Proceedings of the

TRIZ-Future Conference 2008

"Synthesis in Innovation"

Organised by

ETRIA; The European TRIZ Association

The University of Twente, Enschede, The Netherlands

Edited by

Tom Vaneker

Eric Lutters

ISBN 978-90-365-2749-1

Layout: Tom Vaneker
Cover layout: Winnie Dankers
Printed by Printpartners Ipskamp
The Netherands

TRIZ FUTURE 2008 – SYNTHESIS IN INNOVATION

Fred van Houten
University of Twente, Netherlands

Dear conference attendants

In my role as head of the local organizing team I have the honor to be your host for the TRIZfuture'08 conference. We are very happy that you accepted our invitation to come to Twente and to take part in the tutorials and to contribute to the conference by presenting papers and listening to each other.

With great pleasure we welcome you at the University of Twente, an entrepreneurial research university. It was founded in 1961 and offers education and research in areas ranging from engineering to public policy studies and applied physics to biomedical technology. The UT is the Netherlands' only campus university.

The Faculty of Engineering Technology is responsible for the bachelor/master programs in Mechanical Engineering, Industrial Design Engineering and Civil Engineering. The research programs of the Engineering departments are clustered in University Research Institutes.

The department of Design, Production and Management is one of the largest research groups of the university. It teaches design and manufacturing topics to Engineering Technology students but also to students of several other educational programs. The Design Engineering group specifically teaches, studies and develops design methods and tools. Since several years TRIZ is taught at regular design courses in the bachelors programs and is practiced by the students during their projects and assignments. According to our experience TRIZ is a very helpful method to increase the success rate in finding innovative solutions for engineering problems. The TRIZ way of thinking appears to be very appealing to our students.

From our research point of view the TRIZ theory is particularly useful in the area of design synthesis and systems engineering, which are both important topics for the Design Engineering Group. Integrating elements from TRIZ theory into future design support systems like Smart Synthesis Tools offers challenging perspectives.

It is a great pleasure to host so many experts from the world wide TRIZ community. We sincerely hope that this conference meets your expectations and that you enjoy the (academic and informal) atmosphere.

On behalf of the local organizing committee

Prof. Dr. Ir. Fred J.A.M. van Houten

ETRIA TRIZ FUTURE CONFERENCE 2008 – ONE MORE STEP AHEAD

Gaetano Cascini
Polytechnic of Milan, Italy
President of the European TRIZ Association

In a world evolving at growing speed and with dramatic consequences on the society and the environment, finding "inventive" solutions is a mandatory challenge for administrators, managers, technicians and educators.

TRIZ, the Theory of Inventive Problem Solving, for those who know its tremendous potentialities and large versatility, clearly appears as a valuable resource to face these emerging challenges, thanks to its powerful instruments and methods; besides, apart big multinational companies and a small number of pioneer SMEs and universities, TRIZ knowledge is still poorly diffused around the World and indeed Europe is playing the role of the follower compared to North America and the Far East.
If the World needs inventive answers to its tough demands and TRIZ is so effective, why its dissemination is still limited and what should be done to improve it?
The history of TRIZ is marked by the huge "revolutionary" efforts of Genrich Altshuller and all the people who contributed to its development and education: it is well known that especially in the soviet era academia and established scientific societies poorly supported TRIZ dissemination; somehow this "clandestine" nature has characterized the way TRIZ has been spread outside the former Soviet Union and has impacted the contents actually known as Classical TRIZ in the rest of the World.
Indeed, the lack of a clear scientific foundation and its related formalisms, the abuse of self-referencing evaluation systems, as well as some contradictory presentations of Classical TRIZ, contribute increasing the length of the TRIZ learning process and most of all limit the number of people adopting TRIZ in their everyday activities.
In this context, ETRIA, the European TRIZ Association, founded in 2001 to connect individuals, private and public organizations interested in the development, education and dissemination of TRIZ, is dedicating major resources to its proper acknowledgment.
Such a goal requires continuous improvements of the TRIZ Future Conference, the annual meeting of ETRIA members, as well as transparent and rigorous review procedures aligned to the standards of the most acknowledged scientific communities.
This strategy reflects a twofold goal: improving TRIZ visibility in other communities and increasing quality and scientific reliability of our papers and presentations.

The joined efforts of ETRIA board members and all the organizers of previous and present editions of the TRIZ Future Conference have determined a progressive recognition of ETRIA as a reliable partner for contributing to the creation and dissemination of new knowledge in the worldwide engineering society. This year, for the first time in the world, an event of the TRIZ community has been formally recognized by the scientific society and the ETRIA's annual meeting has been accredited as one of the CIRP official conferences (CIRP is the world leading organization in production engineering research and is at the forefront of design, optimization, control and management of processes, machines and systems).
According to the suggestions provided by ETRIA members during the last edition of the conference, the number of papers selected for an oral presentations has been slightly reduced to leave more time for questions and debate. As usual, the conference program is enriched by complementary tutorials and valuable keynotes from industry and academy.
On behalf of ETRIA, I wish a pleasant and successful participation to the conference to all the speakers and attendees and I invite everybody to dedicate the proper efforts for a scientifically sound and professionally effective dissemination, application and implementation of TRIZ.

EVOLVING TRIZ

Valeri Souchkov
ICG Training & Consulting
Co-founder of the European TRIZ Association ETRIA

To me personally, the 8th edition of the ETRIA TRIZ Future conference hosted this year by the University of Twente in the Netherlands is very important and has a symbolic meaning. 15 years ago, in 1993, I arrived at the University of Twente to launch a research project on formalization of TRIZ knowledge. Probably it was the first officially funded (by the Dutch Scientific Organization, NWO) scientific TRIZ project outside the former Soviet Union. At that time, almost no one heard about TRIZ except Russian TRIZ community. When I was introducing TRIZ to engineers and scientists, they mostly treated TRIZ as a curiosity: it was too far away from everything they used to deal with in their everyday practices when they needed to come up with new innovations or solve innovative problems.

A lot has changed during these 15 years. Professional training in TRIZ was introduced at many world-leading companies, such as Boeing, Intel Corp., Procter & Gamble, Philips, Samsung, Siemens. Thousands of organizations have been using TRIZ in their innovative projects worldwide. Four international TRIZ conferences are conducted on the annual basis in Japan, US, Europe, South and Central America. National TRIZ associations were established in a number of countries. In total, more than 140 books on TRIZ were published in nine languages. Research on TRIZ is conducted in the universities of Australia, Brazil, France, Germany, Italy, Japan, Korea, UK, US.

Modern TRIZ is much broader than just a technique or its famous 40 inventive principles. TRIZ has grown into a discipline which includes various theories, methods, tools and techniques. A successful use of TRIZ is based on knowledge and skills with its four basic areas: analytical logic and system thinking; knowledge bases of patterns of inventive solutions; theory of artificial systems evolution; and finally, development of creative imagination. The existing TRIZ methods are constantly improved and new techniques emerge along each direction. New TRIZ techniques were designed and introduced by a number of TRIZ schools and practicing individuals which complement and enhance classical TRIZ. Similarly to any scientific discipline, TRIZ is evolving. Research is being performed to deepen TRIZ knowledge, discover new patterns of thinking, improve and expand the existing TRIZ techniques, uncover and formulate new laws and trends of technology evolution, explore how the basic principles of TRIZ can be applied in areas different from technology. All this leads us to our ultimate goal: to understand creativity and innovation.

And it is not surprising that today we observe that TRIZ is used outside the technological and engineering applications, for instance, in business and management, marketing, advertisement, arts, human resource management, education. This happens due to the fact that general patterns of inventive and creative thinking and a process of solving innovative problems seem to be universal. Genrich Altshuller, originator of TRIZ, managed to create a tremendous foundation for further studies of innovation and creativity. Only today we start to comprehend the true value and meaning of his heritage.

I am very often asked, “How to become an innovator?” A truth is that innovation is not a single and easy to learn activity which can be separated from the rest of our lives. Being an innovator means living innovative lifestyle. If we look closer at those people whom we regard as successful innovators, we will very soon notice that they tend to innovate everything and everywhere besides working on certain projects in their offices. Being innovative means possessing the innovative way of thinking. Before TRIZ emerged, it had been completely unclear how to become an innovator. Now we know that investing efforts to learning TRIZ and practicing it can turn everyone into an innovator. Understanding and applying TRIZ requires a change in our thinking paradigms and in the way we do things. It is not easy, but eventually it pays back. However ambitious it would be to say, but TRIZ brings our thinking and our creativity to the next level.

Of course, TRIZ is still far from being perfect and we have to improve and evolve not only TRIZ itself but also the ways we develop, teach, and implement TRIZ. It is not a secret that today we have various versions of the same TRIZ techniques, coordination of TRIZ research efforts is not sufficient enough, level of TRIZ training does not always comply with high quality or represent contemporary TRIZ. Thereby one of the most important missions of ETRIA and the TRIZ Future conferences is to bring together TRIZ researchers and practitioners and enable a forum for successful networking, knowledge exchange, and developing joint initiatives from which everyone can benefit.

Is it a coincidence that TRIZ starts being accepted on a broad scale today? Probably not. TRIZ seems to be the most effective and adequate response to the situation our world has been experiencing lately: rapid acceleration of technological and business growth, globalization of economy, emerging ecological and social problems demand producing innovative solutions not accidentally but continuously. We are entering economy of innovation. A famous Russian writer of the 19^{th} century Fyodor Dostoevsky once said, “Beauty will save the world”. But probably is it creativity and innovation that will save the world?

I would like to express my deep gratitude to Fred van Houten, Erik Lutters, Inge dos Santos, Tom Vaneker of the University of Twente, and Gaetano Cascini, Denis Cavallucci, Joost Duflou of the ETRIA Board for their considerable efforts to make this edition of the conference happen. As well as to all the authors and visitors of the conference for their contributions to ensure success of our joint event and further evolution of TRIZ.

ORGANIZING COMMITTEE

ETRIA - EUROPEAN TRIZ ASSOCIATION:
Prof. Dr. Gaetano Cascini
Prof. Dr. Denis Cavallucci
Prof. Dr. Joost Duflou
(http://etria.net/portal/)

ICG TRAINING & CONSULTING
Valeri Souchkov MSc.
(http://www.xtriz.com/)

UNIVERSITY OF TWENTE
Prof.dr.ir. Fred van Houten
dr.ir. Eric Lutters
dr.ir. Tom Vaneker
Inge dos Santos (secr.)
(http://www.utwente.nl/)

CONFERENCE SPONSORSHIP

The TrizFuture 2008 conference is sponsored by the CIRP, The International Academy for Production Engineering.
(http://www.cirp.net/)

COMMITTEES

SCIENTIFIC COMMITTEE

Prof. A. Albers, University Karlsruhe, Germany
Prof. D. Cavallucci, INSA Strasbourg, France
Prof. G. Cascini, Polytechnic of Milan, Italy
Prof. R. De Guio, INSA Strasbourg, France
Prof. J. Duflou, K.U.Leuven, Belgium
Prof. N. Leon-Rovira, ITESM Tecnológico de Monterrey, Mexico
Prof. U. Lindemann, Techn. University Munich, Germany
Prof. H. Meerkamm, University Nürnberg-Erlangen, Germany
Prof. G. Moehrle, University Bremen, Germany
Prof. C. Rizzi, Univ. of Bergamo, Italy
Prof. M. Sawaguchi, SANNO Institute of Management, Japan
Prof. G. Schuh, University Aachen (RWTH), Germany
Prof. T. Tomiyama, TUDelft, Netherlands
Prof. J. Vincent, Open University Bath, UK
Prof. F. van Houten, University of Twente, Netherlands
Prof. F. Kimura, University of Tokyo, Japan
Prof. T. Kjellberg, KTH, Sweden
Dr. D. Lutters, University of Twente, Netherlands
Dr. M. Bonnema, University of Twente, Netherlands
Dr. T. Vaneker, University of Twente, Netherlands

INDUSTRIAL& PRACTITIONERS COMMITTEE

Dr. Robert Adunka, Siemens, Germany
Dr. Ellen Domb, PQR Group, USA
Dr. Carsten Gundlach, ITB Hessen, Germany
Dr. Sergei Ikovenko, Gen3Partners, USA
Jürgen Jantschgi, Universität Leoben, Austria
Dr. Pavel Livotov, TriSolver, Germany
Valeri Souchkov, ICG Training & Consulting, Netherlands
Davide Russo, University of Bergamo
Federico Rotini, University of Florence
Filippo Silipigni, Polytechnic of Milan
Daniele Regazzoni, University of Bergamo
Francesco Saverio Frillici, University of Florence
Horst Nähler, Center for Product Innovation, Germany

CONTENT

SCIENTIFIC PAPERS

INDUSTRIAL & PRACTITIONER PAPERS

A Taxonomy of Inventive Principles for Robust Design Concepts
Philip Samuel[1], Rajesh Jugulum[2]
[1]Breakthrough Management Group International, USA
[2]Massachussetts Institute of Technology, USA

POSTER PRESENTATIONS

Keynotes & Tutorials

KEYNOTES

Keynote 1
Title to be announced
Harry Rutten,
DSM, The Netherlands

Keynote 2
TOP-TRIZ: Theory, Applications, Training and Integration
Zinovy Royzen,
trizconsulting, USA

Keynote 3
New approaches to Design Engineering research
Fred van Houten,
University of Twente, Netherlands

Keynote 4
TRIZ and biology, a natural symbiosis
Karel Bolckmans,
Koppert, The Netherlands

TUTORIALS

Tutorial 1:
"Introduction to TRIZ for Technological Applications"
Hongyul Yoon, South Korea

Tutorial 2:
"Introduction to TRIZ for Business and Management Applications"
Valeri Souchkov,
Netherlands

Tutorial 3:
"A systematized use of Su-Field Analysis"
Iouri Belski, Australia

Scientific Papers

Application Characteristics of the Law of System Completeness

Victor Berdonosov[1]
[1]Komsomolsk-na-Amure State Technical University, Faculty of Computer Technologies, Russia

Abstract
Some aspects of the Law of system completeness appearance in technical, information and economic systems are considered in the report. The main system elements revelation technique including a set of criteria for checking of model adequacy to a real system is being proposed. Special attention is being paid to control parameters and control element revelation and its relation with background. A lot of examples are analyzed. It is considered a way of mistake avoiding while main system elements revealing and mistakes of the following analysis.

Keywords
Law of system completeness, Control parameters, Control element, Criteria for checking adequacy

1 INTRODUCTION

The law of system completeness was proposed by G.Altshuller in the 1st revision of laws of technical system evolution. This law specifies system vitality in the time of its creation. How much the specified elements corresponds to the real (artificial) object defines the efficiency of the following system analysis. While analyzing of a system according to the law of system completeness it is possible to make ambiguity or sometimes even serious mistakes. Criteria are required to find if the analysis is correct.

2 THE LAW OF SYSTEM COMPLETENESS – ALTSHULLER'S WORDS

We propose to quote Altshuller from [1]. "…Every new technical system must be examined. A very strict "committee"- life, practice - examines it. The "committee" asks meticulously: "What is this? Oh, this is an engine! Let's see how it works in this system… So, results are satisfactory. And what is that? That is a transmission from the engine to the actuator. The transmission is very good. We may put an excellent mark! And where are control elements? Are there only two buttons? But if work conditions changed? If a breakage happened? Hum, only bad mark.

The "committee" has the following rule: only those systems pass the test which did not get bad marks. An excellent or a good mark, quantity of marks - does not matter.

It is needed, that system be able to work collectively, though satisfactorily. It seems strange but at first almost all modern technical systems had satisfactory marks. The first steamship had a very weak and voracious steam machine, engine-to-wheel flange transmission took most of the energy and the work of the wheels was not good too. But such systems promised well because the combination was perfect, all parts worked inefficient but together.

A technical system is similar to an orchestra, to a sports team and is good when all "parties" plays organically, harmoniously. That is why all forces of inventors are aimed at looking for a "formula of system" – the best combination of parts. This is the first stage in life of a system…".

Here some questions appear: "When must we give a satisfactory mark or a bad mark?"

3 AN ORCHESTRA?!

We may consider an airplane as an example. It is known that a plane must have wings to fly. But fixed wings cannot fly, they must flap, then an engine is required. But the engine does not act upon the wings directly, and then a transmission is necessary that is the body. And also a control element is needed. Hence, an airplane must have: wings, a body, an engine, and control elements (a throttle grip, a control handle of elevator and a control vane). Can we define if such a system with such set of units can fly or not?

Let's look at two technical objects: an aircraft of the Wright brothers (see fig.1) and an aircraft of naval officer Mozhaysky (see fig. 2). We are going to consider the birth of a system that is why we are looking at these two airplanes.

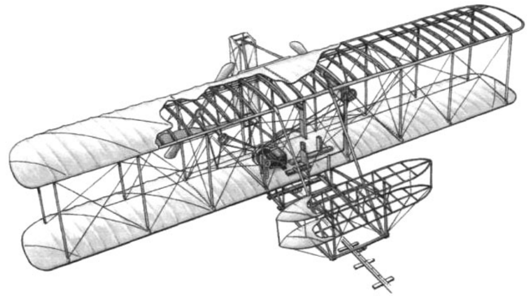


Figure 1: Aircraft of the Wright Brothers

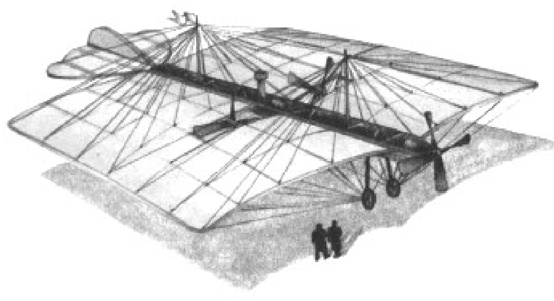


Figure 2: Aircraft of Mozhaysky

As is known one of the airplanes flew and the another one only jumped up some meters skyward. What elements got unsatisfactory marks and why? That is, there is a more suitable question: what criteria should we use to estimate system elements? TRIZ has such a criterion - as every element can be examined as a separate system which passed an evolution way and has ideality. But considering the ideality of elements we should take into account that these elements were aimed at the creation of a concrete system (an aircraft in our case). For a vehicle's elements there will be other criteria, for a submarine's elements – the third ones, etc. That is it must be "an orchestra".

So, the first element we are viewing is an actuator, of course. It is the wing in our example. The useful function of the wing is to create lifting force. The additional function is to guide. Let's see how wings of the first and the second aircrafts realized this function.

Wing lift is specified firstly by the wing's shape: a plane wing (kite analog) has less lift force than a wing with convex shape (see fig.3). By the time of the invention of the airplane fact had been known and checked on air frame.

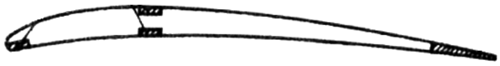


Figure 3: Profile of the wing

We must note that wings of the Wright brothers' airplane were convex while the wings of Mozhaysky's aircraft were plain. They were not even flat as they were so large that to make them that shape was impossible using those construction materials.

The next function is wing controllability. Controllability here is the variability of wing shape to change a position of aircraft. The Wright brothers considered the possibility of bending a wing; it will allow the aircraft to recondition horizontal stability during wind blowing. So these wings could be guided. Mozhaysky's wings did not have such an opportunity.

Now the following element will be examined – an engine. Note that the engine will be viewed together with a holder (aircraft propeller). The useful function of the engine is to thrust the aircraft into moving in the air. What parameters may characterize this function? They are engine power, power-to-weight ratio, and coefficient of efficiency. The engine of the two aircrafts in the example were totally different. The Wrights used combustion engine 16 HP, 80 kg. Mozhaysky used steam machine of 150 HP, 280 kg. See these parameters in the table.

	The Wrights	Mozhaysky
Power (HP)	16	150
Weight (kg)	80	280
Power-to-weight ratio (HP/kg)	0,2	0,54

Table 1: Engine Parameters.

We see that power and power-to-weight ratio of the engine installed on Mozhaysky's aircraft is large but it did not fly. All researchers blame the engine in particular which did not allow Mozhaysky's airplane to fly. That is the critical parameter of this element was not a parameter of advantage but an extravagant one. This extravagant parameter influenced the ideality of the whole system, not only one element through the ideality of another element – wing. To elevate such a big engine large lift force is required. To get large lift force big wings were necessary, but big wings are heavy, inefficient and uncontrollable. It was a contradiction which had not been solved.

Thus for correct analysis it needed to estimate ideality not only of the separate elements of system but ideality of their assembly that is the system as a criterion.

It can be taken into account by estimating undesirable influence of one element of the system on another.

