. Flying cisterns

05-4 Diagnostics
An extremely complicated problem while extinguishing fires in sky scrapers is the supply of water or other fire-fighting materials to the height needed. It's difficult to use helicopters because of the danger that they could fly into the building, because of heavy smoke, or because they could burn, too. How can we improve the chances to fight fires in sky scrapers?

05-4 Reduction
Let's change the administrative contradiction into a technical one. We can formulate the TC like this: the helicopter has to bring water to the height needed and it should not be exposed to the dangers of a wreck or an accident.
This is the TC in a table:

Nr. TC	Effect, Condition, Object						
	helicopter						
	(+) - factor			(-) – factor			
1	brings water to the height needed	16	length of the fixed object	Should not be exposed to the danger of an accident	10	easy to use	05, 29

05-4 Transformation
The idea according to *navigator 05* is to separate water or other fire-fighting materials out into a separate cistern attached to a helicopter with adjustable cables. The helicopter can fly at a safe distance above the building and the cistern can be moved to a zone that is optimal to fight the fire. It can be controlled remotely or by a special crew. The cistern can also be equipped with special instruments for guidance.

05-4 Verification
The TC was resolved.
1st system super-effect: a number of cisterns (not expensive helicopters!) can be made available for use.
2nd system super-effect: the cisterns can be refilled while the helicopters are in use.

05-4 Short description

Materials needed to extinguish a fire high up in a sky scraper are *separated out*, for example, into a cistern that is attached with cables of varying length to a helicopter (*navigator 05*). The means for optimal movement close to the fire can also be moved to the cistern (fig. 21.13).

fig. 21.13. Flying cisterns with the means to extinguish a fire and/or for saving the people

Concluding remarks

Solutions to complex problems in the praxis of engineers are not always strictly based on logical considerations or analogies. Instead, they are usually creative acts that are supported both by logic and analogies.

The instruments of classical TRIZ that we have introduced in this book make it possible to successfully solve at least 70-75% of all "standardized" problems in inventing for the perfection of products and technologies. Together with sufficient experience, combining these instruments can help solve practically 90% of all tasks. But, the remaining 15-20% are just as important as other tasks, because they require solutions to very complex and very important "non-standardized" problems.

The powers of imagination play a crucial role in the solution to any task. This is also the case for the ability to not think in a standardized way, to not move towards the "psychological inertia vector (PIV)", and to not be influenced by the apparent simplicity of guessing a solution. The instruments of classical TRIZ are a great help for overcoming psychological barriers. What's left is motivation. We cannot imagine that it's possible to find an idea for a solution when you're not really after a solution, when the solution is unimportant or even uninteresting to you.

The limits of the possibilities of TRIZ are those of the current limits of scientific knowledge. It is precisely these limits that support TRIZ in the synthesis of ideas. TRIZ actually exceeds these limits because it helps researchers and engineers to overcome them or to burst their framework. The special methods of TRIZ introduced here help in solutions to problems even at the highest level.

Classical TRIZ is classical because its main principle remains unchanged as a set basis for every engineering-technical theory of the synthesis of creative solutions. The systematization and order of the terminology in this book are the first step in the future integration of TRIZ with system-technical and special engineering-technical disciplines. TRIZ should become an inseparable component of every theory of the search for solutions and every theory of projection.

It is absolutely necessary to apply TRIZ concepts and instruments in all engineering-technical disciplines and at all colleges and universities. TRIZ should also become an important part of teaching programs in schools.

The possibilities of TRIZ are also extremely good in the development of creativity in children and in the training of creative personalities. There are innumerable examples of the successful use of TRIZ models to organize learning processes and to make the key components of TRIZ playfully familiar even to very small children.

The integration of TRIZ into different areas of activity that traditionally had no technical character also seems very promising. There are examples of the successful application of TRIZ to solve medical problems, social assignments, problems of management, the organization of election campaigns, the achievement of reliability and safety in technical objects, in projects and organizations.

Here I'd like to quote a statement that is very popular among proponents of TRIZ:

Look out! Learning TRIZ can change the power of your thinking!

If you've already become familiar with this book, this "warning" could already be too late for you. But I believe that in this case you've been convinced of how correct this statement is and can convince others, too. They will then have new weapons in the struggle against coming problems and their abilities to find brilliant ideas will be strengthened. This will also help them experience new things in life from the special joy of creative achievement.

TRIZ teaches us and helps make us used to thinking in paradoxes and contradictions. It inspires us with well-founded optimism and gives us the confidence to solve even the most complex "insolvable" problems. It leads to a more comprehensive viewpoint and better understanding of the world, its complex phenomena, and problems. Its logical models and picturesque metaphors help to overcome the limits of our perception of the world even as they sharpen our wits and the flexibility of our thinking.

Certainly there are many people who are talented by nature. Undoubtedly TRIZ can be useful even for these people as an instrument, a theory of systematic inventing, and a dependable model of thinking!

At this point, I would like to refer again to Sir Norman Foster's extremely successful solutions for the reconstruction of the Reichstag – the parliament building in Berlin (ex. 31). Clearly he did this without knowledge of TRIZ. But, these solutions are so effective that they simply **must** undergo reinventing and be included in the "golden collection" of TRIZ models. Then coming generations of architects can incorporate ready patterns for the rational synthesis of creative ideas in their projects.

One of the most paradox and courageous solutions was the construction of the dome as a location where everyone who's interested can visit the Reichstag without constraint. Large transparent surfaces in the upper curve of the hall allow visitors to observe the representatives as they influence the destiny of the nation. There is a very comfortable illusion that politics and economics are completely understandable to all of us!

However, there is a larger, more concentrated image invisibly present in the dome if we consider the comprehensive relationships of all of those who have a special relationship with this building. These are all free people in a democratic society who have the chance to stand above their representatives. Those representatives *down there* represent these free people. Visitors to the dome are certain that they stand below God, certainly, but above the legislators. There is a model of democracy that I sensed the first time I visited the dome of the Reichstag:

Everyone stands above the government, but under God.

And your first work with this textbook will also conclude an important step in your introduction into the art of TRIZ. I would like to end the book with the words of a participant in one of my seminars who later became a valued colleague:

Classical TRIZ is the way out of the quagmire
of "trial and error" into the sea
of "trial and success"!

But, I believe that there are still more words to be directed towards the inexperienced reader who has just met TRIZ for the first time.

All people reflect in hundreds of mirrors within themselves emotions, capabilities, motives, knowledge, interests, and acts. Everyone is different in their own way and has very different sides. They are contradictory in themselves and have multi-layered relationships to their environment. But, everyone is searching for solutions. We look every day. Often we find them, but sometimes not. Good solutions are not found very often and very good or brilliant ones are very rare.

Can those people who are looking for good solutions be helped in any way? What about those people who are not ready to uselessly waste valuable time in their life to blindly search for solutions just with their feelings and the expectation that chance enlightenment will bring success? Yes, those people need TRIZ.

TRIZ shows for the first time in the history of civilization a systematic way to solve problematic contradictions and find effective ideas. The mental perspective of TRIZ helps consistently to organize other aspects of life more effectively. It helps overcome strokes of fate. It also often helps predict problems and avoid them. It helps find resources in previously hopeless situations. However, this depends strongly on the personal properties of individuals and on their experience in applying TRIZ.

Ω

Thank you for your attention and trust.
I wish you lots of success and good achievements.

… Yes, it is simpler to invent in the old ways. It is simpler to dig a pit with a shovel, than to run an excavator. Walking is much simpler than to drive a car. For speed, power and effectiveness of any action one should pay the price by applying knowledge.

Inventing is no longer an exception. If you want to solve the complex problems quickly and effectively, you have to learn the theory, to master the “inventive physics” and everything else. But ***well organizing your knowledge is more important for solving inventive problems***.

… The solution to the problem is the essence of invention. And the most important is very subtle and exact intellectual transformations.

… The contemporary inventor first of all is a thinker, an intellectual.

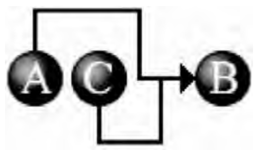
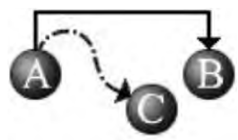
Genrikh Altshuller

And suddenly the inventor appeared,
Moscow, 1987

Appendices:
Tables of the Inventing Navigators in the A-Studio

Appendix 1

TABLE
Functional-Structural Models

Term	Type of FSM	Description	Examples of solution in a general form
1. opposition (counter-action)		A influences B positively, B influences A negatively	Exchange or change in the material of one or both elements, addition of supplements into the elements, onto the surface, or into the environment; change the character of the influence.
2. double influence		A influences B positively and negatively	
3. self-harm		A influences B positively, but also causes harm to itself	
4. incompatible influences		A and C influence B positively, but also disrupt each other	change in the combination (example: add a resource for negotiation) the location, the shape, or in time of the objects' influence; change in B's state; change the problem into a type 1-3 form.
5. influence on two objects		A influences B positively and C negatively	
6. ineffective influence		A interacts with B ineffectively or a necessary influence is missing	

Appendix 2

TABLE

A-Compact -Standards

S1	Supplements
1.1.1-1.1.5 1.2.1-1.2.4 5.1.1-5.1.4 5.2.1-5.2.3 5.4.1 5.5.1-5.5.3	1. take advantage of the possibility to introduce supplements into the extant material (including those in the environment) and/or onto the surface of an object in order to provide the system with the properties needed; 2. take advantage of the possibility to attach supplementary material to the materials in the system; 3. supplementary material can be introduced temporarily; 4. supplementary material can be produced using the materials already in the system; 5. a „hollow space" is introduced to replace material (air, foam, etc.); 6. a field that neutralizes a negative influence is introduced to replace material; 7. highly active supplements are added in small doses; 8. a normal supplement is added that has a very strong influence; 9. models (copies) are used in which supplements can be introduced; 10. material is added to a chemical mixture from which it is then removed at the appropriate time; 11. material is retained by splitting or changing the aggregate state of a part of an object and/or the environment; 12. the particles of material needed are produced by destroying material at a higher level (example: molecules); 13. the particles of material needed (example: molecules) are produced by combining or uniting particles at a lower structural level (example: ions).

S2	Controllability
2.1.1, 2.1.2 2.2.1-2.2.5 5.3.1-5.3.5 2.3.1, 2.3.2 1.2.5 2.4.1-2.4.12 4.4.1-4.4.5 1.1.6-1.1.8 5.4.2	1. take advantage of the possibility to transform a part of the object (material) into a controllable system; 2. take advantage of the possibility to introduce a slightly controllable field or coordinated fields; 3. If the material is supposed to have a certain spatial structure, the process should be carried out in a field with a structure that corresponds to the structure required; 4. take advantage of splitting material (a field), use capillary-porous structures, make fields and components dynamic, take advantage of the phase transitions of material, use the coordination and disruption of rhythms and frequency; 5. take advantage of the supplement of electromagnetic particles to control an object (filings, granulates, "magnetic liquids", etc.) and the influence of electromagnetic fields on these particles; use of ferromagnetic supplements together with capillary-porous materials; 6. take advantage of the possibility to add ferromagnetic materials to the environment; 7. use the maximum work method to attain a minimum (optimum) work method in necessary doses and then eliminate all extras; 8. to maintain a maximum work method, this method can be transferred to another material that is related to the material of the object at hand; 9. take advantage of the maximum effect to selectively guarantee a maximum or minimum work method. The section where the minimal effect is supposed to be attained is protected; the minimum effect is also used. Supplements are added (material, fields) to the functional section intended for the maximum effect that strengthen the minimum effect; 10. use of states of a material that are close to the critical state if energy is stored in the material and the initial signal plays the role of a "start button".