Hundreds years later we may easily argue what is good and what is bad. Now technical systems also appear and it is very important to know what element of the system is a "bottle neck" which prevents the system to be efficient. Inventors do not usually have a sample for comparison during the estimating of a new system. All appraisals are examined. But any estimation must be based on ideality. That is both advantage and expenses shall be considered. We propose to use the easiest graphical model: vertical axis is the advantage, horizontal axis is the expenses. Estimation of the system ideality will be placed in a quadrant depending on a balance between the advantage and the expenses. The quadrant corresponding to assumed estimation is crosshatched.

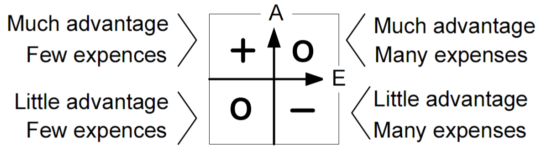


Figure 4: Graphical estimation of ideality

To estimate the ideality of the whole system it is proposed to create a table where estimations of system elements and relations between them are shown in rows.

	Actuator	Trans-mission	Engine	Control element
Actua-tor	+ o / o –	+ o / o –	+ o / o –	+ o / o –
Trans-mission	+ o / o –	+ o / o –	+ o / o –	+ o / o –
Engine	+ o / o –	+ o / o –	+ o / o –	+ o / o –
Control ele-ment	+ o / o –	+ o / o –	+ o / o –	+ o / o –

Table 2: Estimation of ideality of the whole system

The following sense is laid in ideality estimation in table cells. Ideality estimations of respective system elements are placed cornerwise. In cells located out of diagonal ideality estimation of influence of one element on another can be found. For example, estimation of influence of the engine on the actuator will be out in the first cell of the third row.

Now we can see a matrix of estimation for aircrafts concerned.

	Actuator	Transmission	Engine	Control element
Actuator	+ o / o –	+ o / o –	+ o / o –	+ o / o –
Transmission	+ o / o –	+ o / o –	+ o / o –	+ o / o –
Engine	+ o / o –	+ o / o –	+ o / o –	+ o / o –
Control ele-ment	+ o / o –	+ o / o –	+ o / o –	+ o / o –

Table 3: Estimation of ideality of the Wright brothers' aircraft.

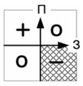
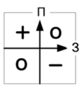
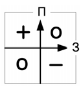
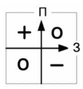
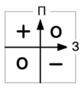
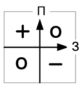
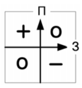
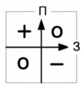
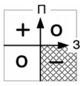
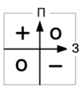
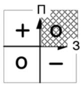
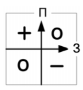
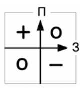
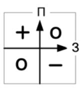
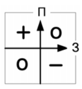
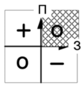
	Actuator	Transmission	Engine	Control element
Actuator				
Transmission				
Engine				
Control element				

Table 4: Estimation of ideality of Mozhaysky's aircraft

As an integral estimate of ideality of the whole system we may use maximin criterion. According to this criterion the worst estimate is taken for every system. That system will win ("survive") which the worst estimate is not less than "0". The Wrights aircraft has the worst estimate "0", the Mozhaysky's aircraft has "–". Hence ideality estimation shows that the Wrights aircraft will survive and Mozhaysky's aircraft will not. You can see in the table that the wing is not functional; its inoperativeness appeared over the engine.

4 WHO IS WHO?

Now we may start discussing a technique of system elements revelation.

All systems can be divided into 2 big groups: the first group – elements and systems may be revealed more or less easily, the second group – it is not so easy to do it. The first systems are airplanes, vehicles, bicycles, etc. That is those systems where there are a lot of movable parts, conversion between the different types of energy, these systems passed a long way of development. Note that almost all these characteristics can be found in such systems. The second group of systems is that where one of above-mentioned characteristics is not available. Examples of the second group are following: a lamp, skies, fins, a table, a chair, etc.

To reveal correctly the elements both of the first and the second group a criterion is required which shows if the received model conforms to a real technical (artificial) system or not. In most cases this criteria may be the correspondence of revealed elements of a system to a definition in a dictionary or to a detailed name of the system.

Let's consider a "lighting lamp". The system attribute is "to light" and "to shine". As per name of system more correct system attribute is "to light" whereas the main useful function is to give necessary light, target area is illuminated surface, surface in particular as it is impossible to light space. It is evident that a ray of light upward directed into the sky will be invisible and will not light anything if the air is non-dusty. Now let's reveal system elements. Actuator: according to the definition of actuator [4] it must be in contact with target object. In a lamp it is neither a filament nor a bulb but the ray of light that is photon flux as it is in contact with illuminated surface exactly [2]. Transmission is the filament. And what is an engine? The engine is also the filament, but the engine is body of filament and transmission is surface of filament.

Now we would like to consider systems difficult from the point of view of elements revelation: fins and rock skies. Unfortunately there is no definition of an artificial system "fins" in the dictionary, only the definition of natural system "fins of pinniped" is available. The situation of definition absence in the dictionary is possible for new coming systems. In this case it is better to find your own intuitive definition: fins are a device which is connected to feet of men (swimmer) to reduce spending of muscular energy while moving in the water. There are several system attributes: to swim easily, to expedite swimming, to reduce, to relax forces of swimmer and we choose the last variant – to relax a swimmer's force. The main useful function is the same as the system attribute. For the following review it is reasonable to show a sketch.

Figure 5: Fins

After defining the system attribute we may consider a target object, that is water, then actuator is fins' surface and transmission is stiffeners which transfer forces from "overshoe" to the fins' surface. Energy source is man's foot and an engine is "overshoe". "Overshoe" is a common concept; there are different types of fin binding. The engine ("overshoe") converts mechanical energy of foot into mechanical energy of impact of fins' surface on water.

And the last element left that is a control unit. It is one of the most difficult elements to reveal. The difficulty lies in the fact that this unit is not evident in all systems. We propose the following technique: at first parameters of each system elements are specified, then among them those elements are revealed which can be guided (changed); and at last that element which control one or several parameters is defined. A number of such elements which are control units is available, Altshuller pointed this out , too.

Now let's come back to aircrafts. We will follow the proposed technique. Wings parameters are following: area, aerodynamic fineness, expansion (length ratio), centre of gravity, center of pressure, wig shape, etc. These parameters were not modified in the first aircrafts except the wing shape of the Wrights aircraft. It was changed by twisting (spanning) for horizontal stability of the aircraft. Engine parameters are as follows: power, engine speed, coefficient of efficiency, fuel rate, oil flow rate, etc. The first airplanes had two controlled parameters: power and engine speed. Both these parameters are guided by one and the same controlled unit, by accelerator footplate or grip in our case.

It should be noted that in classic scheme of system elements illustrating [3] only two system elements are tied with external environment: actuator influence the target object and the engine gets energy from energy source (see fig.6).

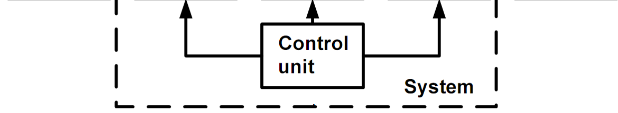


Figure 6: A scheme of system as per the Law of system completeness (canonical form)

But real technical (artificial) systems have one more element that also interrelates with external environment that is control unit. The element of external environment, which the control unit interrelates with, is external control (fig.7). A man acts as a rule as an external control by himself or through a supersystem.

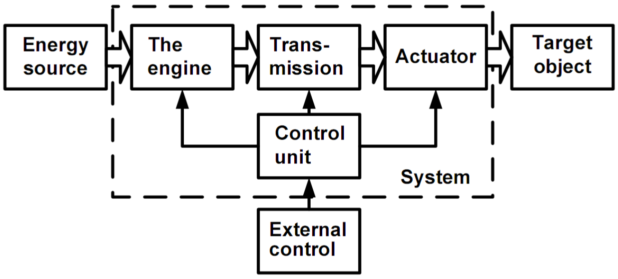


Figure 7: A scheme of system as per the Law of system completeness (proposed variant)

Let's consider illuminating lamp, it is difficult to find a control unit there. We will follow the above-mentioned technique again. The actuator is photon flux, parameters of the actuator are intensity, wave length (colour temperature), space angle where photons travels. Theoretically each of these parameters can be changed: intensity can be changed by coil incandescence temperature, wave length – by optical filter placed inside or outside the bulb; space angle – by reflectors located inside or outside the bulb.

Then we may offer the following control units for the actuator (photon flux):

- To change the intensity it can use the same control unit as for a filament (to be considered below);
- To change wave length it can use mechanical or electronic replacement of filters (or their characteristics);
- To change space angle it can move the reflector or change the focal distance of the reflector.

Parameters of the engine and transmission are as follows: filament temperature, resistance, service life. We should note that all these parameters will change by means of capabilities of the system, not external environment (energy source in this case). So, the temperature of filament can be changed at constant supply voltage either by means of filament resistance change or by means of filament shape. For example, filament in the form of coil will heat better than the filament stretched as in the coil form neighbouring wreath will heat each other and then the whole coil. Usually self-adaptation of resistance depending on the temperature appears in illuminating lamps: while increasing the temperature resistance and power drop, then temperature drops too and vice versa. But it happens within the short range. It is not clear how to change specially filament resistance on-line. So we may propose control unit only for filament shape modification:

- to modify filament shape (for temperature change) we may use compressor-expander of the filament by means of action of magnetic forces for example.

Though there are no critical limits for usage of such control units there are limits related to ideality. Control units modifying the above-mentioned parameters are difficult and expensive but functionality increases in a minor way.

Let's come back to fins and determine control units there. We will use the technique mentioned again. The actuator acts on the surface of the fins. Actuator parameters are as follows: area, extension, shape in side-face, integral rigidity, elastic distribution along the length, speed of rigidity change, speed of rigidity recovery, etc. Let's consider how we can manage some of these parameters. Fin area can be changed, stretching or constricting them, but their rigidity will also change. Also rigidity may be changed by fabricating the fins of sections which overlap each other. If the area is small they overlap, if big - they do not overlap (see fig.8). Rigidity can be modified by means of adding of piezo-fiber.

Figure 8: Double fins

Applying different stress on this fiber we will get different rigidity. The same decision was realized by Head Company in their rock skies with chip intelligent system. Then we may offer the following control unit for fins: battery and controller of stress. Changing of the stress a swimmer will choose optimal fins rigidity.

5 SUMMARY

It is proposed the technique of estimation of system elements functionality based on ideality analysis of not only elements themselves but also interrelation between them. Moreover the ideality is offered to be estimated over the quadrant where the estimated element falls into a binary space "advantage-expenses".

Besides the technique of validity check of revealed system elements is proposed. This technique is based on correspondence of found elements to dictionary definition or to its detailed name.

It is suggested to add an element of external environment "external control" acting on the control unit in the scheme of basic system elements and their relations with the environment.

REFERENCES

[1] Altov H. And Suddenly the Inventor Appeared: TRIZ, the Theory of Inventive Problem Solving (Translated and adapted from the Russian by Lev Shulyak.) Worcester, MA: Technical Innovation Center, 1996. (2—nd Edition).

[2] Ivanov G., Formula of Creativity or How to Learn to Invent: a book for students of secondary school. – Moscow: Prosvescheniye, 1994. – 208 p..

[3] Altshuller G.S., To Find an Idea: Introduction to TRIZ. – Novosibirsk. Nauka, 1986. – 209 p.

[4] Altshuller G.S., Zlotin B.L., Zusman A.V., Filatov V.I.,Search for New Ideas: from Insight to Technology (Theory and Practice of Inventive Problem Solving) / - Kishinev, Kartia Mldoveniaske 1989. - 381 p

CONTACT

Victor Berdonosov

Chair of Design and TRIZ Department
Komsomolsk-na-Amure State Technical University,

International Av 59-5
681024, Komsomolsk-na-Amure – Russia

E-mail: ktriz@knastu.ru

Mobile: +7 (962) 2875141

The Engineers' Innovation Toolkit

G. Maarten Bonnema[1]

[1]University of Twente, Department of Engineering Technology, Laboratory of Design, Production and Management, The Netherlands

Abstract

Most engineers nowadays receive a mono-disciplinary education: Mechanical engineering, Electrical engineering etc. Contradictory, the products they have to design are ever more multidisciplinary and integrated. This requires a different mindset. This paper discusses four tools that fit in the engineers' toolkit to approach these multidisciplinary problems: TRIZ, Systematic Inventive Thinking, Quality Function Deployment and FunKey Architecting. The tools are discussed and rated on four scales: difficulty of problems, complexity of problems, design phase and learning effort. From the characterization a set of heuristics is derived that help in choosing the appropriate tool from the toolkit.

It is concluded that the four tools largely complement each other and should therefore be part of every engineer's toolkit.

Keywords

TRIZ, SIT, QFD, FunKey, Toolkit, Selection, Heuristics, Complex system design

1 INTRODUCTION

Designing present day products has become a complicated process. Due to the highly integrated nature of many modern products, they contain state of the art mechanics, electronics, optics and software, and due to the minimized time to market, designers of these products have to process large amounts of diverse information in a short time span. Successful products require a sufficient mix of newness and familiarity.

Innovation is the successful development and deployment of a new activity. Therefore to innovate, engineers need to develop new activities, overcome or circumnavigate the problems associated with the design, and develop a product that is easy to produce. The reuse of previous developments should be promoted. These three types of activities are very diverse.

The paper will look at how innovation can be made readily accessible for engineers. For this we will first characterize four innovation approaches: TRIZ, Systematic Inventive Thinking (SIT), Quality Function Deployment (QFD) and FunKey Architecting. The latter, though earlier presented at a TRIZ Future Conference [2], is assumed to be less well-known. It will be treated more extensively than the other ones.

Based on the descriptions, a comparison can be made. We will derive a set of heuristics that help in deciding which tool to use, given the problem at hand. We will see that to develop new product ideas with a sufficient portion of newness can be stimulated with SIT. TRIZ can be used to overcome the many problems of implementing the design. FunKey can be used to guide and monitor the entire design process, and to stimulate reuse of previous developments. Largely the same holds for QFD.

2 DESIGNING COMPLEX SYSTEMS

Product design is getting more complicated at present. This is due to the increased number of product functions and due to the increased difficulty of these functions. Also, the number of people involved has increased [3] while simultaneously their distribution over the planet has increased. This reflects the history of the organisations and the increased pressure on costs, and is facilitated by the present communication means.

The tools used are not always up to these new working environments [4]. In that reference it is contended that in the "drawing board environment", the workflow was from "big picture" to detail. The big picture used to be always present in the form of the large overview drawings. In the days of CAD, the models are built up from detail to assemblies to modules to systems. The notion of the big picture is largely absent in the first detailing.

We like to emphasise that systems are designed by humans, not by tools [5]. Although there have been attempts for automated design systems, we focus on helping the designer. In this process we will not take the innovative steps from the human responsibility.

Figure 1 illustrates the problem. At the top of the pyramid there are only a few requirements from the stakeholders.

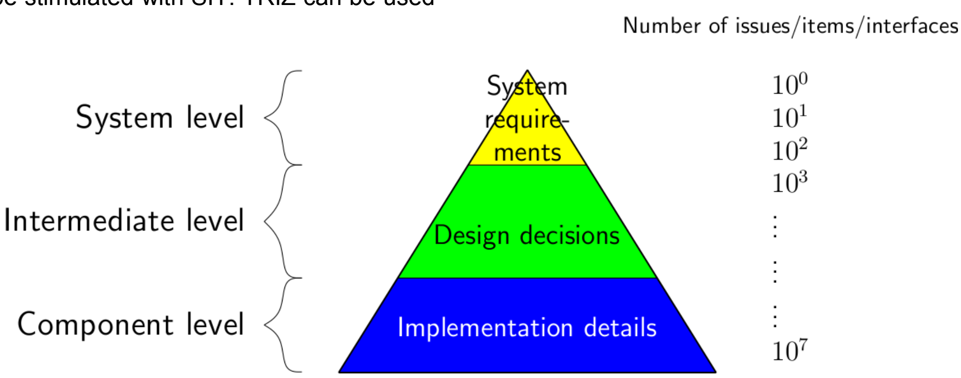


Figure 1: Pyramid of the number of issues, items and interfaces occurring in different stages of the design process [1].

These are at a high level of abstraction. The requirements should reflect their need. The complexity here is not too high. Moving down in the pyramid, those requirements spread through system requirements, subsystems, components, and finally to specifications and detailed design. The complexity at the bottom of the pyramid is high. Fortunately this complexity can mostly be split into mono disciplinary blocks. This represents the architecture of the system. A large team of trained designers can handle this when each designer is given a problem that is as much as possible uncoupled from the rest of the system. Although, as is shown in [6] minimizing the coupling should be aimed at, total decoupling is impossible as a system consists of cooperating parts. If a totally decoupled design can be found, the system is no longer complex. It can even be argued that it is no longer a system, but merely a set of cooperating devices. As described in [7, p.2] a system consists of elements that “cannot be divided into independent subsets.” A consequence of this is that the behaviour of the system as a whole cannot be described by the separate behaviour of the subsystems or components (that is the reductionist approach), but it emerges [8] from the cooperation of and interaction between the subsystems.

At the top of the pyramid, the system level, the number of issues is relatively limited and can be dealt with by a few persons.

This paper will look at how TRIZ-related approaches/ methods can be used in the problems described in this pyramid of designing complex systems. Although many flavours of TRIZ-related tools exist, we will look at the following:

- TRIZ;
- Systematic Inventive Thinking (SIT) and Advanced SIT (ASIT) [9-11], (www.start2think.com and www.sitsite.com);
- FunKey Architecting [2, 12, 13], and
- Quality Function Deployment (QFD) [14, 15].

Each of these approaches will be characterised in the next section.

3 CHARACTERIZING THE APPROACHES

Making a taxonomy of design tools, methods and approaches has been done before ([16, 17] and others). For classifying the different approaches, some metrics are needed. Please note that it is not required to have an exact and absolute measure. It suffices to use scales of comparison. Therefore we will not use any units on the scales.

The first metric we use is the difficulty of the problem at hand. Easy problems relate to routine design work. Difficult problems are those that require a new approach, a new technology. For this we can use the TRIZ five levels of innovation [18]. In this paper we will denote level one as “easy”; level four as “difficult”. Level five is left out of consideration. Discovering new phenomena is not applicable in design. (Fundamental) science is needed for that.

In designing complex systems, the complexity of the problem at hand is an appropriate measure. In this sense, aggregate complexity [19] is meant, where individual elements work in concert to create systems with behaviour that has emergent characteristics [8]. In [13] the complexity scale ranges from simplex to composite. This is what we will use in this paper as well.

A third characteristic is the phase of the design process where the approach is applicable. Although there are many design process models described (see among others [16, 17]), the *communis opinio* is that the following phases occur:

1. Establishing the need;
2. Requirements and specification development;
3. Conceptual design;
4. Embodiment design;
5. Detail design.

These five phases will be used.

Finally, we have to look at the effort required to master the method at hand. We will use a one to five scale again, where one represents “easy”. So within half a day proficiency can be reached with the method. Five represents “laborious”. This means years of practice and training are required for proficiency.

Combining these four scales in one diagram, results in the radar plot in Figure 2. Please note that because we use four characteristics, the diagram looks like a quadrant plot. But each of the four axes should be regarded independently.

In the following subsections, four shapes will be shown in this plot; each representing one of the design approaches.

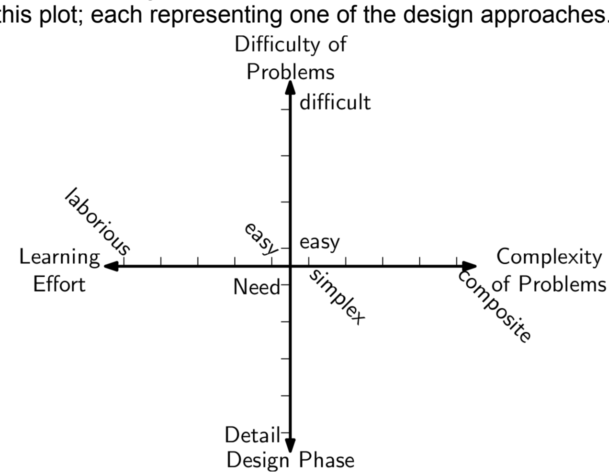


Figure 2: Radar plot used for characterizing the design approaches.

3.1 TRIZ

The Theory of Inventive Problem Solving (TRIZ) requires the shortest introduction in the context of this Conference of TRIZ experts from around the world.

TRIZ is particularly useful in solving difficult problems. As Altshuller has concluded, using TRIZ can help in achieving level 2-4 innovations instead of mere improvements at level 1.

TRIZ is used to resolve contradictions in one of several ways. These contradictions can be (very) hard to remove, yet there are in each case *single* contradictions to resolve. TRIZ is not (by itself) apt for solving (aggregate) composite problems.

As for the phase of the design process, TRIZ (except maybe for the trends of evolution) cannot be used to identify a need or compile the requirements. Finally, becoming a TRIZ-expert requires long training and lots of practice.