S3 4.1.1-4.1.3 4.2.1-4.2.4 4.3.1-4.3.3 4.5.1-4.5.2	**Reveal and Measure** 1. use the possibility to change a task so that it is no longer necessary to reveal or measure anything; 2. use the possibility to change a task so that it can be transformed into a task where the changes are subsequently revealed; 3. transition to the measurement of the first or second derivation of a function; 4. use the possibility to introduces supplements into already extant materials including the environment and/or onto the surface of an object that then lead to fields that can be easily uncovered (measured) to assess the state of the object for observation; 5. transition to double or multiple systems; use of copies; 6. use of technical effects.
S4 3.1.1-3.1.3	**Escalation** 1. use of the relationships of an object with another system or systems in a more complex double or multiple system; 2. acceleration of the development of relationships between the parts of a system and the environment; 3. increase the functional duty of a system and its parts.
S5 3.1.4-3.1.5 3.2.1	**De-escalation** 1. take advantage of the possibility to reduce less stressed or auxiliary parts (elements) of a system; 2. take advantage of the possibility to break up incompatible properties within a system by assigning the factor F to one property and the factor non-F to the other parts of the system; 3. take advantage of the possibility that the system functions at a micro-level - at the level of material and/or fields.

Appendix 3

A-Matrix for the Selection of Specialized A-Navigators

List of plus and minus factors of the:

01. productivity
02. universality, adaptability
03. level of automation
04. reliability
05. precision of manufacture
06. precision of measurements
07. complexity of construction
08. complexity of inspection and measurements
09. ease of manufacture
10. ease of use
11. ease of repair
12. loss of information
13. external damaging factors
14. internal damaging factors
15. length of the moveable object
16. length of the fixed object
17. surface of the moveable object
18. surface of the fixed object
19. volume of the moveable object
20. volume of the fixed object
21. shape
22. speed
23. functional time of the moveable object
24. functional time of the fixed object
25. loss of time
26. quantity of material
27. loss of material
28. strength
29. stabile stricture of the object
30. force
31. tension, pressure
32. weight of the moveable object
33. weight of the fixed object
34. temperature
35. brightness of the lighting
36. power
37. energy use of the moveable object
38. energy use of the fixed object
39. loss of energy

gets worse ➡ gets better ⬇		productivity 01	universality, adaptability 02	level of automation 03	reliability 04	precision of manufacture 05	precision of measurements 06	complexity of construction 07	complex. in inspec.& meas. 08	ease of manufacture 09	ease of use 10	ease of repair 11	loss of information 12	external damaging factors 13	internal damaging factors 14	length of the moveable object 15	length of the fixed object 16
productivity	**01**		01 03 04 27	01 10 35 37	01 02 03 30	03 06 09 02	02 03 04 15	04 18 19 37	01 05 06 13	01 04 05 18	03 04 08 34	02 03 09 29	11 07 36	01 11 18 21	01 06 21 23	04 06 24 30	10 22 25 34
universality, adaptability	**02**	01 04 20 27		01 13 15	01 11 32 18	-	01 02 03 35	04 07 14 27	03	03 11 31	03 07 15 16	03 16 24 34	-	01 09 28 31	-	01 03 05 14	01 03 16
level of automation	**03**	01 10 35 37	01 03 13 24		09 13 28	04 06 10 36	02 04 10 15	02 07 18	13 15 29	03 10 11	03 12 15 37	01 03 11	01 38	05 38	05	04 11 19 22	36
reliability	**04**	01 03 14 30	01 11 18 32	11 13 28		03 09 28	09 12 28 36	01 03 11	04 13 17	-	13 17 19	03 28	02 04	01 05 13 17	01 05 10 17	07 22 24 39	04 07 14 28
precision of manufacture	**05**	02 06 09 23	-	04 06 10 36	03 09 28		-	05 06 10	-	-	01 03 09 36	02 29	-	02 04 10 26	10 15 19 24	02 04 14 27	02 05 09
precision of measurements	**06**	02 04 09 15	01 05 11	02 04 05 15	03 28 35 36	-		01 02 13 15	04 09 10 18	01 06 20 29	03 11 15 19	03 09 11 28	-	04 10 18 21	02 12 23 38	04 10 16 35	04 09 12 16
complexity of construction	**07**	04 19 37	04 07 14 27	03 07 18	01 03 11	09 10 18	02 05 10 15		02 04 07 27	03 10 11 13	10 13 18 39	03 11	-	08 14 17 21	03 08	03 08 10 18	10
complexity of inspection and measurement	**08**	01 06	03 07	15 33	04 13 17 32	-	04 09 10 18	02 04 07 27		04 14 28 35	05 35	10 37	01 13 21 38	04 08 14 21	05 33	10 16 18 19	10
ease of manufacture	**09**	01 02 03 04	05 07 11	04 03 32	-	-	01 03 06 37	03 10 13	03 04 20 28		05 11 16 35	01 03 28 39	06 09 16 18	05 18	-	03 11 14 19	07 13 19
ease of use	**10**	03 04 07	03 07 15 16	03 12 15 37	13 17 19 32	01 03 09 36	05 11 15 29	09 19 29 37	-	05 35 37		03 09 10 37	02 13 21 24	04 05 23 29	-	03 11 19 37	-
ease of repair	**11**	02 03 09	03 16 24 34	01 11 15 34	02 03 16 28	02 29	02 05 11	01 03 11 28	-	01 02 03 28	03 07 10 37		-	01 02 05 16	-	02 03 04 29	06 12 31
loss of information	**12**	07 11 36	-	01	02 04 36	-	-	-	01 38	09	13 21	-		02 03 21	02 21 33	03 10	10
external damaging factors	**13**	01 11 18 21	01 21 28 31	12 15 38	05 13 17 18	02 04 06 10	04 10 36 38	08 14 17 21	08 14 17 21	01 05 18	04 05 23 29	01 02 05	02 05 21		-	03 19 23 24	03 06

surface of the moveable object	surface of the fixed object	volume of the moveable object	volume of the fixed object	shape	speed	func. time of the move. object	func. time of the fixed object	loss of time	quantity of material	loss of material	strength	stabile structure of the object	force	tension, pressure	weight of the moveable object	weight of the fixed object	temperature	brightness of the lighting	power	energy used by the move. object	energy used by the fixed object	loss of energy
17	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**
02 10 15 31	01 02 19 34	02 05 15 20	01 02 05 27	02 15 17 22	-	01 02 05 06	02 16 30 40	-	01 30	01 02 04 36	04 02 06 14	01 12 21 23	02 04 07 26	02 22 27	01 10 18 27	04 07 12 13	01 02 04 33	03 08 10 19	01 02 40	01 02 08 30	03	01 02 04 14
01 14 25 34	07 16	01 07 14	-	03 07 27 32	01 02 22	01 03 11	05 16	01 04	01 07 12	02 05 07 11	01 09 12 20	01 22 25	07 19 40	01 16	03 07 20 32	07 08 14 16	01 05 12 13	03 10 20 21	03 08 14	01 08 11 14	-	03 06 07
11 19 22	-	01 11 16	-	03 07 09 11	02 04	20 39	-	01 04 18 25	01 11	01 02 06 35	11 29	03 06	01 05	01 11	01 04 06 10	01 02 04 10	05 08 10	08 09 32	04 05 13	05 09 11	-	04 36
19 02 22 16	01 09 17 24	02 12 18 22	01 05 18	01 03 16 28	01 04 28 33	01 05 12 29	13 15 17 20	02 24 25	04 12 17 33	01 02 14 23	04 28	-	02 04 12 32	01 02 08 18	02 12 17 32	02 04 12 32	01 02 12	09 11 28	10 28 31 33	08 13 28 33	26 36	01 02 28
04 38 14 09	05 06 14 26	04 05 09	01 02 29	09 17 25	02 04 09	12 13 17	-	04 06 09 10	09 25	01 02 18 31	12 13	06 25	04 08 15 26	01 12	04 06 09 11	01 10 13 39	08 10	09 12	05 09	05 09	-	05 09 11
04 09 10 12	04 09 10 12	09 11 20	-	04 09 20	04 09 11 18	04 09 20	02 10 18	04 09 15 18	05 09 20	02 04 16 31	04 09 20	01 09 11	05 09	04 09 20	01 04 09 10	01 04 10 29	04 08 18 20	03 09 20	09 12 20	09 12 20	-	09 10 13
03 11 16 22	20 26	10 15 20	03 16	04 07 11 14	02 04 15	02 04 07 24	-	14 20	02 11 12 13	01 02 04 14	04 05 11	05 08 19 21	10 16	01 03 08	10 15 25 26	01 05 10 23	05 11 19	11 18 19	08 15 25 40	04 05 13 14	-	01 02 05 11
05 11 06 19	05 16 23 25	03 14 16 24	05 06 10 31	03 11 13 23	01 12 16 24	08 14 23 29	01 15 20 29	04 06 09 39	06 12 13 14	02 03 06 18	04 07 12 13	21 23 25 28	04 08 17 26	01 09 26 27	04 10 11 13	03 04 11 20	01 12 13 16	05 10 18	02 03 08 16	01 30	01 08 16	01 07 08 12
03 10 11 37	16 17	03 11 14 17	01	03 04 11 13	01 03 11 32	03 13 24	01 16	01 04 15 24	01 03 18 36	07 15 38	02 03 09 12	03 11 28	01 37	01 03 08 27	04 07 14 16	03 13 11 26	13 06 10	03 04 13 18	03 13 18 37	04 03 10 13	03 24	01 08
03 19 11 16	06 07 16 23	01 03 07 16	06 23 24 31	04 07 14 15	06 11 15	12 14 29 32	03 16 29	02 04 15 24	01 37	04 05 09 18	04 09 12 17	01 09 25	01 04 11	05 09 37	05 07 11 29	03 11 20 29	10 11 13	03 11 18 19	01 02 05 15	03 11 18	-	05 08 11
07 09 11	16 29	01 05 28 29	03	03 05 11 24	15 39	04 13 14 28	03	02 03 09 29	02 04 05 29	01 05 13 15	03 05 28 39	01 05	02 03 28	11	01 05 13 28	01 05 13 28	02 24	03 07 11	02 05 07 09	03 04 07 16	-	03 07 08 09
10 25	16 25	-	05 21	-	09 10	02	02	04 09 10 18	01 04 18	-	-	-	-	-	01 02 18	01 02 35	-	08	02 08	-	-	02 08
03 04 21 38	01 05 13 23	01 21 27 36	08 13 15 23	01 03 12 21	01 04 21 33	04 07 21 38	03 17 19 38	01 06 15	01 14 31 38	08 17 21 38	01 03 06 27	01 06 18 25	01 06 11 23	05 21 27	13 21 23 33	05 11 18 21	01 05 21 38	03 08 09 11	05 08 21 31	03 13 18 20	02 05 21 27	01 05 21 33

gets worse → gets better ↓		productivity **01**	universality, adaptability **02**	level of automation **03**	reliability **04**	precision of manufacture **05**	precision of measurements **06**	complexity of construction **07**	complex. in inspec..& meas. **08**	ease of manufacture **09**	ease of use **10**	ease of repair **11**	loss of information **12**	external damaging factors **13**	internal damaging factors **14**	length of the moveable object **15**	length of the fixed object **16**
internal damaging factors	**14**	01 06 21 23	-	05	05 17 18 23	10 15 19 24	10 12 38	03 08 31	03 05 13 33	-	-	-	02 14 33	-		07 16 19 21	-
length of the moveable object	**15**	04 14 22 24	03 07 16 22	10 16 18 19	02 14 17 22	02 04 14 27	04 09 24	03 08 10 18	01 03 10 18	03 14 19	01 07 14 24	02 03 04	03 18	03 07 18 19	07 19		-
length of the fixed object	**16**	10 22 25 34	01 03	-	04 07 14	02 05 09	04 09 12	03 10	10	07 13 19	05 29	12	10 18	03 06	-	-	
surface of the moveable object	**17**	02 05 10 15	07 25	04 22 25 36	14 39	05 09	04 09 10 12	03 11 22	05 06 10 26	03 10 11 18	07 11 16 19	02 03 07 11	10 25	03 04 21 38	05 06 19 23	06 07 22 24	-
surface of the fixed object	**18**	02 07 19 34	07 16	36	01 09 17 24	05 06 14 26	04 09 10 12	03 06 26	01 05 06 25	16 17	16 24	16	16 25	01 05 13 23	03 17 21	-	10 23 34 39
volume of the moveable object	**19**	02 05 15 20	07 14	01 15 16 18	03 17 22 28	04 05 16 29	04 10 29	03 10	10 14 24	03 14 17	07 11 25 37	02	05 21	01 13 21 33	03 05 17 19	01 03 04 34	-
volume of the fixed object	**20**	01 02 05 27	-	-	01 05 16	01 02 29	-	03 31	05 10 19	01	-	03	-	08 13 15 23	01 06 24 25	08 22	01 05 22 32
shape	**21**	02 10 15 19	03 07 14	03 07 09	02 16 17	09 17 25	03 04 09	03 04 14 16	07 11 23	03 04 09 19	07 09 10	03 05 11	-	01 03 05 21	01 03	14 15 24 35	02 11 22 34
speed	**22**	-	02 07 10	02 06	01 04 13 28	02 04 09 29	03 04 09 18	02 04 15 24	12 13 15 16	01 03 11 32	04 09 11 37	04 05 13 15	10 11	01 03 04 36	01 05 18 33	11 22 32	-
functional time of the moveable object	**23**	01 08 19 22	01 03 11	02 20	05 11 28	12 13 16 17	12	02 07 14 24	01 08 14 23	03 13 24	13 37	02 13 14	02	04 07 21 38	16 21 23 33	05 08 39	-
functional time of the fixed object	**24**	02 16 30 40	05	03	13 15 17 20	-	02 10 18	-	01 15 20 29	01 02	03	03	02	03 17 19 38	21	-	01 03 17
loss of time	**25**	-	01 04	01 04 18 25	02 24 25	04 06 10 18	04 09 15 18	14 20	02 04 06 09	01 04 15 24	02 04 15 24	02 03 09	04 09 10 18	01 06 15	01 06 21 23	05 07 14	18 22 25 35
quantity of material	**26**	11 12 13 14	07 12 14	01 32	04 06 12 17	25 38	04 05 12	02 11 12 13	06 12 13 14	01 03 13 14	01 02 14 29	02 05 09 29	01 04 18	01 14 31 38	01 12 17 23	01 06 14 22	-

surface of the moveable object	surface of the fixed object	volume of the moveable object	volume of the fixed object	shape	speed	func. time of the move. object.	func. time of the fixed object	loss of time	quantity of material	loss of material	strength	stabile structure of the object	force	tension, pressure	weight of the moveable object	weight of the fixed object	temperature	brightness of the lighting	power	energy use by the move. object	energy use by the fixed object	loss of energy
17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
19 05 06 23	03 17 21	05 17 19	01 06 24 25	01 03	01 04 12 36	07 21 31 38	16 21 23 33	03 21	03 12 18 23	02 03 15	01 05 07 21	01 13 17 23	01 03 04 17	05 06 13 38	07 08 21 23	01 03 21 23	01 05 18 21	08 09 18 23	01 05 06	01 05 20	06 08 21	01 05 21 33
07 19 24	-	01 04 19 34	-	02 03 14 32	11 24 32	08	-	05 07 14	01 14	02 14 24 36	01 14 15 32	03 07 15 32	02 19 24	01 03 32	07 14 15 32	-	02 07 08	09	01 03	01 18 32	-	01 05 23 34
-	02 17 19 34	-	01 05 22 32	07 11 22 34	-	-	01 03 17	14 22 25	-	01 02 04 18	04 07 10 22	01 23 27	02 04	01 03 22	-	01 04 14 17	01 06 12 30	12 29	32 37	-	-	04 20
	-	19 22 24 34	-	14 15 24 35	14 15 24 25	12 20	-	10 24	11 14 20 25	01 02 05 23	07 12 17 22	05 11 23 28	01 05 08 25	02 04 07 26	04 05 14 19	-	05 07 16	07 08 09 11	02 06 08 09	08 09	-	07 10 19 25
-		-	-	-	-	-	02 05 08 25	01 02 06 24	05 06 17 24	02 06 22 23	17	05 30	01 03 06 26	02 07 26 27	-	05 06 22 25	01 23 30	-	09 19	-	-	19 25 34
03 19 24 34	-		-	03 07 14 24	14 15 24 30	01 20 24	-	02 05 15 20	14 25 34	02 15 23 26	07 22 34 39	02 03 04 23	01 07 26 27	01 20 26 27	05 10 14 17	-	02 06 15 23	02 05 11	01 11 06 20	01	-	07 11 16 34
-	-	-		01 05 34	-	-	01 15 30	01 06 09 16	01 12	01 02 15 23	07 19 22 39	01 04 17 18	05 06 27	01 18	-	01 02 08 22	01 20 24	-	20 25	-	-	-
02 15 24 35	-	07 21 22 24	01 05 34		01 06 07 15	10 22 39 29	-	02 15 19 22	21 26	01 12 14 35	02 17 22 25	03 06 24 38	01 02 17 27	02 07 15 22	02 14 17 32	02 07 10 12	08 09 21 22	07 09 11	05 20 24	05 15 20 22	-	22
14 15 25	-	14 15 34	-	01 06 07 15		01 08 12 35	-	-	02 08 14 30	02 04 11 30	10 12 22 32	03 04 06 38	04 07 08 11	06 17 20 30	04 05 11 30	-	04 05 25 26	02 08 11	01 05 08 30	01 07 30 32	-	01 08 22 40
08 12 19	-	02 05 08 25	-	04 10 22 29	01 12 35		-	02 04 06 40	01 02 12 17	04 06 12 13	02 13 12	01 11 12	05 08 16	08 12 13	08 15 31 35	-	01 08 23	01 05 08 24	01 02 08 30	01 04 06 20	-	-
-	-	-	01 15 30	-	-	-		02 04 16 40	01 12 31	06 13 16 30	-	01 12 23 36	-	-	-	08 13 16 20	06 08 26 17	-	16	-	-	-
10 16 24 35	01 02 19 24	02 05 15 35	01 06 09 16	02 15 19 24	-	02 04 06 40	02 04 16 40		01 06 16 30	01 02 06 23	04 06 12 14	01 12 21 35	02 26 27 35	24 26 27	01 02 27 40	02 10 35 40	01 06 14 33	03 08 10 19	01 02 20 40	01 06 08 30	03	02 06 09 35
07 14 22	05 06 17 24	07 14 40	-	01 22	01 04 14 15	01 02 12 17	01 12 31	01 06 16 30		02 12 18 20	01 02 15 22	05 07 17 19	01 12 22	02 12 22 26	01 06 20 31	01 06 10 13	12 19 23	-	01	06 14 15 16	01 12 31	06 29 34

gets worse ➡ gets better ⬇		productivity 01	universality, adaptability 02	level of automation 03	reliability 04	precision of manufacture 05	precision of measurements 06	complexity of construction 07	complex. in inspec.& meas. 08	ease of manufacture 09	ease of use 10	ease of repair 11	loss of information 12	external damaging factors 13	internal damaging factors 14	length of the moveable object 15	length of the fixed object 16
loss of material	**27**	01 02 04 36	02 05 07	01 02 06	01 02 14 23	01 02 18 31	04 15 16 31	01 02 04 18	01 02 06 11	07 15 38	04 05 09 18	01 05 13 15	-	17 21 25 38	03 02 14 15	02 14 22 23	02 04 18
strength	**28**	01 02 14 22	07 09 12	07	12 28	12 13	12 13 16	04 05 11	07 12 13 17	02 09 12 28	04 05 09 17	12 13 28	-	01 03 06 27	01 05 07 21	01 03 07 32	04 07 10 22
stabile structure of the object	**29**	01 12 17 36	01 05 15 25	01 03 32	-	06	11	01 05 10 21	01 21 23 36	01 08	01 09 25	01 02 05 16	-	01 06 18 25	01 13 17 23	03 04 07 11	27
force	**30**	01 04 12 27	06 07 19 40	01 05	01 11 12 33	04 14 26 27	01 02 18 36	01 02 06 10	02 08 26 27	03 06 07 27	03 04 12 29	03 07 28	-	01 03 06 17	11 12 18 26	08 19 26 39	02 04
tension, pressure	**31**	01 02 22 27	01	01 18	01 02 08 11	01 12	04 20 29	01 03 08	05 26 27	01 03 16	28	05	-	05 21 27	05 06 13 38	01 02 26	01 03 16 22
weight of the moveable object	**32**	01 12 18 27	07 14 32 35	01 06 08 10	03 12 13 28	01 04 06 10	01 04 10 13	10 15 25 26	04 09 10 14	03 04 13 26	01 05 12 18	04 05 13 28	01 02 18	06 13 21 33	01 21 23 31	07 14 15 32	-
weight of the fixed object	**33**	01 03 04 07	07 08 14	01 05 10	02 04 12 32	01 02 03 19	04 06 10	02 03 10 23	04 07 19 29	03 04 09	03 09 11 20	04 05 13 28	01 02 07	05 08 21 27	01 03 21 23	-	01 02 03 14
temperature	**34**	01 04 07	05 06 13	05 08 10 16	01 02 08 12	18	08 09 18	05 19 16	01 12 13 31	10 13	10 13	02 16 24	-	01 05 21 38	01 05 18 21	07 08 39	07 08 39
brightness of the lighting	**35**	05 29 16	07 03 08	05 10 02	-	12 09	28 07 09	20 09 11	09 07	08 01 04 10	04 10 08	07 19 11 16	03 20	07 08	01 08 09 23	08 09 16	-
power	**36**	01 04 15	08 15 19	04 05 19	08 10 18 31	05 09	05 07 09	08 15 25 40	01 08 16	02 10 15	01 02 10	01 02 05 15	02 08	05 08 21 31	01 05 06	01 02 03 27	-
energy used by the moveable object	**37**	01 04 37	07 11 16 19	05 09	08 13 28 33	-	03 09 12	04 05 13 14	01 30	04 10 25	01 08	03 04 07 19	-	01 03 13 20	01 05 20	04 37	-
energy used by the fixed object	**38**	03 20	-	-	02 26 36	-	-	-	01 08 16 29	03 24	-	-	-	02 05 21 27	06 08 21	-	-
loss of energy	**39**	01 02 04 14	-	05	01 02 28	-	09	34 36	01 07 12 36	-	01 03 09	05 08	02 08	01 05 21 33	01 05 21 33	05 11 20 34	20 30 34