Combining these observations into the radar plot defined in Figure 2 results in Figure 3.

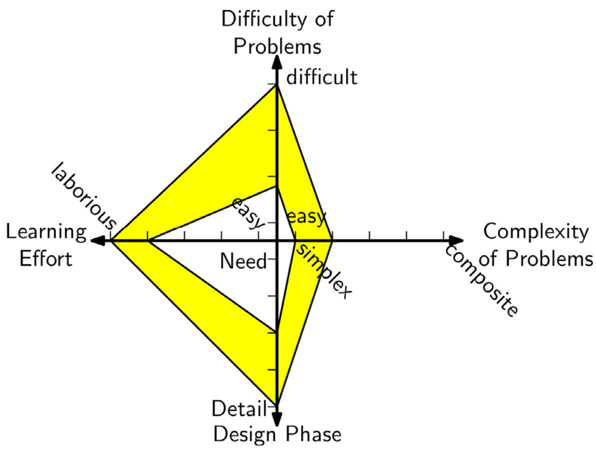


Figure 3: TRIZ characterized in the radar plot of Figure 2.

3.2 SIT

Like TRIZ, (Advanced) Systematic Inventive Thinking (SIT) uses a set of rules or tools to solve problems. Yet a large difference is that SIT helps in particular in finding new product ideas. It is less apt for the resolution of problems and contradictions while designing. Therefore, SIT is used in the earlier phases of the design process. Also, as said, SIT is not particularly fit for solving problems. It merely tries to find alternative solutions, without thoroughly analysing the problem. Although examples exist of SIT as problem solving (the antenna example [10], for instance), it works best in creating new product ideas and concepts.

Finding new products involves many aspects to consider: the customer, the market, the technology available etc. To find suitable product ideas is considered a moderately complex problem. Therefore, the simplex-composite characteristic for SIT is somewhat higher than for TRIZ. Please note that SIT can also be used for creating advertisement campaigns.

Learning SIT requires far less effort than TRIZ. This is an inherent characteristic of the method. It uses a very limited set of tools and principles.

Figure 4 shows the characterization of SIT.

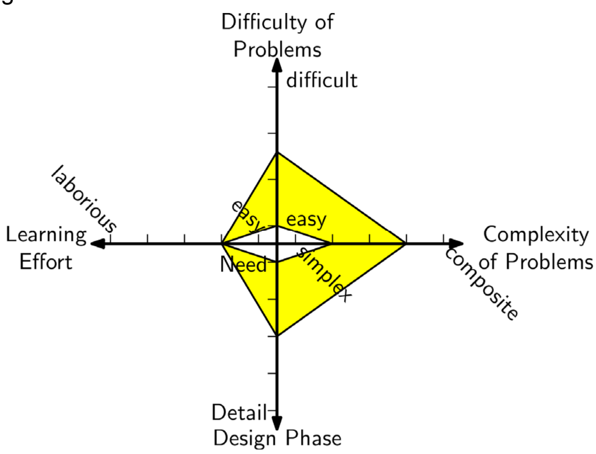


Figure 4: Systematic Inventive Thinking characterized in the radar plot of Figure 2.

3.3 FunKey Architecting

FunKey Architecting [2, 12, 13] requires a bit more of an introduction. It is based on the identification of functions and key drivers. Overview over the system is created and maintained with the help of system budgets. Using these, system architectures can be created. Moreover, TRIZ is easily applied from the FunKey method. It can help in simplifying the architecture and in finding new solutions for implementing the system [2].

The FunKey method uses a coupling matrix *C* to connect functions to key drivers. Functions, as known in TRIZ, are tasks to be performed by the system. [7] defines a function as "a specific or discrete action that is necessary to achieve a given objective" (p.62). Practically, a function is described with a noun and a verb. Examples are *expose wafer*, *transport sand*, *create image*. In general a function can be split into several sub-functions. Transport sand, for instance, contains (among others) the subfunctions *contain sand*, *accelerate sand*, *decelerate sand*, *load sand*, and *unload sand*. Functions and function models are important in the early phase of the design process [20, 21].

Key drivers are generalised requirements that express the customers' interest [22]. Examples of key drivers are *image quality* for a medical imaging device, *load capacity* and *cost per ton per kilometer* for a truck.

Using the functions and key drivers, the FunKey architecting procedure is as follows (see Figure 5).

1. Identify functions and key drivers on system level.
2. Create a table with the functions as rows and the key drivers as columns.
3. Check every cell whether the function contributes to the key driver.
4. Create architectures by naming subsystems and assign functions to subsystems.
5. Create system budgets.
6. Repeat for next hierarchical level.

With system budgets a system requirement can be distributed over the parts constituting the system, as defined by the architecture. Examples are the distribution of available power over the electronics and the distribution of the available time over the (sub) processes in a real time computer program. Budgets are often used in developing high-tech systems [23].

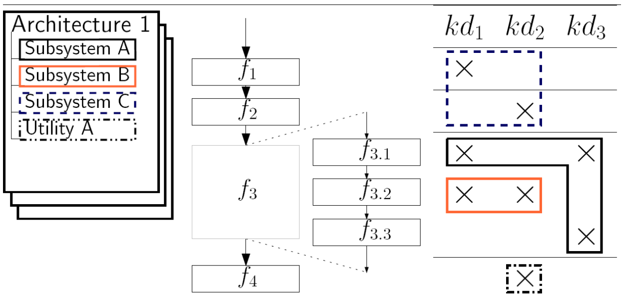


Figure 5: The FunKey architecting method. To the right the coupling matrix ***C*** is shown that connects the functions in the block diagram to the key drivers ***kd**ᵢ*. On the left, one architecture is shown. The subsystems are marked in the coupling matrix. On the top level, functions can also be assigned to the user, the environment and the supersystem.

After initially the matrix *C* has been filled with crosses or ones (when there is a contribution from the corresponding function to the key driver), the contributions can be quantified using either numbers, or symmetrical triangular fuzzy numbers (STFN) [24]. To facilitate the coupling to TRIZ in an early stage, the crosses or ones can be replaced by +es or –es to indicate useful or harmful contributions, respectively.

FunKey Architecting helps in visualizing implicit architectural decisions. Therefore, it is valuable for a team of architects and for communicating architectural decisions between architect and specialist and/or detail designer. For more information, the reader is referred to the earlier mentioned references [12, 13].

The procedure above is invented for the *creation* of the architectures, and presented as such in [12]. Interesting is that the FunKey method can also be used for *monitoring* the design process [25]. Once the initial matrix is filled out, it can be worked out for a next hierarchical level. If on this next level a coupling between a (sub-)function and key driver, or (system) requirement is necessary, this will also modify the top-level matrix. The information can follow two routes: *soll*-values that propagate in a top-down manner; and *ist*-values that are the result of detail design work and propagate bottom-up.

By setting up the system as a database, it is possible to “zoom” in and out. Functions can be expanded into subfunctions and further. Also, the key drivers can be expanded into the system requirements.

From the short introduction to FunKey Architecting above, it can be easily concluded that the whole range of easy to difficult and simplex to complex problems can be handled by the FunKey approach. Moreover, it is wise to use it throughout the design process, from establishing the need to the detail design phase. This way, the system designers can maintain overview, while the detail designers get sufficient context information.

Learning FunKey is not difficult, assuming one has some experience in designing complex systems. In short, FunKey architecting can be classified with Figure 6.

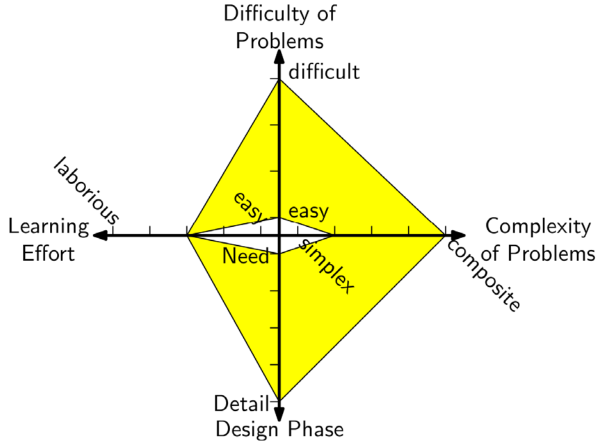


Figure 6: FunKey Architecting characterized in the radar plot of Figure 2.

3.4 QFD

The fourth and last approach is Quality Function Deployment. This method originates from Japan in the 1960’s, and was introduced by professors Shigeru Mizuno and Yoji Akao [14]. Its aim is to incorporate quality in every product, from the outset of the design project. There are several attempts of joining TRIZ and QFD like [26, 27]. QFD is widely used. Therefore the way of working for QFD is assumed to be familiar. The main concept of QFD is that the need and the requirements of the customer are investigated and well documented. As mentioned on [14], QFD:

1. Seeks outspoken and unspoken customer needs from fuzzy Voice of the Customer verbatim;
2. Uncovers "positive" quality that wows the customer;
3. Translates these into designs characteristics and deliverable actions; and
4. Builds and delivers a quality product or service by focusing the various business functions toward achieving a common goal—customer satisfaction.

As with FunKey, QFD can be used in the entire spectrum from easy to difficult and simplex to composite problems. Yet, whether its application in easy and simplex cases is useful is questionable. Further, QFD is particularly aimed at defining the customer’s requirements so that they express the need. In the embodiment and detail phase, these requirements can be used as a reference but there is no feedback mechanism.

In general, QFD is not thought to be difficult or time consuming to learn. Thus QFD can be characterized as shown in Figure 7.

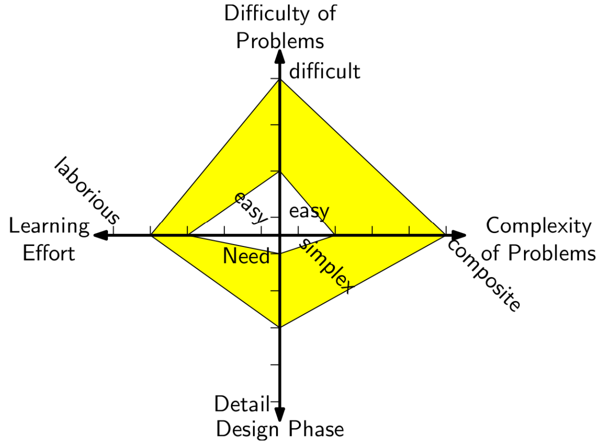


Figure 7: QFD characterized in the radar plot of Figure 2.

4 DISCUSSION

Having characterized these four approaches and restating that we look at their applicability in designing complex systems as shown in Figure 1, it is worthwhile to discuss which approach(es) is (are) best applied in the different parts of the pyramid.

We start at the top of the pyramid where the system requirements have to be compiled. This requires insight in the need, either outspoken or latent. The first situation is where QFD can be used very well. The latent need of a customer can be found by finding new product ideas that might fit that latent need. When such a product is thought up and shown to the customer, the need may become explicit. This results in the first heuristics, valid at the top of the pyramid:

1. For outspoken customer needs use QFD.
2. To investigate any latent needs use SIT.

When the product ideas created with SIT are discussed with the customer, these ideas may be further analyzed using QFD, of course:

3. The need of the customer should be analyzed using QFD.

Then let us move to the bottom of the pyramid. Here many issues are to be resolved. There will be many contradictions to solve, most of them within one domain, or at most between two domains. This is where TRIZ is at its best. When the designers are trained in applying TRIZ, the work at the bottom of the pyramid may progress more rapidly and better directed than without TRIZ.

4. TRIZ should be used for single- and two-domain problems.

Finding these kinds of problems is not always easy. This is where FunKey (and also QFD) comes in. As shown in [2, 13], the FunKey approach can quickly show contradictions to be solved. Moreover, using the priority matrices introduced in [28] and extended in [13], there is no need to describe the contradictions. The possible areas of improvement can be shown by connecting the key drivers with the 39 TRIZ parameters.

5. Use the FunKey approach to investigate areas for improvement early in the design process.
6. Use FunKey to establish contradictions to be solved with the TRIZ parameters.

The two heuristics mentioned above also hold for using QFD [26].

The original goal of the FunKey approach was to assist the system architect; the person defining the system's basic structure and allocation of functions. It is shown [13] that FunKey can be used for that very well. Thus FunKey should be used to divide the system design in smaller, more manageable pieces; the modules or subsystems. The overall performance can still be monitored using FunKey:

7. Create the system architecture using FunKey architecting.

During the design process of a complex system, several people have to monitor the progress, and ensure the basic concepts are not violated [25]. This monitoring can be done easily using the system budgets created with the FunKey approach; for instance by using STFN's as described above.

8. Track progress, in particular from a technical point of view, using FunKey.

We have not yet looked at the learning effort for the four methods. From the figures shown above, we can see that TRIZ requires most learning and practicing effort. It is therefore unfortunate that TRIZ has its largest effectiveness at the more detailed levels of the design process. There, the number of people working is the largest. This disadvantage can be overcome, as suggested more often, by instructing all engineers in the basic principles of TRIZ so that they can identify the problems where TRIZ is expected to be effective. In cooperation with a few TRIZ-experts in a team, these problems can be solved. (This solution is an illustration of the segmentation principle.)

As the other approaches do not require a large learning investment, most people in the team can learn them.

From these heuristics, we can conclude that the four approaches treated in this paper largely complement each other. There is some overlap between QFD and FunKey, but this may work for the better when a possible connection between the two approaches is investigated further.

Therefore, referring to the title of the paper, four tools that belong in the engineers' innovation toolbox are TRIZ, SIT, FunKey and QFD. It is not required for each engineer to be proficient in all four of the methods, yet a basic understanding is welcome. A few TRIZ-experts are needed in each design team.

5 CONCLUSIONS

A summary of the above is shown in Figure 8. SIT is particularly suitable in the top of the design pyramid. It loses its use when more details have to be considered. TRIZ is appropriate in the base of the pyramid and in particular for solving the many difficult problems associated with designing high-tech systems.

FunKey and QFD are both useful in dissecting the design problem into smaller pieces. In addition, FunKey is very useful in creating the architecture and for tracking progress in larger projects.

6 RECOMMENDATIONS

It can be concluded that there are similarities between QFD and FunKey. Although their goal differs, it is wise to investigate a better connection between the two.

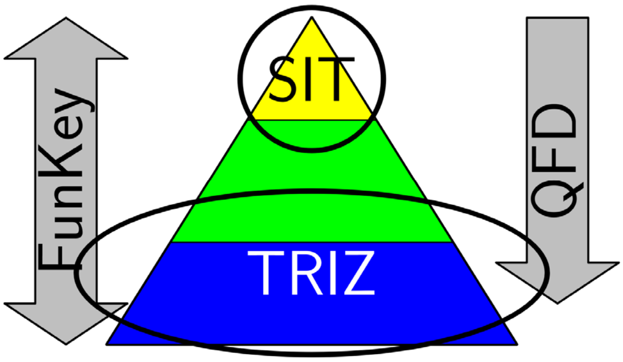


Figure 8: The four approaches and the pyramid of system design.

REFERENCES

[1] Muller, G.J. *Design objectives and design understandability*. 2007 [Last access 7 june 2007]; Available from: http://www.gaudisite.nl/DesignUnderstandabilitySlides.pdf.

[2] Bonnema, G.M., *TRIZ for Systems Architecting*, in *TRIZ Future 2006*. 2006: Kortrijk, Belgium. p. I: 87--92.

[3] Schulz, A.P. and E. Fricke. *Incorporating flexibility, agility, robustness, and adaptability within the design of integrated systems - key to success?* in *Digital Avionics Systems Conference, 1999. Proceedings. 18th*. 1999.

[4] Ottoson, S., *Qualified Product Concept Design Needs a Proper Combination of Pencil-aided Design and Model-aided Design Before Product Data Management.* Journal of Engineering Design 1998. 9(2): p. 107-119.

[5] Axelsson, J., *Towards an Improved Understanding of Humans as the Components that Implement Systems Engineering*, in *12th International Symposium of the International Council on Systems Engineering*. 2002, INCOSE: Las Vegas.

[6] Suh, N.P., *The Principles of Design*. Oxford Series on Advanced Manufacturing, ed. J.R. Crookall and M.C. Shaw. 1990, New York, Oxford: Oxford University Press.

[7] Blanchard, B.S. and W.J. Fabrycky, *Systems Engineering and Analysis*. Third ed. 1998, Upper Saddle River, New Jersey: Prentice Hall.

[8] Lewes, G.H., *The Problems of Life and Mind - First Series: The Foundations of a Creed*. 1875, Kessinger Publishing (2004): London.

[9] Goldenberg, J., et al., *Finding Your Innovation Sweet Spot*, in *Harvard Business Review*. 2003, Harvard Business School Publishing Corporation.

[10] Goldenberg, J. and D. Mazursky, *Creativity in product innovation*. 2002, Cambridge: Cambridge University Press.

[11] Stern, Y., I. Biton, and Z.e. Ma'or, *Systematically Creating Coincidental Product Evolution Case Studies of the Application of the Systematic Inventive Thinking (SIT) Method in the Chemical Industry.* Journal of Business Chemistry, 2006. 3(1): p. 13--21.

[12] Bonnema, G.M., *Function and budget based system architecting*, in *TMCE 2006*. 2006: Ljubljana, Slovenia. p. 1306--1318.

[13] Bonnema, G.M., *FunKey Architecting - An Integrated Approach to System Architecting Using Functions, Key Drivers and System Budgets*. Engineering Technology. Ph.D.-thesis. 2008, Enschede, The Netherlands: University of Twente.

[14] {QFD Institute}. *The official source for QFD*. 2005 [Last access 12 august 2008]; Available from: http://www.qfdi.org/.

[15] Govers, C.P.M., *What and how about quality function deployment (QFD).* International Journal of Production Economics, 1996. 46-47: p. 575--585.

[16] Finger, S. and J.R. Dixon, *A review of research in mechanical engineering design. Part I: Descriptive, prescriptive, and computer-based models of design processes.* Research in Engineering Design, 1989. 1(1): p. 51--67.

[17] Finger, S. and J.R. Dixon, *A review of research in mechanical engineering design. Part II: Representations, analysis, and design for the life cycle.* Research in Engineering Design, 1989. 1(2): p. 121--137.

[18] Altshuller, G.S., *40 Principles - TRIZ Keys to Technical Innovation*. TRIZ Tools. Vol. 1. 1997, Worcester, MA: Technical Innovation Center.

[19] Manson, S.M., *Simplifying complexity: a review of complexity theory.* Geoforum, 2001. 32(3): p. 405--414.

[20] Bonnema, G.M. and F.J.A.M. van Houten, *Use of Models in Conceptual Design.* Journal of Engineering Design, 2006. 17(6): p. 549--562.

[21] Erden, M.S., et al., *A review of function modeling: Approaches and applications.* AI Edam-Artificial Intelligence for Engineering Design Analysis and Manufacturing, 2008. 22(2): p. 147-169.

[22] Muller, G.J., *CAFCR: A Multi-view Method for Embedded Systems Architecting*. Ph.D.-thesis. 2004, Delft: Delft University of Technology.

[23] Frericks, H.J.M., et al., *Budget-based design*, in *Boderc: Model-based design of high-tech systems*, W.P.M.H. Heemels and G.J. Muller, Editors. 2006, Embedded Systems Institute: Eindhoven. p. 59--76.

[24] Chan, L.-K. and M.-L. Wu, *A systematic approach to quality function deployment with a full illustrative example.* Omega, 2005. 33(2): p. 119--139.

[25] Bonnema, G.M. and P.D. Borches, *Design with Overview – how to survive in complex organisations*, in *18th Annual International Symposium of INCOSE (IS2008)*. 2008, INCOSE: Utrecht, The Netherlands.

[26] León-Rovira, N. and H. Aguayo, *A new Model of the Conceptual Design Process using QFD/FA/TRIZ.* TRIZ-Journal, 1998. 7(July).

[27] Domb, E., *QFD and TIPS/TRIZ.* TRIZ-Journal, 1998. 1998(6).

[28] Ivashkov, M. and V. Souchkov, *Establishing Priority of TRIZ Inventive Principles in Early Design*, in *Design 2004*. 2004: Dubrovnik.

Networks of Trends: Systematic Definition of Evolutionary Scenarios

Gaetano Cascini[1,2], Federico Rotini[2], Davide Russo[3]
[1]Politecnico di Milano, Dip. di Meccanica, Italy
[2]Università degli Studi di Firenze, Dip. di Meccanica e Tecn. Ind.li, Italy
[3]Università degli Studi di Bergamo, Dip. di Ingegneria Ind.le, Italy

Abstract

TRIZ literature presents several papers and even books claiming the efficiency of Altshuller's Laws of Engineering System Evolution as a means for produce technology forecasts. Nevertheless, all the instruments and the procedures proposed so far suffer from poor repeatability, while the increasing adoption of innovation as the key factor for being competitive requires reliable and repeatable methods and tools for the analysis of emerging technologies and their potential impact. The present paper proposes an original algorithm to build a Network of Evolutionary Trends for a given Technical System with repeatable steps. Such a goal has been achieved by integrating well known models and instruments for system description and functional analysis. The overall procedure, still under further development, has been clarified by means of one of the case studies carried out for its validation.