surface of the moveable object 17	surface of the fixed object 18	volume of the moveable object 19	volume of the fixed object 20	shape 21	speed 22	func. time of the move. object 23	func. time of the fixed object 24	loss of time 25	quantity of material 26	loss of material 27	strength 28	stabile structure of the object 29	force 30	tension, pressure 31	weight of the moveable object 32	weight of the fixed object 33	temperature 34	brightness of the lighting 35	power 36	energy used by the move. object 37	energy used by the fixed object 38	loss of energy 39
01 02 05 31	02 06 23 31	03 14 25 26	06 12 23 31	01 12 14 35	02 04 11 30	04 06 12 13	06 13 16 30	01 02 06 07	02 12 18 20		01 04 17 31	05 17 22 25	07 06 17 22	02 12 26 27	01 17 20 36	01 09 20 21	23 26 31 33	03 11 20	04 06 13 30	01 06 18 35	04 13 31 37	01 05 13 31
12 14 15 17	04 17 39	02 07 22 34	03 07 19 22	01 02 17 25	10 11 22 32	10 12 13	-	02 04 14 12	02 13 14	01 04 17 31		01 11 19	02 06 12 22	02 06 12 17	03 07 17 32	03 10 13 17	02 17 25	01 08	01 02 04 10	01 02 08	01	01
05 11 28	23	02 04 08 23	01 04 15 17	03 06 21 24	04 06 07 38	01 02 11 13	01 12 23 36	01 13	01 07 09	05 17 22 25	07 19 39		01 02 16 33	01 05 17	01 05 23 33	03 10 17 23	01 03 09	07 09 12 13	01 09 13 31	08 11	06 13 14 24	22 05 20 23
02 07 08	03 06 26 27	07 27 37 39	05 06 26 27	01 02 15 17	04 07 11 37	05 08	-	02 26 27	06 14 22 26	01 17 32 35	01 02 13 22	01 02 33		06 28 33	03 06 27 32	03 04 06 11	01 02 33	-	01 06 08 27	02 08 19	03 16 26 27	07 22
02 04 07 26	02 07 26 27	01 02 20	01 18	01 02 07 24	01 20 26	08 12 13	-	24 26 27	02 22 26	02 12 26 27	06 12 17 39	01 05 17 38	01 26 33		02 17 26 27	02 06 11 14	01 05 08 23	-	01 02 22	02 18 22 27	-	05 26 29
14 15 19 30	-	04 05 14 17	-	02 01 17 22	05 07 30 32	01 15 31 35	-	01 02 04 40	06 10 12 31	01 12 31 35	04 06 13 17	01 03 08 23	02 06 27 32	02 17 26 27		-	14 20 24 30	03 08 09	06 26 31 37	01 15 31 37	-	05 08 15 20
-	01 05 11 25	-	01 05 22 35	02 11 14 22	-	-	05 08 13 20	01 02 10 40	06 08 10 20	11 25 32 35	02 04 05 13	03 10 17 23	01 02 08 32	02 06 11 14	-		04 08 09 21	01 08 09	06 07 08 21	-	03 04 06 08	04 06 07 08
01 06 12 23	01 30	06 15 17 23	01 20 24	08 09 21 22	04 05 25 26	08 11 23	08 06 17 26	01 04 06 33	12 19 23 25	14 26 31 33	02 17 21 25	01 03 09	01 02 12 33	01 05 08 23	20 21 26 30	01 09 21		09 16 25 33	05 19 22 29	07 08 12 19	-	01 19 30 33
08 09 10	-	02 05 11	-	09 25	02 08 11	05 08 20	-	03 08 10 19	03 08	03 11	01 08	09 12 13	08 10 20	-	03 08 09	01 05 09	01 08 09		09	03 08 09	01 03 07 09	03 08 16 20
08 30	09 11 19 30	01 20 30	20 25 29	05 14 17 22	01 05 07	01 02 08 30	16	01 02 20 40	08 15 24	06 04 13 30	02 04 10	01 07 09 31	01 05 10 26	01 02 21	26 30 31 32	08 10 19 13	05 19 22 29	08 16 20		08 16 20 27	-	01 02 30
07 08 29	-	01 06 11	-	05 14 37	01 07 32	01 04 06 20	-	01 06 08 30	06 15 16 36	01 06 18 35	01 08 35 39	08 11 18 19	05 10 16 33	22 29 36	04 06 31 37	-	08 12 18 22	05 07 08	06 08 20 27		-	07 18 21 37
-	-	-	-	-	-	-	-	-	01 12 31	04 06 13 31	01	06 13 14 24	26 27	-	-	08 13 20 39	-	01 05 08 09	-	-		-
07 10 19 25	06 19 25 34	06 34 36	34	-	01 16 30	-	-	02 06 09 34	06 29 34	01 05 13 27	10	05 20 22 23	26 30	-	04 07 08 20	06 08 20 39	08 30 34	03 07 09 11	12 30	-	-	

Appendix 4

TABLE Specialized A-Navigators

List of specialized A-navigators of a/an/the:

01. change in the aggregate state of an object
02. preliminary action
03. segmentation
04. replacement of mechanical matter
05. separation
06. use of mechanical oscillations
07. dynamization
08. periodic action
09. change in color
10. copying
11. inverse action
12. local property
13. inexpensive short-life object as a replacement for expensive long-life one
14. use of pneumatic or hydraulic constructions
15. discard and renewal of parts
16. partial or excess effect
17. use of composite materials
18. mediator
19. transition into another dimension
20. universality
21. transform damage into use
22. spherical-shape
23. use of inert media
24. asymmetry
25. use of flexible covers and thin films
26. phase transitions
27. full use of thermal expansion
28. previously installed cushions
29. self-servicing
30. use of strong oxidants
31. use of porous materials
32. counter-weight
33. quick jump
34. matryoshka (nested doll)
35. unite
36. feedback
37. equipotentiality
38. homogeneity
39. preliminary counter-action
40. uninterrupted useful function

01 CHANGE IN THE AGGREGATE STATE OF AN OBJECT

a) this includes transitions into "pseudo-states" ("pseudo-liquid") and into transitionary states such as the use of the elastic properties of solid objects as well as simple transitions such as from a solid to a liquid state;
b) changes in concentration or consistency, in the degree of flexibility, in temperature, etc.

Ex.01-1. Use of magneto-rheological or electro-rheological liquids to control the degree of viscosity from a liquid to and including a solid state.
Ex.01-2. A diving coach can cause the water to "foam" to make it "softer" so that the danger of injuries is reduced when training dives from a tower into a swimming pool don't function correctly
Ex.01-3. The emergency braking zone on the runways of airports is shaped like a pool that is filled with a viscous liquid and either covered with a thick layer of an elastic material or with waste material.

02 PRELIMINARY ACTION

a) previous necessary (partial or complete) change of an object;
b) prepare objects in advance so that they can be put to work from the best position and are available without loss of time.

Ex. 02-1. Blanks for machine parts are manufactured so that they resemble the final product in shape and size.
Ex. 02-2. When trees are planted at the side of the street, plastic pipes are laid near their roots to facilitate watering.
Ex. 02-3. Hydrants are installed on the streets so that they can be attached to large underground water pipes.

03 SEGMENTATION

a) disassemble an object into individual parts;
b) make it possible to disassemble an object;
c) raise the degree of disassembly (reduction into parts) of an object.

Ex. 03-1. A multi-stage rocket.
Ex. 03-2. A pneumatic tire that is separated into individual areas to increase its working life
Ex. 03-3. Instead of saws, liquid is used at high pressure with abrasive powders to cut stone.

04 REPLACEMENT OF MECHANICAL MATTER

a) replace mechanical schemes with optical, acoustic, or olfactory schemes;
b) use of electrical, magnetic, or electromagnetic fields for the interaction of objects;
c) replacement of static fields with dynamic ones, from temporally fixed to flexible fields, from unstructured fields to fields with a specific structure;
d) use of fields in connection with ferric-magnetic particles.

Ex. 04-1. Work stations and transport systems with linear step-engines.
Ex. 04-2. The functional procedure of a Xerox or ink-stream copier that constructs an electrostatic field with a structure that corresponds exactly to the image (in reference to the object to be copied or the data output of the computer) and controls the intensity and coordination of the transfer of color particles onto paper.
Ex. 04-3. Use of magneto-rheological and electro-rheological liquids (see too navigator 01)

05 SEPARATION

separate the "incompatible part" ("incompatible property") from the object or - turned completely around - separate the only really necessary part (necessary property).

Ex. 05-1. The pedals of a bicycle were incompatible when installed on the front wheel; later they were reinstalled on the frame.
Ex. 05-2. A robot-arm is extended out of a "shuttle" that then sends rockets into orbit. This method replaces the several booster rockets that were previously used.
Ex. 05-3. An unsealed module is pulled along under a ship in which scientists or tourists can take dives. The module can control its own depth.

06 USE OF MECHANICAL OSCILLATIONS

a) cause an object to vibrate;
b) raise the frequency of the vibrations up to and including ultra-high frequencies if the object is already in motion;
c) use of the resonating frequency, application of quartz vibrators;
d) use of ultra-sound vibrations in connection with electromagnetic fields.

Ex. 06-1. Thermo-compression welding, for example, to connect conductors to a metallic contact plate for integrated circuits in which mechanical vibrations influence the welder with an ultra-high control frequency.
Ex. 06-2. Machine parts give off mechanical vibrations where the measurement of the resonating frequency can uncover distortions and find extant defects.
Ex. 06-3. Ultra-high frequency scalpel for surgical procedures

07 DYNAMIZATION

a) the characteristics of an object or an environment are changed to optimize every work procedure;
b) disassemble an object into parts that are moveable among each other;
c) make an object moveable that is otherwise fixed.

Ex. 07-1. Aircraft with adjustable wing angle.
Ex. 07-2. posts to prevent the illegal parking of autos that consist of a column that is mounted on a hinge that can be vertically or horizontally set and then fixed with a lock so that the column cannot be moved in its locked state; see also ***Ex. 35-2***, navigator 35 - hinged connection of the parts of a compound ship.
Ex. 07-3. One of Siemens' exhibition pavilions with a moveable sun protection system for the entire height of the building.

08 PERIODIC ACTION

a) transition from a continuous function to a periodic one (impulse);
b) change the periods if the function already runs that way;
c) use the breaks between impulses for other functions.

Ex. 08-1. Procedure of the controlled heat-processing of machine parts that locally introduces a coolant according to a program in which parameters control the coolant's application in impulses for the entire zone to be cooled (see also navigator 12).
Ex. 08-2. Ship's propellers that are mounted parallel and in a synchronized fashion so that their blades move between the other propeller's blades (see also navigator 34)

09 CHANGE IN COLOR

a) change the color of an object or its environment;
b) change the level of the transparency of an object or its environment;
c) use color supplements to observe objects or processes that are difficult to see;
d) add lighting if this kind of supplements is already in use.

Ex. 09-1. An iron with infra-red reflectors and a transparent base.
Ex. 09-2. A color is added to the flow of a material (air in a wind tunnel, water or another liquid in a hydro-dynamic tunnel) that allows the video observation of the processes of the material's movement with reference to the object to be tested.
Ex. 09-3. Colored threads are added to the materials from which bonds and money are made.

10 COPYING

a) use a simplified and inexpensive copy instead of an inaccessible, complicated, expensive, inappropriate, or fragile object;
b) replace an object or a system of objects with optical copies; use here a change in measurement (blow-up or reduce the copy);
c) if visible copies are used, they can be replaced with infra-red or ultra-violet copies.

Ex. 10-1. Use window dummies or robots in 3 or 2 dimensions, blown-up, reduced, or life-size, moveable or fixed, "speaking" or "singing", etc. to attract the attention of people who go by cafés, businesses, travel agencies, exhibition halls, etc.
Ex. 10-2. Images of horizontal and vertical lines in scale are projected onto a 2-dimensional X-ray or a stereoscopic measuring cube is projected onto a stereoscopic X-ray in order to determine the exact position of a diseased area in a 3-dimensional space.
Ex. 10-3. "Natural" holographic representation of valuable objects such as paintings or sculptures.

11 INVERSE ACTION

a) instead of an action prescribed by the conditions of an assignment, complete a reverse action (heat an object instead of cooling it);
b) make a moveable part of an object or the environment fixed or a fixed part moveable;
c) turn an object "upside down" or around.

Ex. 11-1. A tool to cut metal needs to be cooled. It is cooled with a liquid that then cools the part being cut, too. A technique was developed to locally cool the tool while heating the area to be cut with a laser. This lowered costs and increased the quality of the work (see also navigator 21).
Ex. 11-2. Many training and test devices: athletes do not move in reference to space (the ground): instead a moveable medium moves around them - a stream was installed in a swimming pool to train swimmers and skiers; tests are run in special basins for ship models and underwater devices; aircraft are tested in wind tunnels with "strong" winds, sometimes even at ultra-high frequencies.
Ex.11-3. A chisel is installed from below so that chips don't fall on the part to be processed.

12 LOCAL PROPERTY

a) change the structure of the object (the external environment, external influences) from the same to a different one;
b) different parts of an object have different functions;
c) every object should exist under conditions that correspond best to its functions.

Ex. 12-1. A streetcar-bus has metallic wheels for travel on rails and normal auto wheels for travel on stretches without tracks. The auto wheels function as a drive system on rails while the metal wheels maintain the direction of travel.
Ex. 12-2. A silicon solar cell is equipped with a motor for optimum positioning towards the sun.
Ex. 12-3. Training devices in sport centers that are constructed to train specific muscle groups.

13 INEXPENSIVE SHORT-LIFE OBJECT AS A REPLACEMENT FOR EXPENSIVE LONG-LIFE ONE

replace an expensive object with a group of inexpensive objects without certain properties, for example, long life.

Ex. 13-1. Throw-away hankies such as "TEMPO", a patent by "Procter & Gamble".
Ex. 13-2. Melt and strip fuses to protect electrical devices against overloading.

14 USE OF PNEUMATIC OR HYDRAULIC CONSTRUCTIONS

use gaseous or fluid parts instead of fixed parts in an object: parts that can be blown up or filled with hydraulic fluid, air-cushions, hydrostatic or hydro-reactive parts.

Ex. 14-1. A hydraulic lift that fills elastic cushions installed in a stack with enough fluid to life and to hold a load.
Ex. 14-2. A pneumatic or hydraulic clamp that works with an elastic cushion that holds the part in question with even pressure;
Ex. 14-3. Air tents for exhibition pavilions, temporary "buildings" such as play tents for children; forms inflatable with air or water to manufacture mattresses and portable swimming pools.

15 DISCARD AND RENEWAL OF PARTS

a) parts that have fulfilled their task and are no longer part of an object should be disposed of (dissolved, evaporated, etc.);
b) used parts of an object should be immediately replaced during work.

Ex. 15-1. Jet aircraft or rockets can be equipped with extra fuel containers for take-off that can then be discarded.
Ex. 15-2. Golf balls for golf on cruise ships are produced from a special material that is not harmful to fish and that quickly dissolves in water.
Ex. 15-3. A melting light conductor probe for research is inserted continuously into an area of extremely high temperature at the exact speed at which it melts.

16 PARTIAL OR EXCESS EFFECT

when it is difficult to achieve the desired effect completely, we should try to achieve a bit less or a bit more. This can make the task much easier.

Ex. 16-1. Dip parts in a colored bath and then remove the excess color and dry them by spinning them in a centrifuge.
Ex. 16-2. Some types of fruit and vegetables are harvested in an immature state to improve their longevity. They can reach their mature state while not connected to the parent plant. This makes transport during ripening and a longer shelf-life

17 USE OF COMPOSITE MATERIALS

move from homogeneous materials to combinations.

Ex. 17-1. The parts of an auto body consist of combinations of steel and aluminum, "steel-aluminum honey-comb" or perhaps even "steel-aluminum honey-comb-steel honey-comb", increased hardness is combined with high absorption of vibrations and low weight in a way that is not possible with other procedures.

18 MEDIATOR

a) use another object to transfer or transmit an action;
b) temporarily connect an object with another (easily separable) object.

Ex. 18-1. The steering mechanism for auto wheels includes a "transmission" - the servo-booster.
Ex. 18-2. The plates used in weight training in a fitness center are covered with rubber to reduce the sound of the weights falling to the floor.
Ex. 18-3. Areas of a printed circuit are protected against rays with a (sprayed or wax) material that can then later be easily removed.

19 TRANSITION INTO ANOTHER DIMENSION

a) an object is shaped so that it can move or is placed not only in a linear fashion, but also in two dimensions, meaning on a surface. It is also possible to improve the transition from a surface to a three-dimensional space;
b) do construction on several floors; tip or turn the object on its side; use the back of the space in question;
c) optical rays that strike a neighboring space or the back of the present space.

Ex. 19-1. Storage closets in large stores that are mounted directly below the sales floors; garages for boots with several floors and elevators.
Ex. 19-2. Drawing tables where the angle of the work surface is adjustable (see also navigator 07)
Ex. 19-3. Instructions or games (for advertising) on the inner side of packaging.

20 UNIVERSALITY

an object has several simultaneous functions so that other objects are not needed.

Ex.20-1. Universal bicycle wrench with openings for all necessary nut sizes;
Ex. 20-2. Universal station-wagon;
Ex. 20-3. Multi-functional music system.

21 TRANSFORM DAMAGE INTO USE

a) use damaging factors, especially damaging influences from the environment to achieve a useful effect;
b) eliminate a negative factor by combining it with other negative factors;
c) support the damaging factor until it is no longer causes damage.

Ex. 21-1. Rubber chunks are spread on asphalt that are made in a special process from old tires that would otherwise have to be stored somewhere. This increases the elasticity of the street surface and reduces both noise and the wear of auto tires, thereby slowing the process that creates old auto tires.
See navigator 11: A warming effect is increased while it is directed and localized.

22 SPHERICAL-SHAPE

a) change from linear parts of the objects to curved ones, from flat surfaces to spherical ones; from parts shaped like cubes or parallelepipeds to round structures;
b) use rollers, balls, and springs;
c) change to turning movements by using centrifugal force.

Ex. 22-1. Furniture for a play room without sharply-edged parts.
Ex. 22-2. A transport installation for construction parts that function "by themselves". They are then installed at various heights and are shaped like a spring with precise angles to prevent excessively high speeds when the parts run through the installation.
Ex. 22-3. Electrodes for spot welding shaped like rotating rollers are used to increase longevity.

23 USE OF INERT MEDIA

a) replace a normal medium with an inert one;
b) complete a process in a vacuum.

Ex. 23-1. Cotton is processed with an inert gas to reduce the danger of fire in storage.
Ex. 23-2. Processing silicon plates with a medium of inert gas; completion of various operations in a vacuum, for example, spraying with fumes in a vacuum, ion coatings, etc.

24 ASYMMETRY

a) move from a symmetrical shape of an object to an asymmetrical one;
b) increase the degree if the object is already asymmetrical.

Ex. 24-1. As opposed to other ships, aircraft carriers are asymmetric in the construction of their main deck. The landing strip is cantered to the take-off strip and the command center is to the side. Take-offs and landings can be done separately.
Ex. 24-2. The beam of the right headlight of a car is directed straight ahead, but the left beam is adjusted to the right.
Ex. 24-3. Children's books are often shaped asymmetrically with crooked angles at various corners and complicated construction to attract the attention of kids.

25 USE OF FLEXIBLE COVERS AND THIN FILMS

a) flexible covers and thin layers are used in place of the usual constructions;
b) isolate objects from the external world with flexible covers or thin layers.

Ex. 25-1. Thin-layer constructions in micro-electronics.
Ex. 25-2. Decorative galvanized, glued, or sprayed coverings shaped like a layer: to process mirrors and silverware from metal and other materials, to manufacture optical and automobile glass or layered protective glass, etc.
Ex. 25-3. Various green houses and covered gardens.

26 PHASE TRANSITIONS

full use of phenomena that occur during phase transitions such as a change in volume, radiation or absorption of warmth, etc.

Ex. 26-1. Construction of a heating pipe to transfer heat from a heated to a cold zone to be heated that evaporates the heat conductor at the end with a high temperature (heat absorption) and condenses this conductor at the end with a low temperature (heat radiation).
Ex. 26-2. Thin-walled plastic containers filled with ice cubes are laid in a transport container to temporarily cool heat-sensitive materials such as medicine or food during transport.

27 USE OF THERMAL EXPANSION

a) full use of the expansion (or reduction) of materials when heating them;
b) use of materials with different coefficients of heat expansion.

Ex. 27-1. Bi-metal plates from materials with different coefficients of heat expansion are used to open and close circuits when the control temperature rises or sinks.
Ex. 27-2. Construction of a green house roof out of pipes filled with a steaming liquid that are connected to each other with hinges. The balancing point of the pipes changes with external temperature changes so that the roof rises automatically when the temperature rises and sinks when the temperature falls.

28 PREVIOUSLY INSTALLED CUSHIONS

increase the relatively low security of an object with safety measures in advance.

Ex. 28-1. Airbags in automobiles; life boats, rings, and jackets, inflatable rafts, etc. on ships and in aircraft.
Ex. 28-2. Emergency exits with a "soft landing" for engine or brake failures on mountain roads.
Ex. 28-3. Fire extinguishers at easily accessible places in buildings that can be easily used with little or no preparation.

29 SELF-SERVICING

a) the object services itself with auxiliary and repair functions;
b) reuse waste (energy, material).

Ex. 29-1. A tire that automatically repairs small tears with an integrated ampoule filled with repair material.
Ex. 29-2. The heating of an automobile uses the heat given off by the running engine.

30 USE OF STRONG OXIDANTS

a) replace normal air with an enhanced stream;
b) replace an enhanced stream with oxygen;
c) influence air or oxygen with ionizing rays;
d) use of oxygen with ozone;
e) replace ionized or ozone-oxygen with ozone.

Ex. 30-1. Cut stainless steel with plasma arcs in pure oxygen.
Ex. 30-2. Quick and intensive processing of storage facilities and the fruit or vegetables stored there.

31 USE OF POROUS MATERIALS

a) make an object porous or use supplementary porous elements (inserts, coverings, etc.);
b) if the object already consists of a porous material, the pores can be filled with some kind of material in advance.

Ex. 31-1. Bearings, turbine blades, etc. are manufactured from porous materials where the pores are partially or completely filled with the lubricant or coolant needed.
Ex. 31-2. Different medical or cosmetic compresses, bandages, or masks, etc. that are soaked in disinfecting, pain-killing, healing, or vitamin-rich preparations.

32 COUNTER-WEIGHT

a) compensate for the weight of an object with its connection to another object with lifting power;
b) compensate for the weight of an object using interaction with the external environment (for example, with aerodynamic or hydrodynamic forces).