Keywords

Technology Forecasting, Laws of Engineering Systems Evolution, FBS model, EMS model, Functional Basis

1 INTRODUCTION

Nowadays the analysis of emerging technologies and their potential impact on markets, economies and societies requires reliable and repeatable methods and tools since the related information plays a critical role for strategic decisions of private and public organizations.

Therefore it is not surprising that more than fifty methodologies with different characteristics and specific purposes have been proposed so far in this field [1]. Nevertheless all these techniques reveal several weaknesses [2] as: limited accuracy on middle and long-term forecast; poor repeatability; poor adaptability, i.e. no universal methods are known, besides complementary instruments must be integrated according to the specific goal and data availability.

Within this context TRIZ is emerging as a systematic forecasting methodology and the TRIZ community widely claims the benefits arising from the application of Altshuller's Laws of Engineering System Evolution (LESE) [3, 4] and the corollary trends identified so far.

Besides, as already discussed in [2, 5], also TRIZ instruments suffer from limited repeatability (different teams work independently produce different scenarios) and lack of accredited procedures for their application.

In facts, several TRIZ tools have been proposed to support technology forecasting activities: S-curve, system operator, laws of technical systems evolution, lines of evolution (trends), Ideality increase, morphological analysis, wave model of systems evolution and ARIZ. Nevertheless, while these tools reveal relevant potentialities in several specific situations, their integrated use is limited to inventive problem solving tasks (ARIZ), while it is still missing for forecasting applications.

The present paper proposes a step-by-step algorithm for analyzing a Technical System (TS) and the way its Main useful Function (MUF) is delivered at different detail levels. The working principle is then compared with previous generations of the system in order to build a structured classification of the information, suitable for evolutionary comparisons. These comparisons allow to build a network of scenarios with different involvement of resources, which constitutes a map of the TS evolution, where already commercialized products are visualized together with emerging patented inventions and free spaces for investments. The choice of the favorite strategical direction is still assigned to the beneficiaries of the forecast according to their attitude to the world, their mission and values, as already suggested by Altshuller [3]. Nevertheless, the proposed procedure carefully limits the evolution space by means of a detailed resources analysis.

Such a network of trends proved to be an effective tool for exploratory analysis of potential evolutions of a TS in three extended industrial applications and several minor applications to literature examples.

In this paper, in order to illustrate and clarify the proposed algorithm we report some details from an experience in the field of aseptic filling of beverage containers related to a cooperation with GEA-Procomac. Such an activity has lead to the identification of some specific solutions the company was not aware of, which are actually under development by Procomac's competitors. Moreover new R&D opportunities have been highlighted and the company has positively evaluated the chance to invest in those directions. All these results are considered a positive validation of the proposed procedure.

2 TRIZ INSTRUMENTS AND FORECASTING

Fey and Rivin in [6] first positioned TRIZ as a "powerful structured methodology for a directed development of new products/processes" alternative to more classical Technology Forecasting approaches like trend extrapolation, morphological analyses and Delphi methods. Besides, the methodological description was limited to the LESE with a number of examples, without providing proper details about the way the TRIZ laws should be applied.

Then Cavallucci in [7] started integrating TRIZ LESE into the product development cycle as a means to predict the impact of a technical solution.

The abovementioned approaches, indeed adopted by several TRIZ professionals and implemented in some software applications, are helpful to explore variants of the analyzed TS, but no directions are provided to identify elements and functions to be evaluated and further developed according to the LESE; moreover no specific comparison means are available. As a result, the repeatability of the process is poor and strongly dependent on the skill and the experience of the analyst.

It must be mentioned that a few TRIZ professionals have proposed integrated procedures for technology forecasting purposes [8, 9]; nevertheless, the authors believe that both Directed Evolution by Zlotin, Zusman and Evolution Trees by Shpakovsky are still mostly focused on the interpretation of the LESE than on the analysis of the system the forecast is about.

Such a lack of preliminary classification, especially in case of complex systems, is the main reason for poor repeatability of TRIZ forecasts, since different researchers apply TRIZ LESE to different details/characteristics of the same technical system and/or limit their study to superficial features of the system itself.

In this paper the authors propose an algorithm for the definition of the evolutionary scenarios of a technical systems by applying the LESE. The original contribution of this work is the definition of a systematic procedure to analyze a technical system, compare alternative means to deliver the same functions, synthesize new opportunities of development and assess the limitations of the resulting forecast.

3 ALGORITHM FOR BUILDING A NETWORK OF EVOLUTIONARY TRENDS (NET)

As stated in the previous section, a crucial issue is the identification of the proper function(s) delivered by the analyzed system, the influence on its evolution of auxiliary functions and undesired side effects, the competing alternative technologies. In order to provide systematic directions to function classification and to adopt a terminology well known by the scientific community, the algorithm has been based on well known models of Design Theory.

A further critical task of a technology forecast is the collection and analysis of information; therefore, specific guidelines have been provided to gather information both from experts and patent databases.

3.1 Reference models for system analysis

The following models are adopted as elementary references for the definition of the NET:

- EMS model [10]: Any technical system can be modeled as a black box channeling or converting energy, material and or signals (information) to achieve a desired outcome.
- Minimal Technical System: In [11] the adoption of the EMS model was proposed also for problem formulation and analysis as an alternative means to Su-Field modeling. Nevertheless, the decomposition of the black-box into sub-systems lacks precise directions about the level of details to be provided. In order to deal with a repeatable model, whatever is the complexity of the system to be analyzed, four elements must be recognized (figure 2, above): a Tool, i.e. the working element delivering the function of the TS; a Supply, i.e. the element providing the energy necessary to produce the expected effect of the function; a Transmission, i.e. the element transmitting energy from the Supply to the Tool; a Control, i.e. an element governing at least one of the above elements [3]. According to the classical definition of the minimal technical system, just energy flows are taken into account; besides, the concept of the Law of Completeness of System Parts can be extended also to different types of flows, namely Material and Signals. A detailed explanation of this statement is out of the scopes of the present paper, nevertheless the authors are going to publish a paper fully dedicated to the extension of the first three LESE to a general EMS model.
- System Operator [3]: The analysis must be conducted at different detail levels with a proper hierarchical classification of system elements (figure 3). As a consequence, each of the four elements of the minimal technical system can be further decomposed into four subsystems with the same structure (figure 2, below).

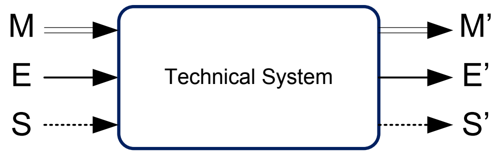


Figure 1: EMS model: Energy, Material and or Signals are channelled or converted to deliver a certain function.

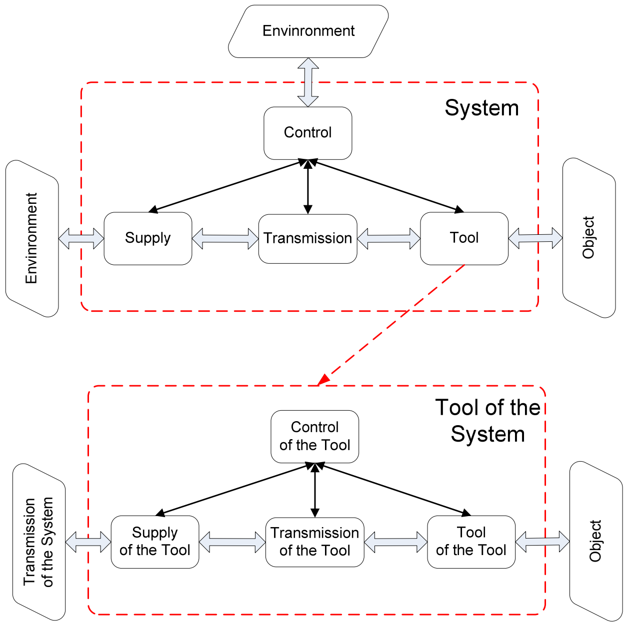


Figure 2: Minimal Technical System (above) and hierarchical decomposition of its elements (below).

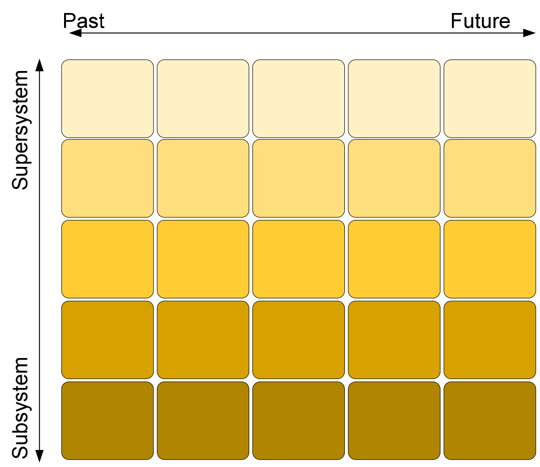


Figure 3: System Operator.

- Function-Behavior-Structure (FBS) [12]: The Function of a TS is the motivation for its existence; at the Structure level, a TS is constituted by entities, attributes of these entities and relations among them; the Behavior, defined as sequential changes of objects state governed by the Laws of Nature [13], is the link between Function and Structure. Different Behaviors can produce the same Function, as well as different Structures can be characterized by the same Behavior.
- Functional Basis for Engineering Design [14]: The need for formalized representations in function-based design is often overlooked in the literature; however, it is an issue of critical importance to reduce ambiguity at the modeling level (when multiple terms are used to mean the same things, or when the same term is used with multiple meanings) and to improve repeatability of the models (the larger the number of terms there are in a vocabulary, the more different ways there are to model or describe a given design concept). The distillation of a large body of terms into a concise basis does not eliminate these problems entirely, but it significantly lessens their occurrence. A further advantage of the functional basis approach is that it fits with the previously mentioned models, since the taxonomy of functions is expressed by a number of functional verbs applied to EMS flows. The formers are hierarchically subdivided into 8 classes, 21 secondary and 24 tertiary actions on flows; these are classified in three levels including 6 secondary and 11 tertiary material flows, 12 secondary and 4 tertiary energy flows, 2 secondary and 7 tertiary signal flows. Nevertheless, it is worth to notice that although these efforts for a standard taxonomy for engineering functions by the NIST Design Repository Project are well established, they still lack operational relationship with FBS behaviors [15].

3.2 Integrated model for function-behavior analysis

The reference models presented in the previous section can be integrated in order to provide systematic and repeatable means to perform the analysis of a TS before applying comparisons and extrapolations based on the LESE.

TRIZ practitioners usually express functions in terms of triads Subject-Verb-Object such that the Subject modifies a parameter of the Object according to the action described by the Verb. In other terms, the pair Verb-Object can be translated into an expression like “changes <parameter> of the Object”. Such a parameter constitutes an evaluation means for assessing the performance of the function and thus the degree of satisfaction of the TS itself.

Besides, in order to adopt a formulation compatible with the Functional Basis for Engineering Design mentioned above, it is suggested to associate an EMS model to the intended function of the TS.

Generally speaking, the EMS model of a TS hides several elementary functions, since the TS may impact several parameters of the same object. As an example, a nozzle for sterilization devices heats (changes temperature) and directs (changes direction) a sterilant.

Thus the EMS model must be split into elementary black boxes each delivering one of the basic actions constituting the Functional Basis. Energy, Material and Signal flows can be detailed according to the secondary and tertiary classes proposed in [14].

Such a detailed functional model still doesn’t represent the specific solution adopted to deliver each function, i.e. the model must be integrated with the behaviour of the TS, or in TRIZ terms the physical, chemical, geometrical effect adopted.

In this paper it is proposed to represent the behaviour of each elementary function by means of the Minimal Technical System model. Figure 4 shows an exemplary integrated model for a sterilizer nozzle: the EMS model is further developed in terms of elementary actions according to the functional basis and each of them is associated to a specific behaviour model representing a way to perform the corresponding function. A Su-Field model related to the interaction Tool-Object has been added to each behaviour model, in order to highlight the nature of the interaction, which is relevant information for evolutionary analyses according to the Standard Solutions (here, mostly Class 2 and 3) and for the Laws of Evolution 7 and 8 [3].

However it is suggested to build a Su-Field model for each pair of interacting elements of the Minimal Technical System model.

3.3 Information gathering and classification

The construction of a network of evolutionary scenarios for a technical system clearly requires collecting and classifying data and information from several sources. These can be mainly divided in two main categories (figure 5): experts somehow involved in the product cycle of the TS, i.e. executives, managers, researchers, designers, sales representatives etc.; scientific and technical literature, i.e. articles, patents, catalogues, etc.. Interviews and searches to elicit information from these sources can be driven by specific tools. At the beginning of the study general structured questionnaires are useful to follow a systematic approach in order to identify functions, relationships with the environment and causal relationships. An example of a structured questionnaire well known by the TRIZ community is the Innovation Situation Questionnaire (ISQ) [16]. The authors have created a customized questionnaire which allows performing a similar investigation, according to the models mentioned in section 3.1, thus collecting information about EMS flows, identifying the main four elements for each function and mapping hierarchical relations among those elements.

The answers provided by the experts can be integrated by specific literature searches; modern text mining technologies provide valuable means to improve the efficiency of this task [17].

Once the general data about the system have been collected, their classification can be approached according to the LESE as explained in the following section. Such a structured view of the gathered information clearly raises new questions both to complete the map under construction and to validate the directions suggested by TRIZ trends of evolution. Again experts and literature are fruitful complementary sources to complete the task.

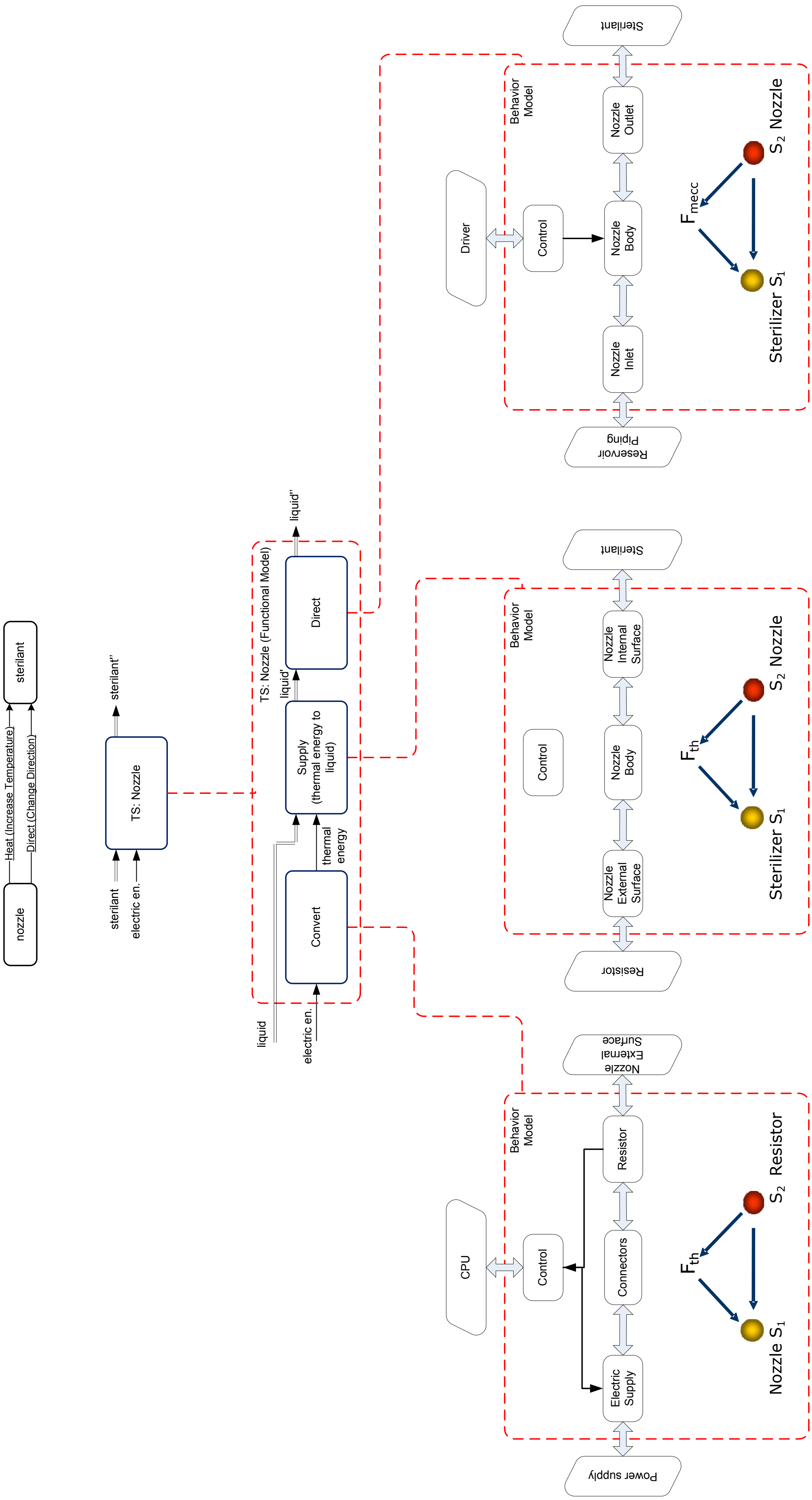


Figure 4: Integrated model for functional-behavioral analysis.

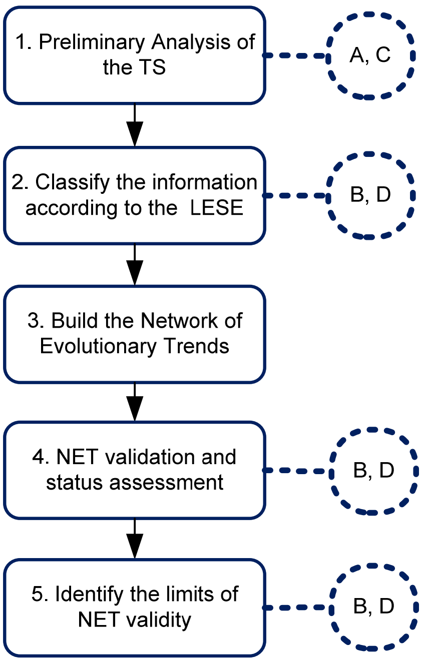
Tools / Sources	Structured Questionnaire	LESE
Experts	A	B
Patents Literature	C	D

Figure 5: Main sources of information and tools for classification.

3.4 Main steps of the algorithm

The main steps of the proposed algorithm are represented in figure 6. Further details of each step will be provided in section 3.5.

The preliminary analysis of the TS aims at the identification of the MUF, the Structure and the Behavior of the system at different detail levels, both of its current version and its historical evolutionary steps. Then the resulting functional and behavioral models are compared according to TRIZ trends of evolution. The third step consists of assembling the relevant trend recognized for each element into a map representing also: links between different generations of the TS characterized by a different behavior, usually due to a Transition to Microlevel; links between the four elements of each minimal technical system associated to each function and links between an element and its subsystems. Browsing the NET is then possible to identify missing implementations of the TS through trends interpolation/extrapolation: within this fourth step, unexpected patent activities of the competitors are likely to appear, as well as virgin scenarios where to focus R&D activities. Finally the limits of the NET validity must be checked by analyzing what happens if an assumption fails or a certain functional parameter has sudden variations out of the expected range.



3.5

Figure 6: Main steps of the algorithm and relationships with Information sources and gathering tools (fig. 5).

3.6 Detailed description of the algorithm

Each of the abovementioned steps consists in several sub-steps and clearly requires a detailed description within the limits of the paper extension. In order to clarify the proposed concepts, some trivial over-simplified examples are reported.

1. Preliminary analysis of the TS

1.1 Identify the MUF of the TS, its characterizing parameters and expected values
- Identify the Evaluation Parameters defining the performance of the MUF
- Decompose the MUF, according to the Functional Basis [14], into elementary functions needed to impact those Evaluation Parameters
- Identify constraints and minimum performance values (e.g. due to standards, certification systems etc.)

1.2 Analyze the goal of the TS and the role of its MUF at a super-system level; identify all the functions acting on the same object of the MUF
- E.g.: Let's consider a sterilization module in a machinery for aseptic filling of beverage containers; its function is reducing the amount of pathogenic organisms (Evaluation Parameter) in the container, e.g. a bottle, before to fill it, until a sealed cap will be applied; in this case it is important to identify further functions acting on the bottle, e.g. handling, because they can interfere with the TS under study.

1.3 Identify the alternative Behavioral Models (BM) of the TS capable to produce the expected MUF
- This task should be performed taking into account also out-of-date configurations of the TS
- Only different BM of the MUF should be mapped, while other differences between possible embodiments (structures) of the TS can be neglected at this stage
- E.g.: Let's consider a machine for rubber pulverization (MUF): alternative BMs are cryogenic milling, high-speed cutting, high compression and shear milling, waterjet cutting etc.

1.4 Identify the Auxiliary Functions requested by each specific BM of the MUF
- E.g.: in the example of bottle sterilization, if the elimination of bacteria is obtained through a chemical substance like peracetic acid, an auxiliary function to be delivered is bottle rinsing, since even small drops of the sterilizer could negatively impact the taste of the beverage.

1.5 Identify the undesired Harmful Effects generated by each specific BM of the MUF
- This step leads to the identification of Technical Contradictions in the following form: the Structure of the TS should have the behavior represented by BM in order to deliver the MUF, but should not have such a behavior in order to avoid its harmful effects

1.6 Identify the amount of resources required by each BM to deliver the MUF
- In order to allow a comparison between different systems with the same BM, the resources should be normalized to the same performance parameter

or vice versa performances can be compared with respect to the same usage of resources

- In order to allow a comparison between different BMs, resources should be grouped into homogeneous classes, the most general classification being resources related to Space, Time, Energy, Material, Information
- The analysis of the resources must take into account also the Auxiliary (necessary) Functions identified at step 1.4

1.7 Build the Minimal Technical System model of each BM of the MUF and of the other functions identified at step 1.2-1.4

- Complete the model with Su-Field analysis of each pair of interacting elements (e.g. figure 4)

2. Classify the information according to the LESE

2.1 Compare the BMs of the MUF according to the Law of Transition to Microlevel

- The transition from macro to micro level, i.e. a transition to a smaller scale of the principle a BM is based on, is a typical trend of technical systems. Since such a transition is typically associated to major changes in the TS, it is suggested to apply this classification of the BMs before proceeding with more detailed comparisons

2.2 Analyze the Structure associated to each BM of the MUF and its level of completeness according to the first Law of evolution

- Check if the supply of the flow characterizing the MUF is integrated in the TS
- Check if the control of the flow characterizing the MUF is integrated in the TS and which is the controlled element
- This step, as well as the following, should be performed iteratively for each BM of the MUF

2.3 Analyze the Structure associated to each Auxiliary Function and its level of completeness according to the first Law of Evolution

2.4 Analyze the interactions between each pair of elements of the Minimal Technical System for each BM of the MUF and perform a comparison according to the LESE and the TRIZ trends of evolution

- The priority should be given to the interaction existing between the Tool and the Object, then to the other pairs of elements, i.e. Transmission-Tool, Supply-Transmission, Control-Tool etc.
- Among the different formulations of TRIZ trends of evolution available in literature, the authors make use of the following to be applied to each pair of elements
- Increase of controllability: introduce closed-loop feedbacks, move the control closer to the tool
- Geometric harmonization: geometrical evolution (1D-2D-3D and related modifications), increase of asymmetry, segmentations (voids, surface, volume), dynamization
- Rhythm harmonization: parts coordination, frequency of action
- Material harmonization (it is worth to note that this is not a classical TRIZ trend; nevertheless, the authors have encountered several systems evolving towards a harmonization of the materials of interacting elements)
- Mono-Bi-Poly and Trimming: Mono-Function Homogeneous systems, Mono-Function systems with Shifted Characteristics, Multi-Function Heterogeneous systems, Inverse Function, Partial Trimming, Extended Trimming; the assessment of the evolution-convolution stage should be performed also by taking into account the ratio between the performance of the function under analysis and the resources involved for its implementation
- Increase of Fields involvement

2.5 Analysis of the contradictions and their relationships with the trends formulated at step 2.4

- Contradictions identified at step 1.5 disappearing due to the application of one or more trends
- Contradictions identified at step 1.5 not solved by the trends
- New contradictions emerging by the application of a specific trend of evolution
- New contradictions emerging by the application of two or more trends generating conflicts between the available resources

3. Build the Network of Evolutionary Trends

3.1 Order the Minimal Technical System models of each BM of the MUF according to the trend Transition to Microlevel analyzed at step 2.1

3.2 Within the same stage of Transition to Microlevel, order the BMs according to their completeness (without recurring to the support of external systems or to humans)

3.3 Add the models of decomposed subsystems (figure 2, below)

3.4 Add the models of the functions identified at step 1.2

3.5 Represent as branches of a network the trends identified at step 2 by links to the corresponding elements of the model built at steps 3.1-3.4

4. NET Validation and status assessment

4.1 Mark the nodes of the network corresponding to an existing configuration of the TS

- The authors usually apply a red circle around these nodes; further differentiations can be applied by highlighting with different colors sub-classifications like competitors, years of development, market sectors etc.

4.2 Mark the nodes of the network corresponding to features found in patents, but still not brought to the market

- The authors usually apply a yellow circle around these nodes (figure 7, above).

4.3 Identify new opportunities of implementation of the TS

- Recognize interpolation opportunities due to missing configurations in a trend of evolution (figure 7, middle).
- Recognize extrapolation opportunities due to not exhausted trends of evolution (figure 7, below).
- The authors usually apply a green circle around these nodes

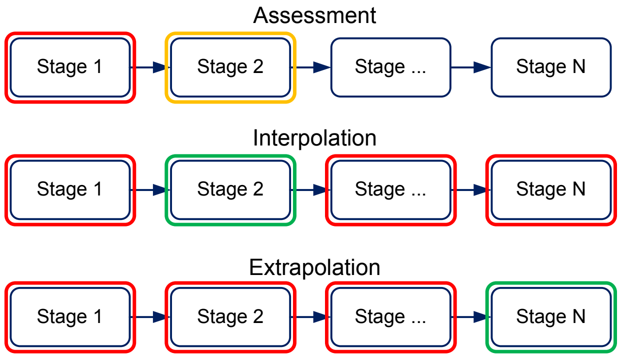


Figure 7: Evolutionary assessment of the NET branches and identification of new opportunities for the TS.

5. Identify the limits of NET validity

5.1 Search for functions alternative to the MUF capable to achieve the same overall goal

- It is suggested to start from the results of the analysis performed at step 1.2 and to apply the System Operator in order to identify alternative functions (in different screens) providing the same benefits of the MUF to the supersystem

5.2 Analyze the parameters of the object of the MUF and check which variation of such parameters makes the TS incapable to provide the expected benefits, thus failing in the achievement of the goal

5.3 Analyze the parameters of the object of the MUF and check which variation of such parameters makes the TS useless

5.4 Investigate the impact of the removal of the constraints identified at step 1.1 or the introduction of new ones

The description of the algorithm (and most of all, steps 2.4 and 2.5) should be further detailed, but due to space limitations the authors have limited the explanation of tasks accomplished according to procedures already well discussed in literature (e.g. [8, 9]).

It is worth to notice that the structured approach of the investigation together with the precise directions of search provided by the trends (e.g. in step 2.4) allows to perform very precise questions to the experts, thus triggering their implicit knowledge, as well as to make use to a maximum extent of the functionalities provided by modern Text-Mining technologies, while analyzing electronic documents like patents and scientific papers.

4 EXEMPLARY APPLICATION: BOTTLE STERILIZATION FOR ASEPTIC FILLING

The authors have tested the proposed algorithm in three extended case studies related to disabled walkers, wood pellets production and aseptic filling of beverage containers. The latter is here reported as exemplary application.

The case study was conducted from September 2007 to February 2008 within a project aimed at the identification of next future technologies for bottle sterilization, coordinated by the R&D Department of GEA-Procomac a leading company in the field of aseptic filling.

The role of the University of Florence was the definition of a structured set of scenarios to support company's management in the selection of the most appropriate directions for investment.

The algorithm was carefully applied to collect and classify the implicit knowledge of company's experts as well as to direct the search for further relevant information from patent databases and other scientific sources.

Figure 4 is an exemplary result of the partial results produced after accomplishing the step 1.7, related to the function performed by the nozzle to the sterilant (tool of the sterilization process).

A comparison of the behavioral models according to the Law of Transition to Microlevel (step 3.1) and to the Law of Completeness (step 3.2) allows creating a preliminary overall map of the TS evolution (figure 8).

Then each behavior has been detailed by identifying the stage of development of each interacting pair of the corresponding Minimal Technical System according to the trends of systems evolution.

An excerpt of the resulting NET is shown in figure 9: the application of hydrogen peroxide (H_2O_2) as sterilant through a condensing film is performed by means of a nozzle subjected to several trends of evolution, but still open to further exploitation (figure 9).

For confidentiality issues the authors are not allowed to show further details from the most actual portions of the NET. Nevertheless, it is worth to mention that at the end of the project it was possible to identify several relevant patents not known before to Procomac's R&D department, even outside the traditional field of sterilization by means of chemicals. Due to the high compatibility of those solutions with the possible scenarios of evolution, the company has therefore identified new technologies to be monitored to avoid the appearance of unexpected innovations from the competitors.

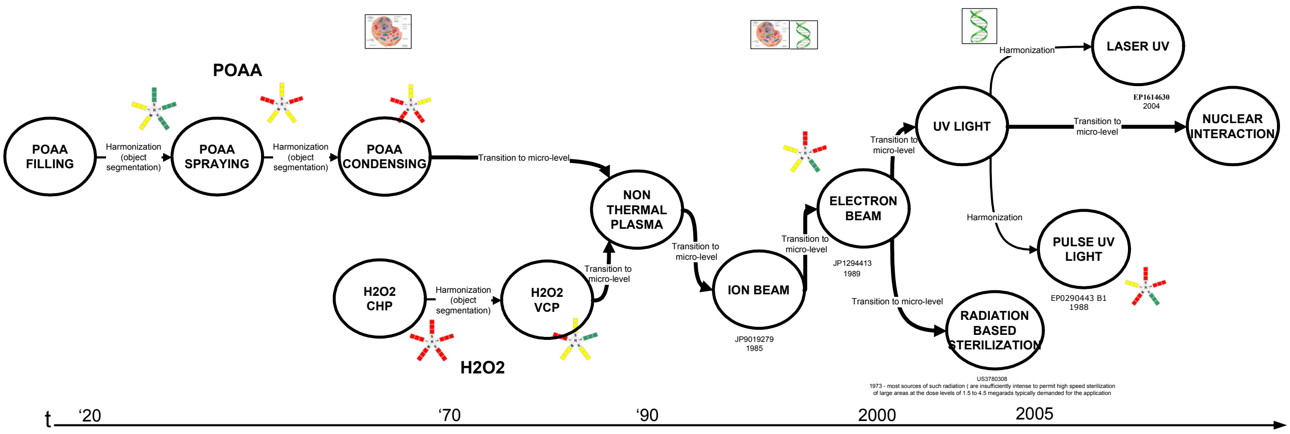


Figure 8: Aseptic filling: ordered set of Behaviors related to the MUF of a sterilizing apparatus, i.e. reduce the amount of pathogenic bacteria on a beverage container (step 3.1 of the proposed algorithm).

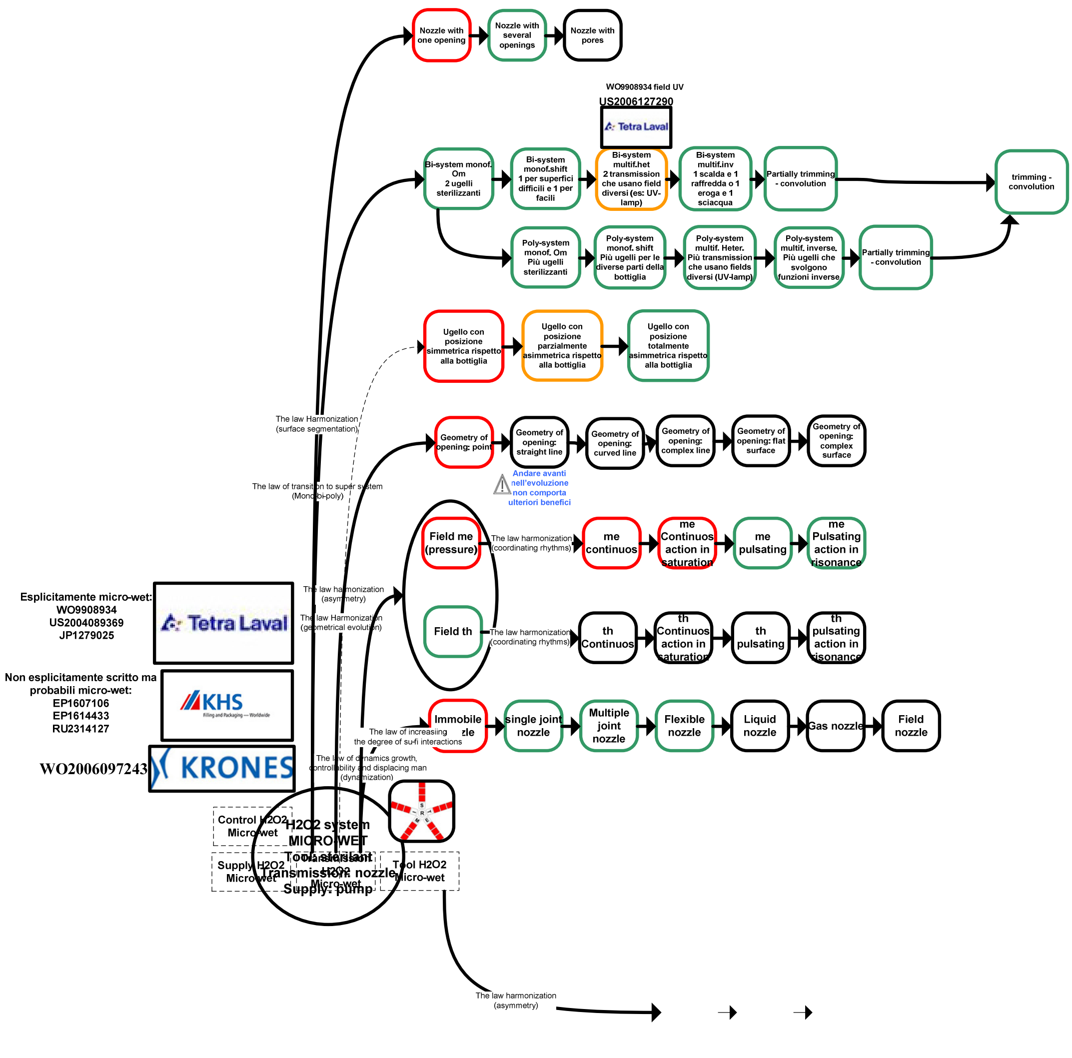


Figure 9: Aseptic filling: excerpt of the NET related to the so-called “microwet” technology for H_2O_2 based sterilization.

Moreover, the NET has been used to define the strategic development of R&D activities, of course in accordance with the company’s vision. The authors consider the positive judgment by the company of the proposed results a contribution to the validation of the algorithm presented in this paper.

5 CONCLUSIONS

The original algorithm for system analysis presented in this paper has revealed so far an adequate applicability to technical systems belonging to different fields of application and with radically different characteristics (operating machines, end products etc).

As a result it is possible to build with systematic and repeatable steps a Network of Evolutionary Trends to be used for supporting multi-criteria decisions and to highlight opportunities of development.

Compared with TRIZ-based forecasting approaches published in literature, the authors have focused their attention on the definition of a precise procedure to identify the elements and the features to be analyzed and benchmarked according to the TRIZ Laws of Evolution.

The authors are further developing the proposed algorithm with the aim of taking into account the analysis of entire business processes, where the evolution of each technical system involved in the process is impacted also by the development of the engineering systems adopted in the other phases; thus, the process itself as a whole is considered as an evolutionary engineering system.

A further direction for investigation is the definition of criteria to prioritize the analysis of certain branches or details of the network. Indeed, when an express analysis is needed due to time or resources constraints, it is suggested to limit the study to the interactions Tool-Object and Control-X (according to the element of the system subjected to a control action). By the way, despite its intuitive nature, the last statement is still to be supported by a proper validation.

6 ACKNOWLEDGMENTS

The authors would like to thank Alessandro Cardillo and Tiziano Montecchi from Università di Firenze for their contribution to the development of the present research and to Paolo Pagliarini R&D Director at Procomac and his team for the feedbacks related to the implementation of the algorithm in a real case study.

7 LIST OF ACRONYMS

BM: Behavioral model

EMS: Energy-Material-Signal

FBS: Function-Behavior-Structure

LESE: Laws of Engineering System Evolution

MUF: Main useful Function

NET: Network of Evolutionary Trends

TS: Technical System

8 REFERENCES

[1] Porter, A.L. et al.: “Technology Future Analysis: Toward integration of the field and new methods”. Technological Forecasting & Social Change 71, pp. 287–303, 2004.

[2] Kucharavy, D. and De Guio, R.: “Problems of Forecast”. Proceedings of the 5th ETRIA TRIZ Future Conference, ISBN 3-7011-0057-8, Graz, Austria, November 16-18, 2005.

[3] Altshuller, G.S.: “Creativity as an Exact Science: The Theory of the Solution of Inventive Problems”. Gordon and Breach Science Publishers, ISBN 0-677-21230-5, 1984 (original publication in Russian - 1979).

[4] Salamatov, Y.P.: “System of The Laws of Technical Systems Evolution” in Chance to Adventure (in Russian), ISBN 5-7545-0337-7. Karelia Publishing House, Petrozavodsk, 1991. pp. 7-174.

[5] Kucharavy, D.: “TRIZ instruments for forecasting: past, present and future”. Tutorials at the 7th ETRIA TRIZ Future Conference, Frankfurt, Germany, 6-8 November 2007.

[6] Fey V. R., Rivin E. I.: “Guided Technology Evolution (TRIZ Technology Forecasting)”. The TRIZ Journal, January 1999, available at http://www.triz-journal.com/archives/1999/01/c/index.htm.

[7] Cavallucci, D.: “Integrating Altshuller's development laws for technical systems into the design process”. CIRP Annals - Manufacturing Technology, vol. 50(1), 2001, pp. 115-120.

[8] Zlotin, B.L. and Zusman, A.V.: “Directed Evolution. Philosophy, Theory and Practice”. Ideation International Inc. ISBN 192874706X, 2001.

[9] Shpakovsky N.: “Evolution Trees. Analysis of technical information and generation of new ideas” (in Russian), ISBN 5-9348-6048-8, TRIZ Profi, 2006.

[10] Pahl, G. and Beitz, W.: “Engineering Design. A Systematic Approach”, 2nd edition, Springer, ISBN:3540199179, 544 pp., 1996.

[11] Ogot M.: “EMS Models: adaptation of engineering design black-box models for use in TRIZ”, Proceedings of the 4th TRIZ Future Conference, Florence, 3-5 November 2004, published by Firenze University Press, ISBN 88-8453-221-3, pp.333-343.

[12] Gero, J.S. and Rosenman, M.A.: “A conceptual framework for knowledge based design research at Sydney University’s Design Computing Unit”. Artificial Intelligence in Engineering, Vol. 5(2), 1990, pp. 65-77.

[13] Takeda, H., Yoshioka, M., Tomiyama, T. and Simomura, Y.: “Analysis of Design Processes by Functional Evaluation Process”, in N. Cross, H. Christiaans and K. Dorst eds., Analysing Design Activity, John Wiley & Sons, Chichester 1996, pp. 187–209.

[14] Hirtz, J., Stone, R. B., McAdams, D. A., Szykman, S. and Wood, K. L.: “A Functional Basis for Engineering Design: Reconciling and Evolving Previous Efforts”, NIST (National Institute of Standards and Technology) Technical Note 1447, February 2002.

[15] Kitamura, Y., Kashiwase, M., Fuse, M., Mizoguchi, R.: “Deployment of an ontological framework of functional design knowledge”, Advanced Engineering Informatics, Volume 18, Issue 2, April 2004, Special Issue on Ontology and it's Applications to Knowledge-Intensive Engineering, Pages 115-127.

[16] Terninko, J., Zusman, A., Zlotin, B.: “Systematic Innovation: An Introduction to TRIZ”, St. Lucie Press, ISBN 1574441116, 208 pages, 1998.

[17] Cascini, G., Fantechi, A., Spinicci, E.: “Natural Language Processing of Patents and Technical Documentation”, Lecture Notes in Computer Science, Springer-Verlag Heidelberg, ISBN: 3-540-23060-2, DOI: 10.1007/b100557, December 2004, pp. 508-519.