Ex. 32-1. Hot-air balloons, air ships, parachutes, ships, submarines; the patented idea of a house that is buoyant during floods - the cellar is shaped like a pontoon and filled with foam.
Ex. 32-2. Speed boats with hydrofoils.

33 QUICK JUMP

complete a process or some of its (damaging or dangerous) stages at high speed.

Ex. 33-1. In Ex. 40-2 navigator 40, a laser beam "jumps" over the photo pattern at high speed by moving from the previous ("exiting") mirror to the next ("arriving") one. Thus it never hits a point not desired in the photo pattern being produced.
Ex. 33-2. The apparatus for cutting elastic (from plastic or other materials) thin-walled pipes of large diameter cuts the walls so quickly that the material has no time to distort.

34 MATRYOSHKA (NESTED DOLL)

a) an object is inside another object that is also inside another, etc.;
b) an object runs through a hollow space in another object.

Ex. 34-1. Telescopic fishing; the retractable arm of the mechanism of lifts for automobiles.

35 UNITE

a) unite similar objects or objects for neighboring operations;
b) temporarily unite similar objects or objects for neighboring operations.

Ex. 35-1. Rocket motor systems out of 4, 6, 8 or more individual motors.
Ex. 35-2. Ocean and river-going ships that consist of different parts with and without motors. The parts can be fixed or connected to each other with hinges.

36 FEEDBACK

a) create a retroactive influence;
b) change a retroactive influence that already exists.

Ex. 36-1. A device that maintains a given speed continuously measures the true speed and adjusts the flow of fuel to the motor accordingly, just like an experienced driver.

37 EQUIPOTENTIALITY

change work conditions so that it is not necessary to lift or lower an object.

Ex. 37-1. Bath tub with handles on the sides to make it easier for elderly or immobile persons to get in and out (a system to drain the tub quickly is also sensible).
Ex. 37-2. "Bridges" that connect buildings or several floors with each other.

38 HOMOGENEITY

objects that interact with the object in question must be made from the same material (or from one with similar properties).

Ex. 38-1. The contacts inside micro-electronic circuits are connected with conductors from the same material, mostly from gold.
Ex. 38-2. Gears that interact with each other to transmit power are usually manufactured from the same material to avoid uneven wear.

39 PRELIMINARY COUNTER-ACTION

if the conditions of a task require an action, then a opposite action should be taken in advance.

Ex. 39-1. Pre-formed steel-reinforced concrete: make the concrete function better by "shortening" it with a press so that it can then be stretched.
Ex. 39-2. Railroad beds are tilted to the side in curves in the opposite direction to the centrifugal forces released.

40 UNINTERRUPTED USEFUL FUNCTION

a) complete a job without interruptions where all parts work continuously at full capacity;
b) eliminate idle running and interruptions.

Ex. 40-1. The method by which a laser beam creates a "drawing" on a photo pattern by moving back and forth (the "moving" mirror).
Ex. 40-2. The method by which a laser beam creates a "drawing" on a photo pattern with rays that only move straight ahead. There are no transitions or interruptions because the beam is reflected by another mirror that takes over from the previous one (the "rotating" mirror).

Appendix 5

TABLE

Fundamental Transformations

#	term	content	example
01	separation in space	One property is realized in one area of space, the opposite property takes place in another area.	Ways that overlap lay at different levels - one is higher than the other.
02	separation in time	One property is realized in interval of time, the opposite property takes place in another interval.	Work of a traffic light at a crossroads
03	separation in structure	One part of a system has one property while the entire system has another one.	A flexible bicycle chain consists of fixed elements.
04	separation in material (energy)	A material or energy field (or its parts) has one property for one goal and another for another goal.	Water (*liquid*) is frozen in a pipe to create a temporary plug (*fixed*) for its repair.

Appendix 6

TABLE

Fundamental Transformations

and A-Compact -Standards

Basic Model	Expanded Transformations	Example
1 separation in space	**1.1.** separation of conflicting properties **in space**	**Ex. 1.** Water drops should be small to prevent dust formations in mines. But, small drops create mist. Our proposal is to surround the small drops with cones made of large drops.
2 separation in time	**2.1.** separation of conflicting properties **in time**	**Ex. 2 (standard S2 - 2.2.3*).** The width of a flat electrode is adjusted in accordance with the width of a welded seam.
3 separation in structure	**3.1. system transition 1-a:** unification of similar systems into a super-system	**Ex. 3 (standard S4 - 3.1.1).** Poured pieces (hot metal blocks) are transported next to each other on roller belts so that the sides don't cool.
	3.2. system transition 1-b: from the system into an anti-system or the connection of the system with an anti-system	**Ex. 4 (standard S4 - 3.1.3).** A method to coagulate blood is to apply a compress to a wound that has been soaked in blood from another blood type.
	3.3. system transition 1-c: the entire system is equipped with the property C, but its parts with the property anti-C.	**Ex. 5 (standard S5 - 3.1.5).** supporting parts of vises to press construction parts together with a complicated shape: every part (a steel form) is fixed, but the shape of the pressure applied can be adjusted.
	3.4. system transition 2: transition to a system that functions at a micro-level	**Ex. 6 (standard S5 - 3.2.1).** Instead of a mechanical crane, a "thermo-crane" is used that consists of two materials with different coefficients of linear expansion. Heating produces an open slot.

* The numbers of the compact standards (i.e., S2) as well as the numbers of standards in the complete TRIZ-catalogue (i.e., 2.2.3.) are included in parentheses.

4 separation in material (energy)	**4.1. phase transition 1:** change in the phase state of a part of the system or the environment	**Ex. 7 (standard S2 - 5.3.1).** procedure to provide gas to a mine - Reduced gas is transported.
	4.2. phase transition 2: "double state" of a part of the system (transition of this part of the system from one state into another in accordance with the functioning conditions)	**Ex. 8 (standard S2 - 5.3.2).** Heat exchangers have blades out of nickel-titanium (a material that can maintain shapes). To raise the temperature, the blades are extended to increase the cooling surface.
	4.3. phase transition 3: full use of phenomena that accompany the phase transition	**Ex. 9 (standard S2 - 5.3.3).** devices to transport frozen goods have support elements shaped like ice chunks (reduced friction with melting ice)
	4.4. phase transition 4: replace a material with one phase with another one with two phases	**Ex. 10 (standards S2 - 5.3.4 and 5.3.5).** polishing procedure: The working material consists of a liquid (molten lead) and ferric-magnetic abrasive particles.
	4.5. physical-chemical transition: development and disappearance of a material using disassembly, combination, ionization - recombination	**Ex. 11 (standards S1 - 5.5.1 and 5.5.2).** make wood more flexible (increase in elasticity and malleability in processing). The wood is dipped in ammonium to soak it with ammonium salts that friction then dissolves.

Appendix 7

TABLE

Fundamental Transformations and Specialized A-navigators

principle of transformation	connection to A-navigators
1 separation of the conflicting properties in space	**05 separation:** remove the disruptive part, emphasize the part needed. **10 copying:** use of simplified and inexpensive copies. **19 transition into another dimension:** increase the freedom of an object, use construction in several layers, use lateral and other surfaces. **22 spherical-shape:** transition to curved surfaces and shapes, use of wheels, balls, or springs. **24 asymmetry:** transition to asymmetrical shapes, increase asymmetry. **25 use of flexible covers and thin films:** use flexible covers and thin films instead of normal constructions. **34 matryoshka:** store an object in another one in stages, place an object in the hollow space of another one.
2 separation of the conflicting properties in time	**02 preliminary action:** run the necessary effect partially or completely; arrange the objects so that they can go to work faster. **07 dynamization:** make an object (or its parts) moveable, optimize the characteristics of the process (of an object) in every stage. **08 periodic action:** transition from a continuous effect to a periodic one, change the periodicity, interruptions in the effect. **18b mediator:** connect an object with another (easily removable) one for a specific time. **28 previously installed cushion:** consider possible disruptions in advance. **33 quick jump:** accelerate a process strongly so that damages don't even appear. **35b unite:** temporally unite similar or neighboring operations with each other. **39 preliminary counter-action:** an opposite effect must be completed in advance to run the primary effect. **40 uninterrupted useful function:** eliminate idle time and interruptions so that all parts of an object function at full capacity.

3 separation of the conflicting properties in structure	**03 separation:** disassemble an object into its parts, increase the degree of "disassembly". **11 inverse action:** take the opposite action from the one that is apparently given by the conditions at hand. **12 local property:** transition from a similar to a different structure so that every part can complete its function under the best condition. **15 discard and renewal of parts:** a used-up part can be disposed of or regenerated during its function. **18a mediator:** use a part to transmit an action. **35a unite:** temporarily unite similar objects or objects for neighboring operations with each other.
4 separation of the conflicting properties in material	**01 change in the aggregate state of an object:** change the concentration or consistency, full use of properties like the elasticity of materials, etc. **17 use of composite materials:** transition from similar materials to those consisting of several components. **23 use of inert media:** replace a medium with something inert. Let processes run in a vacuum. **26 phase transitions:** full use of phenomena that occur during phase transitions: changes in volume, in the radiation or absorption of heat. **27 full use of thermal expansion:** full use of the heat expansion of materials, the use of materials with different heat expansion. **29b self-servicing:** use of the waste of material and energy. **30 use of strong oxidants:** replace air with oxygen, influence air with ion beams, use of ozone. **31 use of porous materials:** shape an object in a porous way, fill porous parts with some kind of material. **38 homogeneity:** manufacture objects that influence each other from one and the same material.

Appendix 8

A-TABLE Physical Effects

#	required effect, property	physical phenomenon, effect, method
1	temperature measurement	Thermal expansion and changes it causes in the frequency of vibrations, thermal-electrical phenomena, radiation spectrum, changes in the optical - electromagnetic properties of materials, exceed the Courie point, Hopkinson's effect, Barkhausen's effect, radiation of warmth
2	reduce temperature	Thermal conduction, convection, radiation, phase transitions, Joule-Thompson effect, Ranke effect, magneto-caloric effect, thermal-electrical phenomena
3	raise temperature	Thermal conduction, convection, radiation, electro-magnetic induction, dielectric warming, electronic warming, electrical discharges, absorption of radiation by material, thermal-electrical phenomena, shrinking of an object, nuclear reaction.
4	stabilize temperature	Phase transitions (for example, exceeding the Courie point), thermal isolation.
5	indication of the condition and location of an object	Introduction of markings - materials that reshape external fields (luminophores) or create their own fields (ferro-magnets) and are therefore easy to recognize, reflection or radiation of light, photo effect, reshaping, X-rays or radioactive rays, electrical discharges, Doppler effect, interference.
6	control of a change in position of the object	Use a magnet to influence an object or a ferro-magnet that is connected to the object., use a magnetic field to influence a loaded or electrified object, transfer of pressure using liquids or gases, mechanical vibrations, centrifugal forces, thermal expansion, light pressure, piezo-effect, Magnus effect.
7	control of the movement of a liquid or a gas	Capillarity, osmosis, electro-osmosis, Thomson effect, Bernoulli effect, movement in waves, centrifugal forces, Weissenberg effect, introduce gas into a liquid, Coanda effect.
8	control of the flow of aerosols (dust, smoke, mist)	Electrify, electrical and magnetic fields, light pressure, condensation, sound waves, infra sound.

9	thorough mix of mixtures	Creation of solutions, ultra-high frequency sound, cavitation, diffusion, electrical fields, magnetic fields in connection with a ferro-magnetic material, electrophores, resonance.
10	separation of mixtures	Electro- and magnetic separation, changes in the apparent thickness of a boundary liquid using electrical or magnetic fields, centrifugal forces, phase transitions, diffusion, osmosis.
11	stabilize the position of an object	Electrical and magnetic fields, fix objects in liquids that become solid in magnetic and electrical fields, hygroscopic effect, reactive movement, reshaping, melting, diffusion melting, phase transitions.
12	influence of force, regulation of force, creation of high pressure.	Influence of a magnetic field using ferro-magnetic material, phase transitions, thermal expansion, centrifugal forces, changes in the apparent thickness of a magnetic or electrically conducting liquid within a magnetic field.
13	change in friction	Johnson-Rabeck effect, influence of radiation, Kragelski phenomenon, vibrations, influence of a magnetic field with ferro-magnetic particles, phase transitions, super-fluidity, electro-osmosis.
14	destruction of an object	Electrical discharges, electro-hydraulic effect, resonance, ultra-high frequency sound, cavitation, induced radiation, phase transitions, thermal expansion, explosion..
15	accumulation of mechanical and thermal energy	Elastic reshaping, swing wheels, phase transitions, hydrostatic pressure, thermal-electrical phenomena
16	transmission of mechanical, thermal, radiation, and electrical energy	Reshaping, vibrations, Alexandrov effect, wave movement, including thrusting waves, radiation, thermal conductivity, convection, light reflectivity (light conductor), induced radiation, Seebeck effect, electro-magnetic induction, super conductivity, transformation of energy from one form into another that is better for transmission, infra-sound, effect of saving a shape
17	creation of interaction between the moveable (changeable) and fixed (unchangeable) object	Use of electro-magnetic fields to move from „material“ to „field“ connections, full use of the flow of liquids and gases, effect of saving a shape.
18	order of the size of objects	Size of the frequency of vibrations, transfer and reading of magnetic and electrical parameters, holography.

19	Changes in the size and shape of objects	Thermal expansion, bi-metal constructions, reshaping, magnetic- electrostriction, piezo-electrical effect, phase transitions, effect of saving a shape.
20	Control the state and properties of objects in space and on the surface	Electrical discharges, reflection of light, emission of electrons, moire effect, radiation, holography.
21	Changes in surface properties	Friction, adsorption, diffusion, Bauschinger effect, electrical discharges, mechanical and acoustic vibrations, irradiation, solidification, thermal processing.
22	Control the state and properties of an object in space	Installation of markings - from materials that transform external fields (luminophores) or that create their own field (ferromagnets) - that are dependent on the state and properties of the object to be investigated, changes in the specific electrical resistance in accordance with changes in the structure and properties of an object, absorb, reflect, split light, electro-optical and magneto-optical phenomena, polarized light, X-rays and radioactive rays, electronic paramagnetic and nuclear-magnetic resonance, magneto-flexible effect, exceeding the Courie point, Hopkinson and Barkhausen effect, measuring an object's own vibrations, ultra-high frequency and infra-sound, Mossbauer effect, Hall effect, holography, acoustic emission.
23	Changes in the spatial properties of an object	Change in the properties of a liquid (thickness, viscosity) using electrical and magnetic fields, introduction of ferro-magnetic particles and the effect of a magnetic field, thermal effect, phase transitions, ionization and the effect of an electrical field, ultraviolet rays, X-rays, and radioactive rays, diffusion, electrical and magnetic fields, Bauschinger effect, thermal-electrical, thermal-magnetic and magneto-optical effects, cavitation, photo-chromatic effect, internal photo effect, „displacement" of liquids using gas, foaming, high frequency radiation.
24	Create the given structure. Stabilize the structure of an object	Interference of waves, diffraction, stationary waves, moire effect, magnetic and electrical fields, phase transitions, mechanical and acoustic vibrations, cavitation.

25	Display of electrical and magnetic fields	Osmosis, electrification of objects, electrical discharges, discharges, piezo-electrical effects, electretes, electron emission, electro-optical phenomena, Hopkinson and Barkhausen effect, Hall effect, nuclear-magnetic resonance, hydro-magnetic and magneto-optical phenomena, electro-luminescence, ferromagnetism.
26	Display of radiatioin	Optical-acoustic effect, thermal expansion, photo-plastic effect, electrical discharges.
27	Generation of electromagnetic radiation	Josephson effect, phenomenon of induced radiation, tunnel effect, luminescence, Hanne effect, Cerenkov effect, Zeemann effect.
28	Control of electromagnetic fields	Protection, changes in the state of the environment, for example, increase or reduce its electrical conductivity, changes in the surface shape of objects that interact with fields, Pinch effect.
29	Control of light beam, modulation of light	Break and reflect light, electro and magneto-optical phenomena, photo flexibility, Kerr and Faraday effect, Hanne effect, Franz-Keldysh-effect, transformation of a light beam into an electrical signal and back, stimulated radiation.
30	Start and intensify chemical transformations	Ultra-high frequency sound, infra-sound, cavitation, ultra-violet rays, X-rays, and radioactive rays, electrical discharges, reshaping, thrusting waves, catalyzation, heating.
31	Analysis of the composition of objects	Sorption, osmosis, electrical fields, radiation effect, analysis of the radiation reflected from objects, optical-acustic effect, Mossbauer effect, electronic para-magnetic and nuclear-magnetic resonance, polarized light.

Appendix 9 A-Table Chemical Effects

#	Necessary effect, property	Property, chemical effect, phenomenon, reactive material types
1	Temperature measurement	Thermo-chromatic reactions, movement of the chemical balance with temperature changes, chemical luminescence.
2	Reduce temperature	Endothermic reactions, dissolve materials, split gases.
3	Raise temperature	Exothermic reactions, burning, high-temperature synthesis that propagates itself, use of strong oxidants, use of thermite mixtures.
4	Stabilize temperature	Use of metallic hydrates, application of thermal isolation from foam polymers.
5	Proof of the condition and changes in the condition of an object	Use of markings based on colored materials, chemical luminescence, reactions with released gases.
6	Control of changes in the condition of an object	Reactions with released gases, burning, explosion, use of materials active on the surface, electrolysis.
7	Control of the movement of liquids and gases	Use of diaphragms, transport reactions, reactions with released gases, explosion, use of hydrides.
8	Control of aerosol streams and suspensions	Spray materials that interact chemically with aerosol particles, means of reduction.
9	Mix of mixtures	Mixtures from materials that don't react chemically with each other, synergistic effect, release, transport reactions, oxidation-deoxidization reactions, chemical bonding of gases, use of hydrates and hydrides, use of complex builders.
10	Separation of a material	Electrolysis, transport reactions, deoxidization (reduction) reactions, release of chemically bonded gases, movement of the chemical balance, removal of hydrides and adsorbers, use of complex builders, use of diaphragms, movement of one of the components into another state, including phase states.
11	Stabilization of the condition of an object	Reactions of polymerization (use of glues, liquid glass, self-hardening synthetic materials), use of helium, use of materials active on the surface, dissolving bonds.

12	Influence of force, regulation of forces, production of high and low pressure.	Explosion, split gas hydrates and hydrides, sources of metal while absorbing hydrogen, reactions with released gases, polymerization reactions.
13	Changes in friction	Removal of a metal from a bond, electrolysis with released gases, use of materials active on the surface and polymer layers, hydration.
14	Destruction of an object	Dissolve, oxidation-deoxidization reactions, burning, explosion, photo and electro-chemical reactions, transport reactions, reduction of material to its components, hydrate, movement of the chemical balance in mixtures.
15	Accumulation of mechanical, thermal, and electrical energy	Exothermic and endothermic reactions, dissolving, reduction of material to its components (for storage), phase transitions, electro-chemical reactions, chemical-mechanical effect
16	Energy transfer	Exothermic and endothermic reactions, dissolving, chemical luminescence, transport reactions, hydrides, electro-chemical reactions, transformation of energy from one form to another one more appropriate for a transfer.
17	Creation of interaction between moveable and fixed objects	Mix, transport reactions, movement of the chemical balance, hydrate, self-clustering molecules, chemical luminescence, electrolysis, self-propagating high temperature synthesis.
18	Measuring the size of an object	In accordance with the speed and duration of interaction with the environment.
19	Changes in the size and shape of an object	Transport reactions, use of hydrides and hydrates, dissolving (also to reduced gases), explosion, oxidation reactions, burning, movement to a chemically bonded form, electrolysis, use of elastic and plastic materials.
20	Control of the state and properties of surfaces	Radical recombination luminescence, use of hydrophilic and hydrophobic materials, oxidation-deoxidization reactions, use of photo, electrical, and thermal chromes.
21	Changes in surface properties	Transport reactions, use of hydrides and hydrates, application of photo chromes, use of materials active on the surface, self-clustering molecules, electrolysis, etching, exchange reactions, use of lacquers.

22	Control of the state and properties of an object in space	Reaction with the use of materials with a color reaction or indicator materials, chemical reactions with light measurement, production of helium.
23	Changes in the spatial properties of an object (heavy concentration)	Chemical reactions that lead to changes in the properties of a material of which an object consists (oxidation, reduction reactions, exchange reactions), transport reaction, movement into a chemically bonded form, hydrate, dissolve, weaken a solution, burning, use of helium.
24	Production of the given structure, stabilize the structure of an object.	Electro-chemical reactions, transport reactions, gas hydrates and hydrides, self-clustering molecules, complex molecules.
25	Proof of electrical fields	Electrolysis, electro-chemical (including electro-chromic) reactions
26	Proof of electro-magnetic radiation	Photo, thermo, and radio-chemical reactions (including photo, thermo, and radio-chromic reactions).
27	Generate electro-magnetic radiation	Burning reactions, chemical luminescence, chemical reactions in gases - in the active area of lasers, luminescence, bio-luminescence.
28	Control of electro-magnetic fields	Dissolving with the production of electrolytes, production of metals from oxides and salts, electrolysis.
29	Control of light beams, modulate light	Photo-chromic reactions, electro-chemical reactions, reactions of reversible electro-sedimentation, periodic reaction, burning reactions.
30	Production and intensification of chemical transformations	Catalyzing, use of stronger oxidants, deoxidizers, stimulation of molecules, sharing the products of a reaction, use of magnetized water.
31	Analysis of the construction of an object	Oxidation-deoxidization reactions, use of indicator materials.
32	Dehydrate	Movement into a hydrated state, hydrate, use of molecular membranes.
33	Changes in a phase state	Splitting, chemical bonding of gases, separate (remove) from solutions, reactions with released gases, use of helium, burning, dissolving.
34	Postpone and prevent chemical transformations	Inhibitors, use of inert gases, use of protector materials, changes in surface properties (see also *changes in surface properties*)

Appendix 10

A-Table Geometric Effects

#	Necessary effect, property	Geometric effect
1	Decrease or increase in the scope of an object	Compact packaging of elements, compression, single-shell hyperboloid.
2	Decrease or increase the surface of length of an object without changes in mass	Construction with several floors, use of geometric shapes with flexible outlines, Mobius tape, use neighboring surfaces.
3	Transformation of one way to move into another one	Releau triangle, cone-shaped ram, crank-cam propulsion.
4	Concentration of the flow of energy, particles	Paraboloids, ellipses, cycloids.
5	Intensify a process	Transition from a linear process to a process on the entire surface, Mobius book, eccentricity, compression, screwing, brushing.
6	Decrease material and energy losses	Compression, changes in the cutting surface of the work place, Mobius tape.
7	Increase the precision of the process	Special choice of the shape or path of the movement of the processing instrument, brushing.
8	Increase the controllability	Brushing, balls, hyperboloids, spirals, triangles, use of shape-changing objects, transition from a linear movement to a rotating one, screw mechanism without an axis.
9	Decrease the controllability	Eccentricity, replace round objects with ones with multiple angles.
10	Increase the life, reliability of an object	Balls, Mobius tape, changes in the contact surface, special choice of the shape.
11	Reduce effort	Principle of analogies, diagram with the correct perspective, hyperboloid, use of a combination of simple geometric shapes.