On contradiction clouds

Denis Cavallucci, François Rousselot, Cecilia Zanni
INSA Graduate School of Science and Technology, Design Engineering Laboratory, Strasbourg-France

Abstract

Our proposal, through this article, addresses the issue of obtaining, representing and selecting the appropriate subset of contradictions among a complete set of contradictions resulting from an initial situation framing within a specific domain. This contribution has to be understood within the Inventive Design context since most of its grounding relies on the fact that any problem can be formulated as a contradiction (in the sense of TRIZ). By proposing the concept of "contradiction cloud" as three value graphical representation of a set of elementary contradictions, we claim that designers considerably reduce the fuzziness of a contradiction choice prior entering in a solving phase in Inventive Design processes. The modes of interpretation of this cloud will be also presented. The impact of this new element in the teaching of TRIZ was tested both in educational situations within the framework of our engineering curriculum and in several industrial partnerships. A discussion section will then highlight the assets, the limits and the perspectives of our contribution.

Keywords

Contradiction, Clouds, TRIZ, Problem Framing.

1 INTRODUCTION

In the frame of the formalization of inventive practices, few emerging theories propose a really new approach that differs from the quality concerns. Among these theoretical proposals, during the last decades, TRIZ [1] [2] [3] [4] appears as a breakthrough, since its groundings propose a totally new paradigm in design. This places TRIZ ahead several expectations from its potential users, but compared to other quality based approaches, this theory possess its internal own contradiction: to be both [fully axiomatically described] in order to be learnt, transferred and practiced worldwide (also by non experts) AND [fuzzily described] in order to leave spaces for numerous broad and multidisciplinary understandings and interpretations.

In current TRIZ expert practices, the formulation of a contradiction remains a fundamental stage whose relevance can engage the quality of the whole resolution process that follows [5]. Among the available articles and books written by Altshuller, many examples illustrate the way in which a given contradiction can reflect a particular situation. These explanations are extremely useful in a theoretical logic of training on the concept of contradiction, but prove to be of a poor impact in a logic of practical application of this knowledge by a non-expert.

On this subject, two elements seem to be missed in the knowledge corpus on the subject of TRIZ that is written and available. Which role does the perception of an individual play in his way of observing the world when formulating this contradiction? When do formulations of contradictions have to end in the description of an initial situation and with which depth of description?

This lack of completeness in the definition of TRIZ especially limits the modes of transmission of the theory (its learning) moreover in engineering and scientific worlds. But even if a choice of representation is taken, so as a choice of description's depth, it nevertheless leaves to the designer a whole set of contradictions representing key-problems associated with the evolution of a technical system. This statement currently does not allow engaging a relevant resolution process. Indeed, how to represent this whole set of contradictions? How to structure their interrelationships? How to associate this mode of representation with a particular corporate strategy?

2 ON THE NOTION OF CONTRADICTION

As it has already stated in [6], a Contradiction includes 3 types of components: the elements, the parameters, the values. For each of these terms, in the next paragraphs we will clarify their meanings according to our proposed framework.

Elements

The Elements are constituents of a system. From a syntax viewpoint, they may be names or groups of names or nouns (for example: the hammer drives the nail, E = hammer). The nature of the elements can change any time based on the description which is given upon a certain viewpoint. Thus "the hammer drives the nail" may become "the anvil pushes the nail" when expressed by another expert. In the second case, E = anvil. For a third expert "The man pushes the nail". In this case E = The man. It is important, when identical situations are described with divergent points to organize a consensus in forcing the reformulation within the meaning of fundamental physics and the systemic decomposition according to contradiction's syntax.

Parameters

Parameters describe elements by assigning them a specificity, which reflects an explicit knowledge of the area observed. They are mainly names, objects or adverbs. The form of expression is diverse, sometimes contradictory when expressed by different experts. We distinguish two categories of parameters:

- Active Parameters (AP) (sometimes also called "control parameters"): On which the designer has the power to modify its state (the designer can make the choice to design an anvil having a light volume or small one, in this case volume = AP). This type of formulation has generally two directions that can potentially result in positive impacts on the object or its super system.

- Evaluating Parameters (EP): The nature of these parameters can be observed in their ability to evaluate both positive and negative results of a designer's choice. The consequence of designing an anvil having an important mass is that its ease of driving is improved (in this case ease of driving = EP). This type of parameter has often a logical sense of progress (its positive direction seems obvious) while the other seems absurd.

Values

Values are mostly adjectives used to describe a parameter (the volume of the anvil should be heavy; in this case V = heavy). Note that the fundamental aspect of the concept of contradiction, when expressed at a physical level, is the qualitative difference of values of a parameter: if the meaning induced by the adjective associated with the V leads to positive aspects, then it is essential (in order to complete a contradiction) to investigate adjectives qualifying V's antonyms to highlight the contradictory aspects of the analysis and then to validate it or not. We choose, as a first step for practical reasons, to limit the values of V pairs consisting of an adjective and its antonym. Thus, a heavy anvil volume leads to an ease of driving while a light anvil volume results in an ease of manipulation; in this case the pair chosen for V is heavy / light.

$TC_{n.m}$	Active Parameter AP_n	
	Va	V$\bar{a}$
Evaluating Parameter EPx		
Evaluating Parameter EPy		

Figure 1: Generic table of a contradiction (from the TRIZ point of view) according to [6] [7].

3 GATHERING ELEMENTS FOR CONTRADICTIONS SYNTHESIS

Since Parameters are crucial components of contradictions. There is a need for a structured way to collect them, to ensure exhaustively their domain coverage and to trace their link with laws of engineering systems evolution in order to later be able to associate contradictions and laws. Within TRIZ body of knowledge, there exist three sources that facilitate the emergence of parameters prior to the synthesis of contradictions.

Multi-screens represent a permanent ongoing picture of the studied system in the context of its evolution correlated with its supersystems and its internal subsystems. To fully understand the mechanism of a system's evolution, it can be observed that parameters are involved in this evolution in the sense that they have evolved either in a positive way or in a negative way. Such an evolution through parameter's synthesis can be disclosed with domain experts using multiscreen scheme (see figure 2) as a graphical support for group discussion.

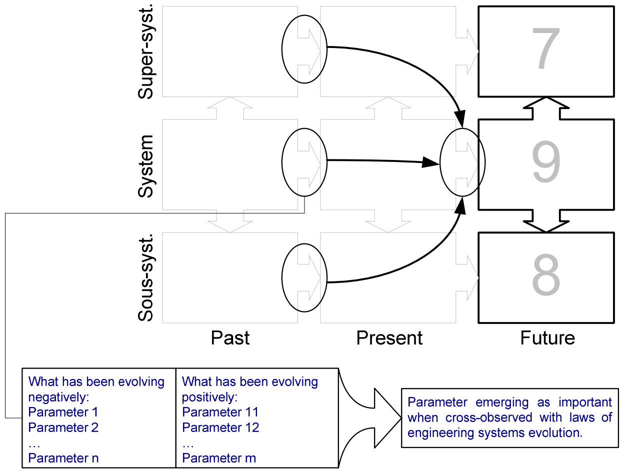


Figure 2: Location of parameters extracted from the multiscreen scheme analysis

Another important point of a TRIZ study is to observe an engineering system in the context of its evolution through Altshuller's laws. Here, each law become an opportunity to observe the studied system statement (its actual maturity regarding "S" curve, its potential evolution (through a minor improvement or a breakthrough – see figure 3). As a result it will be pointed out the importance of a law or another in the evolution (see a more detailed explanation in [8]) and the list of parameters previously started using multiscreen can here be completed by initiating a group discussion on each law and adding any new emerging parameter to the list. At this point, it is important to preserve a trace of a link between a parameter and a law since we will later need to use these links for contradiction ranking.

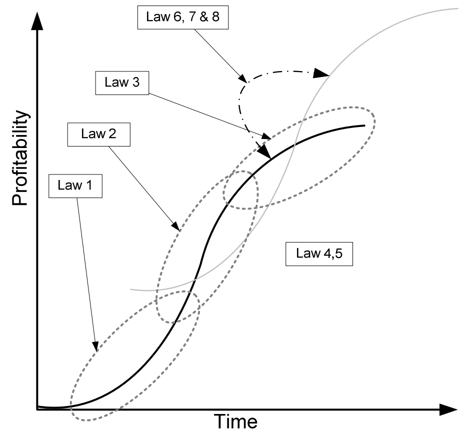


Figure 3: Summary of Altshuller's laws location along the "S –curve" scheme

A third opportunity to complete parameter's list is to use ENV template (from OTSM-TRIZ) [9] [10]. Here we are assuming two major steps in the contradiction synthesis. The creation of influencing links between parameters (revealing also whether a parameter is active or evaluating) and the contradiction synthesis whose formalism forces us to find parameters influencing the opposite state of an assumption for a correct contradiction formulation. Until ENV template is not complete (Figure 4), we can't consider that all influencing parameter of the study are disclosed.

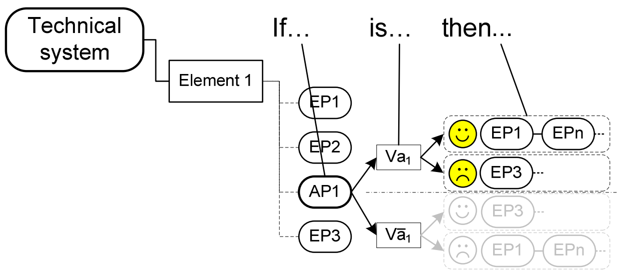


Figure 4: Template for ENV diagram completion (after OTSM)

Let us note that there is a high probability that the nature of the expressed knowledge will not appear using the contradiction syntax. Indeed, few experts are used to formulate both sides of a contradiction since traditionally a single side of a contradiction is expressed. Nevertheless through this single side formulation, we propose to enter in the contradiction syntax, with the aim to systematically questioning experts to highlight the opposite side of the contradiction. In case of impossibility of finding an inverse positive situation, there might not be any contradiction attached to this AP. In other cases we can either reveal a new EP or a link with an existing one.

Links between contradictions to form a network

We have observed, within solving processes, that when contradictions having the same active parameter were considered, solutions concepts generated by design members were likely guiding the thinking process to similar categories of ideas. This creates a limitation in the scope covered by solutions. In a reverse way, when a similar couple of EP is considered, a solution concept impacts unexpected contradictions since we did not engage the solving process through these ones. As a consequence and in order to be able to compute and observe the consequence of a specific solution concept (for instance useful in R&D decision making) links between contradictions have the same pair of EP can be created and sorted upon the fact that their root problems are sorted the same way.

On the amount of contradictions: from one to many

When analyzing TRIZ literature standards, one can easily find a huge amount of examples of contradiction formulation starting from an initial situation description. Among 150 example found in TRIZ literature (this is not an exhaustive amount but simply a statistically relevant population), 95% only express a single contradiction behind a more or less wide initial situation. We can therefore ask ourselves several questions:

1. Is the contradiction formulated in this way the only existing one behind the initial situation?
2. Would another designer/engineer (even trained to TRIZ) formulate the same one?
3. If the initial situation is described in other terms (although expressing the same thing) will the contradiction be formulated in the same terms?

The first question rise the problematic of “space coverage” where within a given domain, an existing problematic situation (possibly called an administrative contradiction in TRIZ terms). Behind this notion sub-questions appeared and invited us to consider further investigations for clarifying possible answers since we couldn’t find any references in TRIZ literature. Among these questions: “how deep should an initial situation description stop in order to obtain satisfactory domain coverage for an efficient solving process to be engaged?”

The second question raises the problem of the “point of view” and its possible links with the nature of the contradiction terms. Will the evaluating parameters be the same if the concerns of the “formulator” changes? Are there elements within the TRIZ literature that are helpful for appropriately observing an initial situation? Again we couldn’t find any elements to axiomatically setup a process and ensure a relevant guide for a contradiction formulation process.

The third question raises the problem of the “description accuracy” and its possible links to lead the “formulator” to an inappropriate contradiction formulation. Regarding this issue, we can also link our observations with some existing field of research like semantic analysis and text mining procedures. Here, we already have partial answers proposing to observe patents as a voice of authority to describe accurately inventive problems. But beyond patents or reference texts (such as encyclopaedia or informational web-contents) there is a human interpretation or expertise in which we should pay attention to since it represent 98% of a resources for contradiction formulation in TRIZ literature. Several sub-questions should once more be formulated: “how much inaccurate understanding of an expert “a formulator” leads to an inappropriate contradiction formulation?”

To conclude on this subject, our proposal to consider the expressed questions in this section is to cover the domain and the problem space in crossing several experts viewpoints and text of authority known and accepted in their domain (patent, research reports, peer reviewed scientific literature). This is not a way to avoid any precise answers on the posed questions, but simply to lower the inaccuracy of contradiction formulation by spending more time and resources for a wider domain coverage and co-validation prior to decide which sub-set of contradiction shall be engaged in an inventive problem solving process using any existing TRIZ technique.

4 REPRESENTING AND POSITIONING CONTRADICTIONS

We have identified 3 ways for differentiating contradictions. Our aim is to be able to use a graphical display of these differences in order to be able to analyse, rank and choose which contradiction subset can be engaged in a solving process. The next paragraphs summarize our 3 ways of contradiction weighting:

- Importance
- Universality
- Amplitude

Importance

The contradictions components (an Active Parameter a pair of Evaluating Parameters) do not have the same importance; Evaluating Parameters better characterize the essentials of the problem than others. Thus, it is possible to associate a qualitative value to each Evaluating Parameters which compose a group of contradictions. This evaluation has only the aim to place them on a relative scale of importance. The essence to be preserved among parameters relationship is the scale amplitude to be simply established around a certain amount of divisions out of a scale allowing this differentiation.

Then, the role of the Active Parameter within a contradiction is not of the same order as the one provided by Evaluating Parameters. Very often, the active parameter represents the element on which it is necessary to act in a contradiction. We propose that the element which will allow differentiating a set of active parameters between them articulates around the potential impact that this APx (setted at Va AND Vā) will have on the problems to which it is related. This fundamental aspect in the importance of a contradiction is likely to atrophy or dope the importance of a pair of EPs, we gave the APs capacity to influence EPs by a multiplying coefficient. This way, we allow the addition of both EPs (EPn+ EPm) to be reduced when facing a weak impact or to be multiplied when facing a strong impact. For this multiplying coefficient, we agreed on a range from 0,5 to 2.

Therefore, X (importance), the first criterion of differentiation among different technical contradictions may be expressed:

Let us consider ITC, the set of all the identified technical contradictions and a technical contradiction TC $\in$ ITC, represented by a triplet:

$$TC = (AP_i, EP_j, EP_k)$$

meaning the association among an active parameter AP_i and two evaluating parameters EP_j and EP_k.

AP_i is associated with a multiplicative coefficient α_{AP_i} and EP_j and EP_k are associated with $C_{EP_j}$and C_{EP_j},coefficients that represent the relative importance among evaluating parameters.

Within this framework, the importance X of TC is:

$$X_{TC} = \alpha_{AP_i} * (C_{EP_j} + C_{EP_k})$$

Universality

In our observations of the typology of sets of contradictions, we noted that EPs qualify the objectives sometimes hidden in inventive challenges. Some of these EPs seem to appear in a recurring way in a large amount of contradictions. This observation led us to build the assumption that a simple measurement of the universality of a contradiction could be established. This measurement would aim at specifying that a contradiction having recurrently present EPs in a large amount of other contradictions represents the universality of this same contradiction. The universality criterion Y thus takes the following form:

Let us consider again the expression of a technical contradiction TC = $(AP_i, EP_j, EP_k) \in$ ITC.

We calculate QTY_{EP_j} and QTY_{EP_k}, the quantities of occurrences of EP_j and EP_k in ITC.

Within this framework, the universality Y of TC is:

$$Y_{TC} = QTY_{EP_j} + QTY_{EP_k}$$

Amplitude

In the structure of a contradiction, an AP is associated with a pair of EPs. But in a more general way, the same AP is often associated with a variable quantity of EPs. As a result, some APs involve the opposition of only one pair of EPs whereas others have an impact on a large amount of EPs and involve the opposition of a consequent series of pairs of EPs. Our proposal is thus to establish a third criterion of differentiation, Z (amplitude), that is related to the quantity of pairs of evaluating parameters associated with the same active parameter, to form different contradictions. This criterion would take the following form:

Let us consider again the expression of a technical contradiction TC = $(AP_i, EP_j, EP_k) \in$ ITC.

We calculate QTY_{AP_i}, the quantity of all the pairs (EP_x, EP_y) related to the same AP_i that appear in ITC.

Within this framework, the amplitude Z of TC is:

$$Z_{TC} = QTY_{AP_i}$$

We thus have 3 criteria X, Y and Z to differentiate contradictions. While placing criteria X and Y according to a system of axis, we obtain a cloud of dots. By associating each point of this cloud criterion Z, we obtain (as represented on figure 6) a group of dots with variable diameters.

Linking contradictions

The notion of contradiction network has been sometimes brought forward by several publications. What remains unclear so far is the way a contradiction will be linked to the other. Even if some proposals have been made, a clearly elaborated contradiction network representing a set of contradictions within a given domain has not been published so far. Another rising question is about the term used, are we concerned by a network or by a graph? Despite the fact that both terms have been declared as very close [11], in our approach, we will start by formulating the aim of such eventual links. Then, since we are aiming at using algorithms for considering the set of connected contradictions, the term "graph" seems closer than the term "network". A first type of link is to represent either a cause-and-effect chain or a mono-directional engineering consequence between sets of evaluating parameters. This will undoubtedly be helpful for identification of the root contradiction to be considered in priority. Revealing such links can additionally be eased using a table representation.

A second type of link is to draw a bidirectional line between two contradictions having the same set of evaluating parameters. Such a link has been proven to be helpful when using Inventive Principles associated to Altshuller's matrix since both entry parameters (to be improved and not to be degraded) are the set of evaluating parameters from the considered contradiction. Added to the layout proposed in our cloud representation such links can highlight subsets of contradictions possible resolved in chain by considering the most weighted one as a priority target.

The advantage of "clouds" representation

The obtained set of dots with variable diameter is sometimes insufficient for highlighting a subset of contradictions since we have already tested the proposed method in [12]. We encounter a limitation in choosing often a subset within a group of contradiction possessing the same active parameter. In several other situations, we have observed that when the active parameter was different, the core element at the heart of the observation provoked solution concepts of a different type, enlarging the scope of the proposed solution to different areas.

This had a positive impact on the study since a wider solution space was covered with a limited amount of solution concept, more evenly distributed within several scientific domains. Here, we would like to underline that what is targeted is not the quantity of solution concepts but their layout among several domains, a situation convenient for inventive outcomes.

As a result we have enhanced our graphical representation from a single set of dots to several sets belonging to the same active parameter, highlighted by a set of clouds covering the space of each subset of contradiction belonging to the same active parameter. The range displayed in the X and Y axis automatically adjusts in order to display all existing dots in optimizing the graphical area.

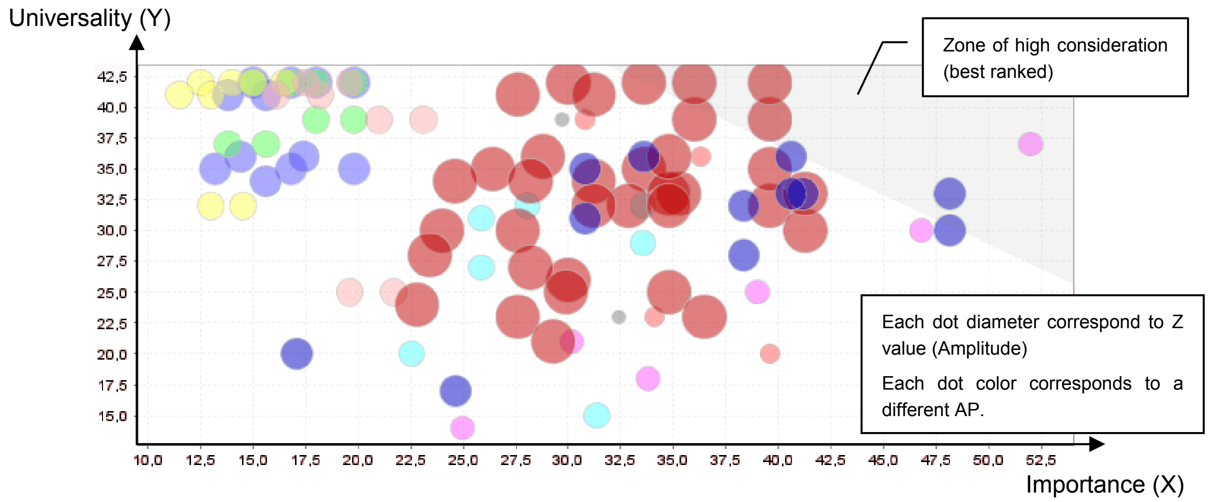


Figure 5: Graphical display of clouds featuring X, Y and Z values

Choosing a reduced set of contradictions among others

The advantage of such a representation is to clearly display all contradictions concerning a problematic domain. This display, organized based on the 3 value described before, highlight that some contradictions, among others, have a more significant impact of the covered domain if located in the upper right corner of our graph (see grey zone). Therefore, the logical use of such a representation is to decide, considering time resources, which contradictions are to be treated in priority for a wider impact on an initial complex problematic.

5 TEACHING SITUATIONS: FIFTH ENGINEERING YEAR OF INSA STRASBOURG

We have started a testing through 85 engineering student of the fifth year, coming from seven different field of engineering. The condition of this campaign started with the constitution of groups from 3 to 4 persons working on a technical object's evolution. The first part of this directed work consisted in using our approach in order to synthesize and represent a set of contradictions. Based on this representation a choice needed to be justified in the chosen subset of contradiction prior to engage a solving process using Inventive Principles and the matrix.

The available time for this test was 28 hours:

• 14 hours of theory for teaching our approach

• 14 hours of project divided in 7 sessions of two hours each.

Due to the limitation of time, both for teaching and directed work, chosen objects should be simple (not carrying a lot of components and different technologies). Only basics of TRIZ were taught and subjected to use (for instance limited to Multiscreen, laws and Inventive Principles).

Summary of the teaching session's results

What appears the most significant outcome from the teaching sessions is the improvement of the student's autonomy in conducting the gathering of parameter and the choice of the contradiction to be engaged in the solving process. Compared to the previous year (when our approach was absent from the syllabus) the students requested much more assistance when conducting contradiction synthesis and choice. As a result, we decided to develop this procedure in a software prototype for further investigations and confirmation of our first observations.

6 INDUSTRIAL CASE STUDY: ARCELORMITTAL'S CONTINUOUS ANNEALING FURNACE

Steel material hardens after cold rolling due to the dislocation tangling generated by plastic deformation. Annealing is therefore carried out to soften the material. The continuous annealing process comprises heating, holding of the material at an elevated temperature (soaking), and cooling of the material. Heating facilitates the movement of iron atoms, resulting in the disappearance of tangled dislocations and the formation and growth of new grains of various sizes, which depend on the heating and soaking conditions. These phenomena make hardened steel crystals recover and re-crystallize to be softened.

This type of annealing involves uncoiling, and welding strips together, passing the welded strips continuously through a heating furnace, and then dividing and re-joining the strips.

The total length of the strip in the line is approximately 2,000m while its travel speed is about 200 to 700 m/min for a strip of 0.15mm in thickness (a maximum speed of 1,000 m/min. is still possible). To operate such lines, speed control, tension control, and tracking control of the strip are necessary, in addition to a high level of automatic temperature and atmosphere control.

Our company partner has observed for already several years that among these parameters an optimum situation is reachable but strip defect are observed and provoke line interruption regularly.

Line interruptions are provoked mainly due to thermal situation within the furnace.

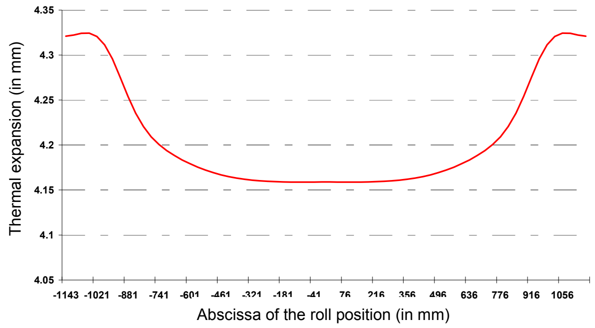


Figure 6: Roll profile distortion under thermal influence in a furnace at Max. Temperature

The observed thermal expansion of rolls (transporting the strip) is unevenly distributed along its volume (see figure 5) resulting in two different situations:

- Lateral strip movement due to non-perpendicular velocity of the strip to roll axis. As a result, the strip is hitting the furnace and gets degraded.
- The formation of thermal folds, depending directly on strip traction, provoke the necessity to stop the process, remove either partially or completely the damaged strip and start over the production line.

Summary of the industrial use's results

The partnership consisted in proposing a technologically validated solution to these recurrent problems, taking into consideration all existing attempts (both partial successes and failures) already tested and their competitor's known solutions (mostly observable through patents).

The figure 4, used for explaining our graphical way of representing contradictions, displays the result of our first investigation in gathering all contradictions of the problematic domain expressed by ArcelorMittal's experts. A sum of 105 contradictions was expressed and the clouds graph has highlighted in the upper right corner several of them (figure 7). When discussing on this first set, a reduced choice was made to treat four of them (one belonging to each AP top ranked in the graph). This choice can be explained by the decision of the group to address a wider way of resolving the case, but also to efficiently use our available time with continuous annealing experts.

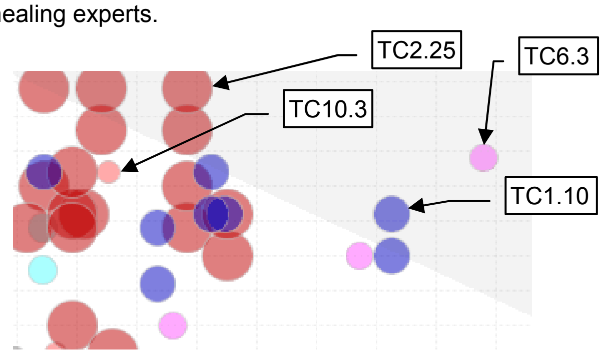


Figure 7: Upper right corner of the clouds graph with selected set of contradictions

The result of the decision discussion was to treat in priority:

- **TC6.3**: (E)[Roll]'s (AP6)[Geometry in cold states] must be both (Va)[plane] for (EP7)[minimising strip bending] AND (Vā)[curved] for (EP6)[minimizing strip deviation].
- **TC2.25**: (E)[Roll]'s (AP2)[local adaptability] must be both (Va)[yes] for (EP7)[minimising strip bending] AND (Vā)[no] for (EP12)[minimizing roll's complexity].
- **TC1.10**: (E)[Roll]'s (AP1)[thermal expansion coefficient] must be both (Va)[low] for (EP7)[minimising strip bending] AND (Vā)[high] for (EP11)[cost reduction].
- **TC10.3**: (E)[Roll]'s (AP10)[diameter] must be both (Va)[small] for (EP6)[minimising strip deviation] AND (Vā)[big] for (EP2)[maximizing line productivity].

What has been observed in the industrial situation is a significant reduction of fuzziness concerning the choice of the contradictions to be engaged in a solving process. Methodologically, the prior art was to intuitively decide which problem to tackle without a deep analysis of the impact of this choice on the efficiency of the findings. As a result, various brainstorming-like sessions have led to numerous alternatives having a low satisfactory impact in terms of expected results. In our case, after the four contradiction resolution using classical TRIZ tools, thermo-mechanical calculations of the chosen solution concept have proven that a simple concept might have an important impact on continuous annealing lines. This has raised the confidence in the choices undertaken and eased the justification of resources demands that engineers have requested to their managers for developing the concept and test in real "on line" situations.

7 DISCUSSIONS

The proposed contribution has been proven to be efficient both in educational and industrial contexts. The accuracy of the methodology description does not leave place for fuzziness and allows educators to base their Inventive Design teaching on a precisely established procedure. In parallel, such accuracy has also been appreciated in industrial situations since each engineer involved in the study can easily understand why we choose this problem and how we formulate it prior to engaging a solving process despite the fact that they might not have been trained to TRIZ fundamentals.

The limitation of our proposal has also been studied and the most evident one we found was that our study mostly relies on the fact that an appropriate set of active parameters has been disclosed. Even if a consequent knowledge mapping work is achieved within a study team, we are nevertheless directly dependent on the fact that the known partial solutions are exhaustive or that the team has properly identified all potentially concerned active parameters. In light of this observation, our next investigation in line with the subject developed in this article will be devoted to the study of the completeness of a set of active parameters to describe an initial solution space.

8 CONCLUSIONS

As an introduction to this paper, we underlined the lack of procedure for contradiction gathering and representation in TRIZ literature. Although TRIZ practices still remain rather intuitive (expert dependent), there is an urgent need for formalizing procedures aiming at simplifying both TRIZ education and robust industrial practices. By proposing a 3 value weighing and comparison together with a graphical representation, we have observed a significant improvement of the confidence practitioners (both students and experiences engineers) were claiming regarding TRIZ. Compared to situations where they were more relying on the voice of authority and the expert's intuitive know-how, the observed situation shows a willingness to appropriate themselves the methodology and a capacity to later justify to their managers (for engineers) or during a viva (for students) the way they have investigated their initial situation, stated the problem and engaged efforts in a specific direction more than another.

Finally, our developed approach is aiming at being an open framework for discussion and improvement. We have observed that using a software prototype, the observed phenomena was even more visible and has open new perspectives in the systematization of Computer Assistance to Inventive Practices.

REFERENCES

[1] Altshuller G.S., 'To Find an Idea: Introduction to the Theory of Inventive Problems Solving', Novosibirsk, Nauka, 1986.

[2] G.S. Altshuller: 1999, The Innovation Algorithm: TRIZ, systematic innovation, and technical creativity, Worchester, Massachusetts: Technical Innovation Center. ISBN 0964074044 (origin: G.S. Altshuller: 1969, 1973. ALGORITHM OF INVENTION, Moscowskiy Rabochy, Moscow)

[3] Althsuller G.S., Zlotin B.L., Zusman A.V., Filatov V.I. "In search for new ideas: from insight to technology", Kishinev: Kartya Moldovenyaska Publishing House, 1989. ISBN 5-362-00147-7.

[4] G.S. Altshuller: 1984, "Creativity as an exact science: The Theory of the Solution of Inventive Problems", Gordon & Breach, ISBN 0-677-21230-5 (origin: G.S. Altshuller: 1979. CREATIVITY AS AN EXACT SCIENCE. Sovietskoe radio, Moscow.)

[5] Pinyayev A., "Transition from administrative contradiction to the technical one in the analysis of inventive problems". *Manuscript*.

[6] Cavallucci, D. and Eltzer, T., 2007, Parameter Network as a mean for Driving Problem Solving Process, International Journal of Computer Applications in Technology", Vol. 30, No.1/2 pp. 125 – 136.

[7] Zanni C., Cavallucci, D. and Rousselot, F. (article submitted); An Ontological Basis for Computer Aided Innovation, Special Issue of Computers in Industry "Computer Aided Innovation", ISSN:0166-3615, ELSEVIER.

[8] Cavallucci, D. and Rousselot, F. (2007); Evolution Hypothesis as a means for linking system parameters and laws of engineering system evolution, 7th ETRIA's International TRIZ Future Conference (TFC2007), Nov. 6-8, Franckfurth – Germany.

[9] Khomenko, N. and De Guio, R., OTSM Network of Problems for representing and analysing problem situations with computer support, 2nd IFIP Working Conference on Computer Aided Innovation, Technical Center Brighton, USA, Springer (2007).

[10] Khomenko N., De Guio R. , Lelait L. and Kaikov I., A framework for OTSM-TRIZ based computer support to be used in complex problem management, International Journal of Computer Applications in Technology, Vol. 30, No. 1/2, 2007, pp 88-104.

[11] G. D. Batosta, P. Eades, R. Tamassia, and I. G. Tollis, *Graph Drawing: Algorithms for the Visualization of Graphs,* Prentice Hall, Upper Saddle River, New Jersey, 1999.

[12] Cavallucci D., Rousselot F. and Zanni C.; Representing and selecting problems in Contradiction Networks, 2nd IFIP Session on Computer-Aided Innovation, WCC 2008 Sept., MILANO.

Development of a framework for using TRIZ in a co-disciplinary design environment

Rogier W. de Vries[1], Tom H.J. Vaneker[1], Valeri Souchkov[2]
[1]University of Twente, Faculty of Engineering Technology, Netherlands
[2]ICG Training & Consulting, Netherlands

Abstract

The work that is described in this report consists of creating a framework for facilitating the use of TRIZ in analysing and solving mono- and co-disciplinary design issues during design of electromechanical products at a large company in the Netherlands. Guidelines have been developed that serve as a strategy for implementation of this framework against the background of (co-disciplinary) design issues. The guidelines are based on interviews with employees from different disciplines and lessons learned from a previous attempt at introducing TRIZ. Both for the development of the framework as well as for the testing thereof intensive case studies were used. As the case studies contain many company proprietary details they cannot be depicted in this article. Consequently the paper will remain focussed on the framework developed.

Keywords

TRIZ, Co-disciplinary Design

1 INTRODUCTION

For many complex electromechanical products the demands posed on the performance of such a system are quite exhaustive, because of the nominal performance that is expected, market demands, product to market times, usability, serviceability etc. To come to a design that complies with these demands several engineering disciplines (a.o. mechanical, thermal, electrical, and systems engineering) have to work together in close harmony. What is observed in general practice is that design issues that arise during the conceptual design stage often lead to trade-offs on the required functionality of the individual disciplines. This occurs because these types of design issues often require more than a simple (numeric) optimization of a number of parameters. For example, the search for a solution can become a battle to decide which discipline is most important. As in true multi-disciplinary design no dominant discipline can be defined, these battles are decided on other aspects, such as seniority, personal skills of the designers or the *perception* of the importance of a discipline etc.

Within this paper the search for a structured, easily implementable and maintainable process/method to come to an original, integrated, “out of the box” solution will be described. Such a solution should be able to satisfy the demands of all the involved engineers / disciplines uncompromisingly. After an investigation of several methods TRIZ has been identified as the most promising starting point for further research, because classical TRIZ offers a multitude of solution creation algorithms. It does however not specifically have any methods that facilitate solving issues that spring from multiple disciplines. If a co-disciplinary issue would be solved by means of classical TRIZ, the co-disciplinarity of the issue solving process would to a large extend depend on the extent in which the people involved are able to look beyond their areas of expertise. Hence, in order to use TRIZ in a co-disciplinary design environment with the goal of interdisciplinary design innovation, it was decided that a framework needed to be created around TRIZ that facilitates direct problem solving in an interdisciplinary way.

For that reason a master thesis project was defined (emerged) with the following subject: “*Create a framework for facilitating the use of TRIZ in analyzing and solving mono and co-disciplinary design issues during the design of complex electromechanical products*”. This paper reports on the results of that thesis project.

2 RESEARCH APPROACH

This chapter will describe three facets of the assignment: a research into what is meant with “co-disciplinary design”, a research into an actual co-disciplinary design environment, and finally in paragraph 2.2 an outline is given of the proposed solution route for the development of the framework.

2.1 Co-disciplinary design

The thesis work should lead to a framework that facilitates the use of TRIZ in solving co-disciplinary design issues. Within this project Co-disciplinary design is defined as a possible combination of all styles of discipline cooperation in product development. For that it should be investigated what kind of disciplinary cooperation categories are available and what effects they might have on the development of the framework.

Mono-disciplinary design

Mono disciplinary design focuses on products that can be successfully developed based on the knowledge of only one discipline. It is however often sheerly impossible to finish a product design without knowledge from multiple disciplines. For that reason mono-disciplinary design and research must be considered a theoretical bottom line in disciplinary integration.

Multi-disciplinary design

Multi-disciplinary is defined [1] as disciplinary cooperation with the least amount of discipline integration. In multi-disciplinary design, engineers from two or more different disciplines work on a project but do not synthesize their methods. The design process occurs in parallel.

Trans-disciplinary design

Trans-disciplinary [2] is in some respect opposite to multi-disciplinary as it has the *largest* amount of integration possible in co-disciplinary: the integration is at such a level, that the individual disciplines can be marginally recognized by their methods and terminologies. In literature trans-disciplinary is sometimes stated as a philosophical, utopian concept.

Inter-disciplinary design

Inter-disciplinary is positioned between multi-disciplinary and trans-disciplinary. Depending on the balance between multi- and trans-disciplinary, there are quite a few definitions on interdisciplinary. For example [3] states "*Interdisciplinary research is any study or group of studies undertaken by scholars from two or more distinct scientific disciplines. The research is based upon a conceptual model that links or integrates theoretical frameworks from those disciplines, uses study design and methodology that is not limited to any one field, and requires the use of perspectives and skills of the involved disciplines throughout multiple phases of the research process*".

It can be concluded that for successful development of the framework for co-disciplinary design the framework should be able to deal with a varying number of involved disciplines. Furthermore the level of integration of those disciplines can vary from non-existent (multi-disciplinary) to fully integrated (trans-disciplinary).

2.2 The design process characteristics

In most companies that develop high end electrical products, successful product design used to be about the application of the most sophisticated electric and mechanical components; utilization of superior components would lead to an improved final product. But times have changed. Nowadays the specs for nominal performance include items addressing aspects such as a very high reliability and superior serviceability, continuous miniaturization, reduced total system weight, customizability etc.

These ever increasing demands inevitably lead to design issues. As an example: improving the number of processes depending on electrical power leads to an increase of the heat generated by the active components. On the other hand, the demands for lighter weight and miniaturization lead to compression of the active components within the smallest possible volume. This again leads to cooling problems. From a historic point of view, designers of active electrical/electronic components were often regarded as "the dominant discipline". But this is no longer the case, because for successful development of new high end electrical products it is considered that these 3 disciplines (mechanical, electrical and thermal design) require equal priorities.

2.3 Framework requirements

Edison once stated that "genius is one percent inspiration and 99 percent perspiration". On the other hand, Altshuller stated about TRIZ: "inventive problem solving using TRIZ should be efficient; it should be able to solve problems that are stagnant, and should be able to utilize newfound methods [4]". The above statements explain why TRIZ was identified as a possible basis for setting up the framework for co-disciplinary design support. In contradiction to classical trial-and-error based methods TRIZ already incorporates the aspects that facilitate (stimulate) looking across the border of one's own discipline. With that in mind, successful application of TRIZ is likely to lead to conception of inventive integrated solutions requiring fewer design iterations.

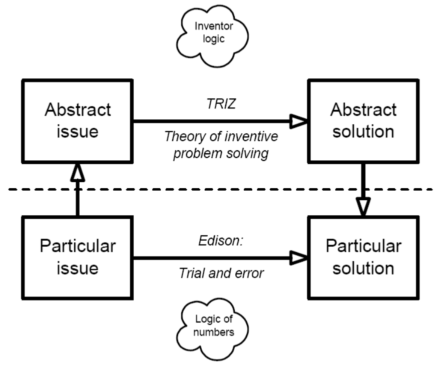


Figure 1: Problem abstraction using TRIZ

When looking at the example of paragraph 2.2 one could imagine that the preferred solution route would focus on developing knowledge that would transform the group of product development disciplines involved from multi-disciplinary towards trans-disciplinary. Although this approach might work, a disadvantage is that a new body of knowledge has to be developed for each new subgroup of disciplines needed to solve a design issue. This is why TRIZ is chosen as a possible basis for product development in a co-disciplinary design environment. If all disciplines are able to abstract their design issues (Figure 1), communication (integration) between disciplines could take place on the abstract level.

One of the requirements set by the company at which the research was executed was that introduction of TRIZ in the product development process should not imply that all product developers should be forced to become a TRIZ *expert*. So in a nutshell it was requested to develop a framework that supports the use of the TRIZ methods during product development whilst utilizing the smallest number of hours of TRIZ training for product developers.

Interviews with employees that were previously introduced to the use of TRIZ revealed some important insights. The abstraction process was seen by the interviewees as the constraining part of the process. This was aggravated by a perceived lack of TRIZ-experience.

2.4 Definition of framework Characteristics

Largely based on the observations described above, the following list of project and framework requirements was defined.

1. When applying TRIZ, one should be familiar with its background and philosophy and not just treat it as a quick fix.
2. The creation of abstract issues should be well supported, since it can be hard for engineers to make the transition from their particular problem to a more abstract problem that TRIZ can use as input.
3. TRIZ should be carefully marketed as a design tool and not simply be forced onto the engineers that are expected to work with it.
4. Because the opinion on a framework that uses TRIZ is not positive beforehand, the development and implementation of a framework should be very well organized and well executed to give it the benefit of the doubt.
5. Multiple case studies in different disciplines should be performed to provide proof for the correct functioning of the framework.
6. In a conflicting situation, the framework should provide the conflicting discipline's engineers with mutual insight into the technical significance of the conflict from the discipline's standpoint.

7. The framework should promote problem solving as an integrated effort, not as an iterative effort. As such it should result in fewer iteration cycles.

3 BASIC FRAMEWORK DEFINITION

Based on this list of characteristics the subsequent basic layout of the framework was proposed.

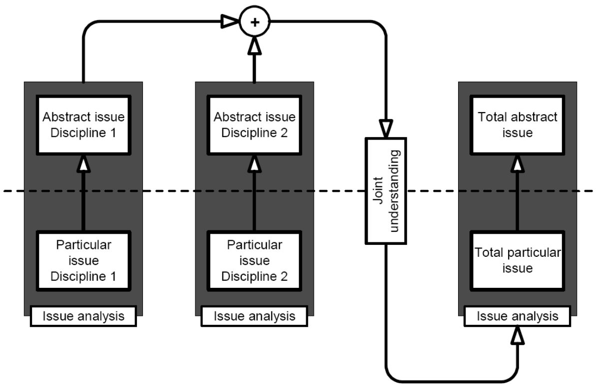


Figure 2: Basic framework layout.