ANSWERS AND SOLUTIONS

Exercises 3 - 5

1. A sound portrait. Here the combination of physical (reflection of sounds) and geometric effects was used. A cave is shaped like a regular ellipse, or spatially like a honey-dew melon. The sound of hands clapping or yells are therefore reflected several times from the walls and ceiling into one of the centers of the ellipse where they can be heard repeatedly for a long time. These 10 echoes are reminiscent of a running herd. Soft sounds come back as "the answer of the ancestors" that are painted on the walls.

2. The lighthouse at Alexandria. The builder hid his name under a thick layer of stucco that naturally crumbled with time (resources of time, material and space – see navigator 34 *matryoshka*).

3. The puzzle of the pyramids. A physical effect (liquids are "level" in relatively small hollow spaces such as grooves, tubes, and trenches) and effects of geometric similarity were used.

a) Let's assume that a trench was dug and then filled with water when the foundation of the pyramid to be built was measured. The builders could check how level the site was by observing the tilt of the water's surface in relationship to the edges of the trench.

b) This answer is well known. Based on the principle of similarity, the height of a pyramid was measured using the height of a vertical marking staff in the very moment when the height of the staff was the same as the length of its shadow. At that moment the length of the pyramid's shadow was also the same as its height.

c) The property of a straight line could have been used. Two staffs could be set up from two sides so that a third staff is installed in the middle of the surface as a third point that lies on two lines laid out at 90° to each other on which two staffs and the middle staff stand respectively. As the pyramid gets larger, the builders needed only to check the condition of the middle staff that raised along with the upper level of the construction.

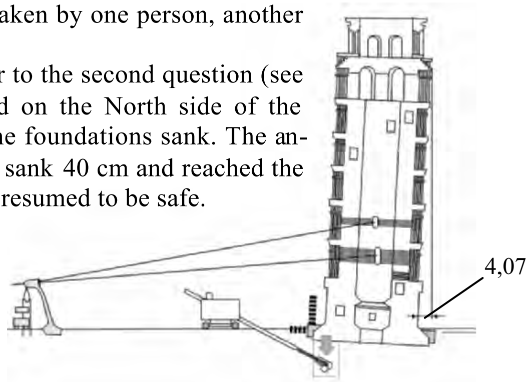
d) There are two hypotheses that are based on one and the same effect. This is a pile of sand that is carefully poured from the upper tip like a fixed body that seems to flow has the shape of a regular cone with sides tipped at approximately 52°. It would now be possible to use the middle staff as a symmetry check to pour a sufficiently high sand cone and check both the symmetry and angle of the edges during construction. According to the second hypothesis, pyramids were built with a sand cone in the middle that reached the upper tip of the respective pyramid. After the cone reached gigantic proportions, it was surrounded with blocks (that can also be seen externally) and solid rooms and halls were built with blocks in the cone.

4. The ambassador Ismenius. The ambassador dropped a ring from his finger on purpose and bent down to retrieve it. The contradiction was solved in its structure (action): externally the same actions were taken, but the content was different.

5. The crowning of these emperors. Charlemagne took the crown from the Pope and set it on his head himself. Napoleon did the same.

The contradiction was solved in time and space - one part of the action (the crowning) was taken by one person, another part by another person.

6. The tower of Pizza, answer to the second question (see diagram): 12 holes were bored on the North side of the foundations of the tower and the foundations sank. The angle of the 7th floor of the tower sank 40 cm and reached the value of 4.07 m, which is now presumed to be safe.



Exercises 6 – 9

7. Ice cubes. This is ideal functional modeling. They are shaped like inverted cones with slightly angled edges so that the ice "squeezes itself out" when it swells. A stronger effect is caused by the flexible floor of the form that is also filled with water that them squeezes the cubes up while freezing. The procedures and standards are connected to the phase transition.

8. Aggressive liquid. Ideal final result: an aggressive liquid is poured into a container consisting of the material to be investigated (navigator 11 *inverse action*).

9. Candle cover. The cover is fastened to a wire holder with the shape of a tube underneath that is directly placed on the upper part of the candle. The holder with its cover sinks in direct proportion to the way the candle burns (navigators 5, 6, 21 and 29).

10. Kremlin star. The turning axle of the star is installed so that the star functions like a weather vane. The stronger the wind, the steadier the star points towards it (navigators 21 *transform damage into use* and 29 *self-servicing*).

11. Tea pot. A container for tea leaves is built into the lower front part of the pot (see figure). Solution to the contradiction in space and structure.

12. Toy. Inflatable, movable toy. Solution to the contradiction in time, space, and structure.

13. Transition to the beach. Straw and dry grass can be used to prevent sand from being carried on shoes onto the promenade. Navigators 18 *mediator*, 28 *previously installed cushion* and 31 *use of porous materials*.

14. Training for drivers. The answer is in section 12.3, ex. 79.

15. Subway trains. The train has fewer cars – solution to the contradiction in structure and space.

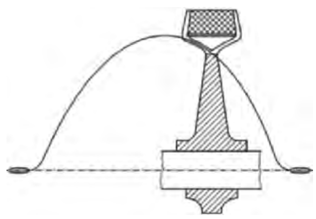
16. Guy de Maupassant and Gustave Eiffel's tower. You can hide in a part of the whole so you don't see the whole. Navigator 34 *matryoshka*, but primarily – solution to the contradiction in structure and space.

17. Direction of a liquid's movement in pipes. Heat a point in the pipe close to the damaged section and next to that measure the temperature of the pipe. If the temperature rises, you know that the water is flowing from the heat towards the spot being measured. If the water temperature doesn't change, it's flowing in the other direction. Solution to the contradiction in material and time.
18. Shelves in a shoe store. Individual cartons are pulled out and play the role of shelves. Navigators 5, 12, 13, 19 and 24.

Exercises 10 – 13

19. Advertizing poster (1). The firm 3M added glass micro-balls to the glue layer so that the poster can be easily readjusted until it's pressed onto a surface. Solution to a contradiction in material and in structure. The complex standard for the introduction of supplements and principles for the integration of alternative systems was use.
20. Advertizing poster (2). The poster is manufactured from a perforated material. From the back side, you can see everything on the other side if your eyes are close to the perforations. Solution to a contradiction in structure and in material. A side effect can be seen in areas with hot weather – the poster protects surfaces from the sun.
21. Any pan - Teflon layer! Navigator 18 *mediator*: the firm Dupont manufactures skins with a Teflon layer that can be placed in pans and containers and used several times.
22. Door bell. Navigators 4, 5, 10 and 12: a miniature sound maker with a radio receiver is used that fits into your pocket. The door bell gives off a radio signal that causes the pocket "bell" to ring. The next task is to adjust the bell so that only it rings when someone is at this door and not the pocket bells in other apartments.
23. Tire wear. The firm Michelin (France) manufactures colored auto tires that could certainly become fashionable. An analogous procedure based on several technical effects such as the chemical effect 22 is to manufacture tires with a signal layer in another color that appears when the outer layer is worn away.
24. Neutralization of exhaust gases from a cold engine. SAAB (Sweden) has manufactured an experimental car with a container in the trunk that collects exhaust gases for a set time after the engine is started. These gases are then passed on to the catalytic converter after the engine has warmed up. Chemical effect 10 *Separation of material* together with the navigators 5 *separation* and 39 *preliminary counter-action*.
25. Heating clothes. The firm Gateway Technologies has developed a material containing micro-capsules the polyethylene glycol. At freezing temperatures, the material gives off a part of the heat that was stored when it was in a warm room. Complex standard for the introduction of supplements and technical effects that are connected with phase transitions such as physical effect 4 *Stabilization of the temperature*.
26. Micro-tweezers. Use of material that saves its shape as in the physical effects 6 and 12.

27. How do eagles and hawks live? Physical effect 17 and navigator 18 *mediator*: today it can be done simply and effectively by installing miniature cameras with a nuclear power source for observation.
28. White light diode. Researchers at the Institute for Applied Solid-state Physics in Freiburg (Germany) have introduced several micro-grams of a luminescent colored material into the transparent lens-shaped body of a blue light diode. The material soaks up the blue rays of the gallium nitrite and the diode is white. Chemical effect 27 etc.
29. Mirror for a telescope. The slow rotation of a 45 ton molten mass in a special die produced a parabolic rotation body. Here the firm Schott in Germany used several geometric effects such as effect 8 *Increase in controllability* and also the physical effect 6 *Control of the movement of objects*.
30. Freezing berries and fruit. Freezing is done with a stream of extremely cold (pseudo-frozen) air. The products freeze before they come into contact with the moving line so that they don't freeze together. Navigator 33 *Quick jump* and physical effects from group 2 *Reduction in temperature* and group 6 *Control of the movement of objects* are used in a new facility developed in St. Petersburg in Russia.
31. Standing tooth brush. See ex. 41 in section 9.2 *Functional ideal modeling*.
32. Training mountain climbers. Scientists at the University of Potsdam have developed a special wall with a rotating disc with recesses to support hands and feet. The turning axle of the disc can also change its position. Navigators 7, 10, 19, 20 and 22.
33. Super-swing wheel. The solution is based on a special physical effect.



Constructions shaped in a static state like a "frozen" dynamic surface with special properties behave in a dynamic state under stress like elastic objects.
The surface of the mount has a curve analogous to the line of the greatest tension of a spinning jump rope. This was the basis for the development of a center by a team at the Moscow Aeronautical Institute (MAI) under the direction of Professor Guliya that builds super-swing wheels and drives.
34. Testing lines. At SIEMENS in Germany, a part of a conductor from a contact line was shaped into a ring with a diameter of 3 meters and mounted on a disc that is turned by a controlled electric drive. New power contacts and processes of radio and electromagnetic radiation are tested and investigated with this facility. Navigators 7, 10, 11 and 22 together with the physical effects 17, 20 etc.

Exercises 14 – 15

All of these tasks seem to be prognoses and none of them had control answers at the time of publication.

Exercises 16 - 17

44. Tempering basin. Derive the solution to the three assignments from example 113. Use the formulations from that example (step 10 at the end of section 16.2). Control solution: installation of a layer of carbon dioxide in the basin.

Find answers to the other questions ***45-48*** yourself.

Exercises 18 – 19

49. See what's "invisible". A copy of a bunch of X-rays shaped like harmless visible light rays is projected onto a body. This radiated light is used before the X-ray machine is turned on (navigators 09 and 10).
50. Allow the "impossible". Here we won't influence your search with our control ideas.
51. Understand the "inexplicable". Again, find the solution yourself.

INDEX

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Some books by G. Altshuller are now translated in English and could be found at Amazon etc.

You could find the works of other authors with help of Internet searching machines by key word "TRIZ books" or similar.

ADDITIONAL SOURCES OF INFORMATION

www.triz-journal.com

Michael Orloff's main website:
www.modern-triz-academy.com