To use this framework, experts from individual disciplines will be asked to abstract the issue from their disciplinary standpoint. For the abstraction process itself, several well known TRIZ tools can be used. To facilitate the abstraction process each discipline within a co-disciplinary design problem will need the support of a TRIZ expert. At the abstract level the individual criteria are evaluated and the involved TRIZ expert tries to come to an understanding of the total issue. Based on that understanding the abstraction process is entered again in order to define an overall issue and come to a general solution.

The basic framework depicted above addresses characteristics 2, 6 and 7 as listed above. But, for a successful introduction, four more characteristics have been defined. To investigate how these demands can be incorporated into the framework and introduction process several case studies have been executed. Based on these case studies a final layout of the framework has been proposed.

4 CASES

Three TRIZ case studies have been performed to investigate the (co-disciplinary) applicability of TRIZ. As such, performing these case studies will satisfy guideline 5. To prove that TRIZ can be used for just about any issue, a "social science" (i.e. non-technical) case study has been added to this list.

1. Mechanical engineering
2. Electrotechnical engineering
3. Social science

These case studies should be successful in two areas: providing innovative design concepts that have potential of being implemented, be it after some research. These two areas are chosen to make sure that the use of TRIZ is not just a "nicety", but actually provides useable design concepts.

The actual instance of the framework used for the cases is displayed in more detail below. The engineering experts from the company, assisted by the master student, have taken on the engineering roles. Although backed up by an experienced TRIZ user, the role of the expert is also taken on by the master student.

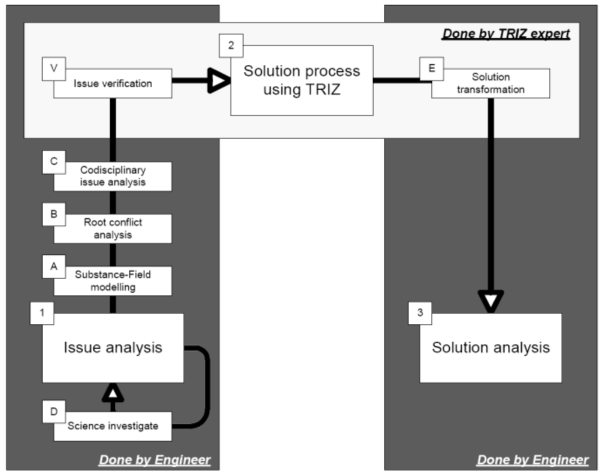


Figure 3: Framework layout for test cases

4.1 Cases 1 & 2

Cases 1 and 2 have been omitted from this paper. The topics of both these cases were linked to current strategic development programmes within the host company. For this reason all details of these cases have been classified as company proprietary information and therefore cannot be discussed here.

4.2 Case 3: Optimizing remote teamwork

(This case was described in more detail in [5]).

For this case study geographical separation of members of the same team is considered. Many companies struggle with this as employees are increasingly demanding about their residential location, which is not necessarily in the vicinity of a company's offices. Therefore, employees like to have the option to work from their homes, and some companies react to this by setting up auxiliary branches that are geographically dispersed.

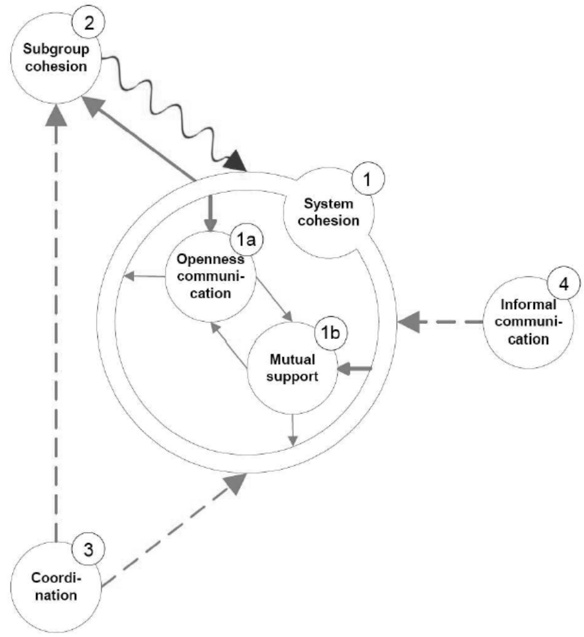


Figure 4: Function analysis of case 3

For this case it was decided to use a Function analysis based approach. A literature study on teamwork has been performed and critical elements for teamwork success have been identified. These elements have been mapped in an FA-style analysis, which identified critical "teamwork element" interactions in the case of geographically separating a team. This is shown in Figure 4, in which “Subgroup cohesion” (index 2) is defined as the “togetherness” of a local team (in for instance an auxiliary branch of a company), and “System cohesion” (index 1) is defined as the “togetherness” of the company as a whole. The solution to one of the issues, in which “Informal communication” has an “insufficient” relation with “System cohesion” has been tackled.

Because the teams are separated, there is less informal communication than in the non-geographically separated scenario. In, for example, a cubical style office colleagues can freely walk around and start talks with every person. Of course, in a geographically separated situation this is not possible. There are telephone systems and video conferences available for communication, but these systems hardly simulate actual office life. Telephone calls and conferences need to be set up and communication must be well-timed to be possible at all. They do not allow people to see each other in their true office setting. However, if one would consider (hypothetically) that this *would* be possible, and that this would be exaggerated as is proposed by the inventive standard that is used here. This would imply a “remote office” with continuous “real” communication in both audio and visual means between (for example) cubicles. Imagine a cubicle with “window blinds” in the wall that allows people to continuously see each other through the wall. What if these window blinds would be replaced by a flat screen that continuously shows the colleagues office? This would create an excessive amount of potential communication. Even better would be to show one colleague sitting behind his desk, from a viewpoint as if there is actually an office behind the “window blinds”. The force that is to keep this excessive communication under control should be represented by a project manager who determines whose office space one will see behind the “virtual blinds”. This makes sure that there will be little abuse of the system and only the colleague will be shown that one needs to form a team with. The concept of the “virtual office” can be extended to other office areas, such as the coffee corner: why not have a “remote coffee machine” at which employees can chat with geographically separated colleagues? This would increase the potential informal communication a lot, which otherwise would not be possible without travelling.

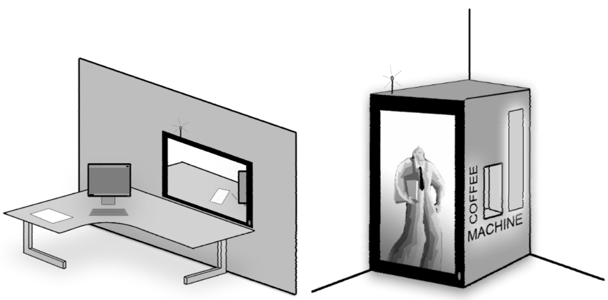


Figure 5: Remote office cubicle (left) and coffee machine

5 THE TRIZ BASED FRAMEWORK FOR CO-DISCIPLINARY DESIGN

Based on the interviews and the cases executed an improved initial version of the framework has been defined. This initial version has been set up to incorporate all requirements from chapter 3 and lessons learned from the cases. The *inventive framework*, of which an outline has already been shown in Figure 3, has several feedback and feed-forward loops to provide practical “ways out” of the framework if the process does not proceed according to plan. This is illustrated in Figure 6 (displayed at the end of the paper). The fact that these loops have been added here does not imply that all possible practical ways out of the framework have been covered, which would be sheerly impossible and would not contribute to the overall clarity of the framework arrangement. Rather, these loops show what kind of routes can be taken if the standard framework sequence cannot be followed. Figures 7, 8 and 9 go into more detail on the proposed schemes for the sections “Issue Analysis”, “Solution Process using TRIZ” and “Solution Analysis”.

The framework was defined so that engineers possibly need training in the <u>use of the framework</u>, not necessarily in the <u>use of TRIZ</u>. This is one of the major cornerstones of the framework. To test the final framework a software program was written that would guide the users through the use of the framework. The software needs to be improved so that the abstraction steps can easily be done by the engineers, without knowledge of TRIZ. After this abstraction, engineers brief the TRIZ expert in what the issue is about by means of the abstract terms and possibly some context information.

With the help of engineers two framework application cases were tackled; a mechanical case and one of a more co-disciplinary origin. Again the results of these cases cannot be depicted in this paper.

Based on the evaluation of the decisions made by the engineers some remarks could be made on the framework. The mono-disciplinary mechanical case came to a satisfying result. The co-disciplinary case, however, did not. The results of the issue analyses performed by both engineers in the co-disciplinary case were satisfactory. That is, they both provided the relevant components that influenced the issue from their discipline standpoint. But a problem arose with combining both the results into a unified problem statement that could be used for a joint issue analysis. The level of detail used in both analyses differed greatly, and as such the issue components were of a different level and could hardly be compared. A flaw of the framework had been discovered: in analyzing a co-disciplinary issue, there is no prescribed method of making sure that issue analyses performed by multiple disciplines are actually performed on the same level of detail. If this is not leveled and the analyses start at different levels, the outcome of the issue analyses is bound to not be on the same level either.
Furthermore, one of the hypotheses in setting up the framework was that the engineers involved should not have any obligatory training in TRIZ. According to the framework’s set up, this is not required. However, as observed during the framework case studies, the framework’s sequence of events is not immediately clear to every engineer. Therefore for the framework’s sequence to be successful in practice, engineers still need some basic training in using the framework. If the framework software can be expanded and finalized, it could be made more user-friendly and self-explanatory so that the training can be reduced to a minimum. However, the fact remains that some form of training will always be required.

6 SUMMARY

This paper describes the results of a master thesis assignment. Within this assignment a framework for the efficient implementation of TRIZ in a co-disciplinary design environment was targeted. A framework was proposed in which a TRIZ expert works together with one or more technical disciplines to overcome co-disciplinary design issues.

The final case studies showed flaws in the setup and also showed that more research is needed to overcome these issues. The most prominent issue is that engineers from different disciplines not only address different subjects, they also may be used to work on another level of detail. This implies that after issue abstraction there may still be major difficulties in arriving at a joined understanding of the combined abstract issue.

REFERENCES

[1] Gantois, K et al: “The multi-disciplinary design of a large-scale civil aircraft wing taking account of manufacturing costs”, Structural multidisciplinary optimisation, issue 28, 2004

[2] Nicolescu, B: ”A new vision of the world: Transdisciplinarity”, excerpt from “Manifesto of transdisciplinarity”, SUNY Press USA, translated by K.-C. Voss, http://nicol.club.fr/ciret/ , page updated on March 5, 2007

[3] Aboelela, W et al: “Defining interdisciplinary research: conclusions from a critical review of the literature”, Health services research, volume 42, February 2007

[4] Altshuller, G.S.: “The innovation algorithm”, translated edited and annotated by L. Shulyak and S. Rodman, first edition, Technical Innovation Centre Inc., Worcester, Mass, 1999

[5] Vries, R. de, Souchkov, V., Mannak J.: “Remote team Problem Solving with TRIZ”, The TRIZJournal, www.trizjournal.com.

CONTACT

Tom Vaneker

University of Twente,

7500 AE, Enschede, Netherlands

E-mail: t.vaneker@ctw.utwente.nl

Phone: +31 (53) 4892472

FAX: +31 (53) 4893631

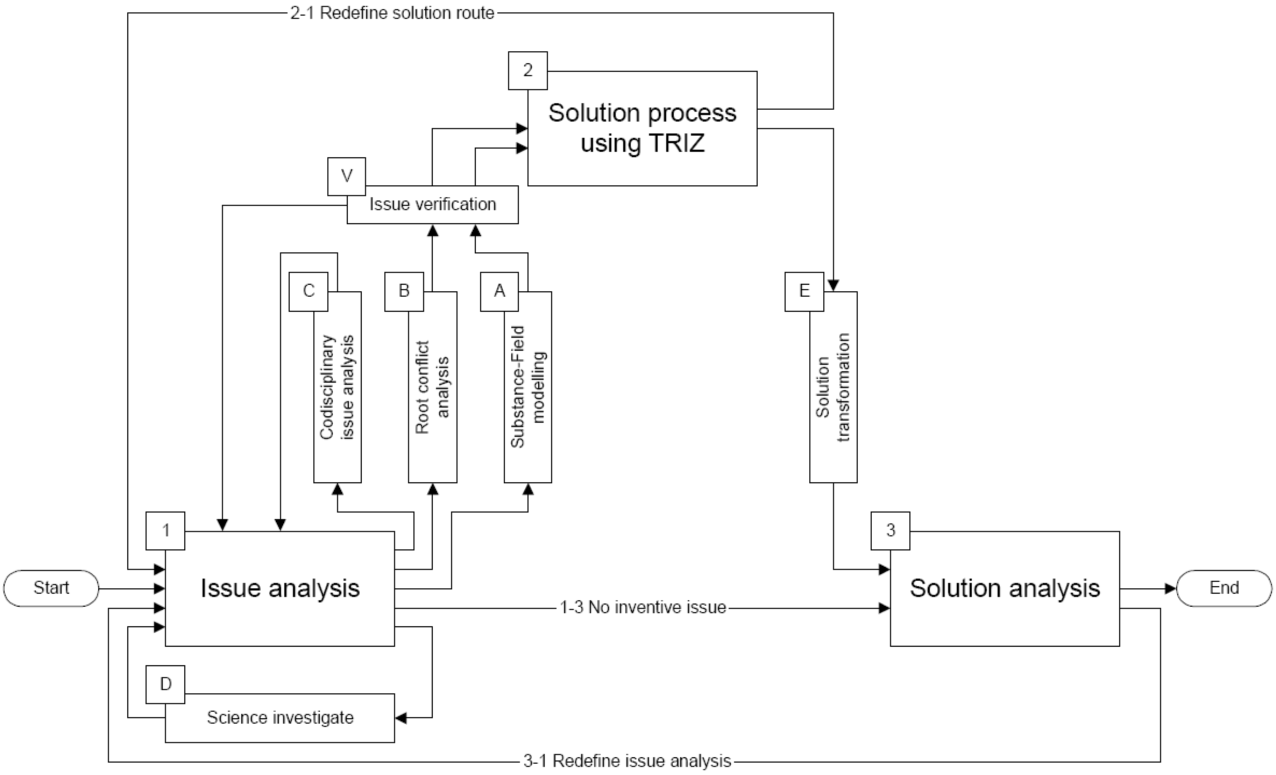


Figure 6: Final proposal for the layout of the framework for the support of TRIZ based co-disciplinary design. Events 1, 2 and3 will be depicted in more detail in the figures below.

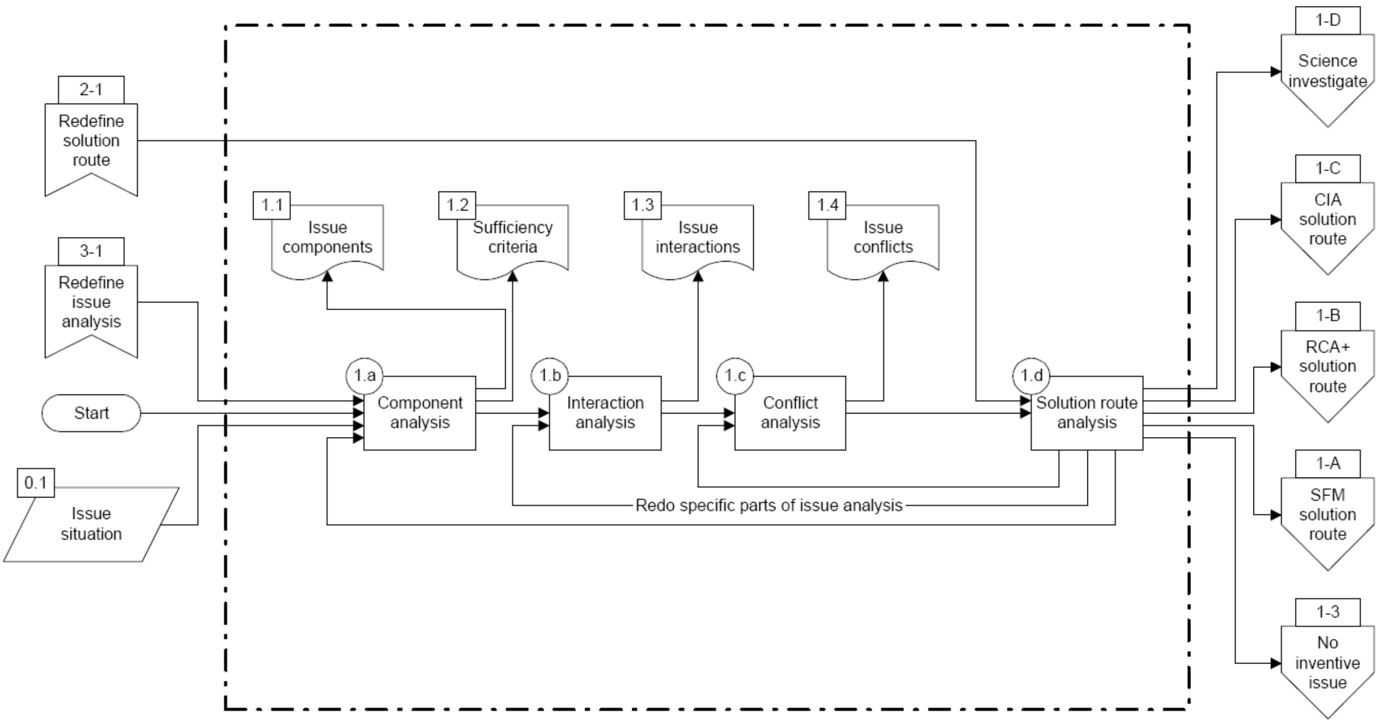


Figure 7: Issue analysis

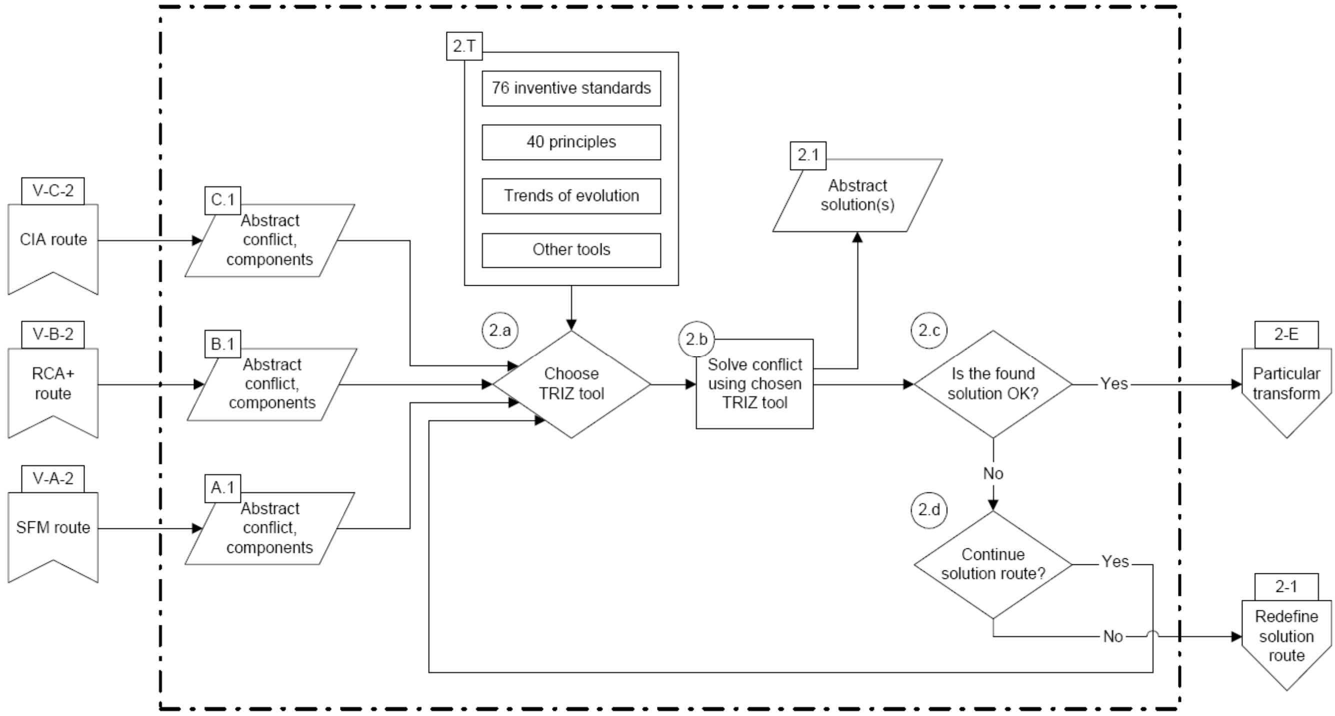


Figure 8: Solution process using TRIZ

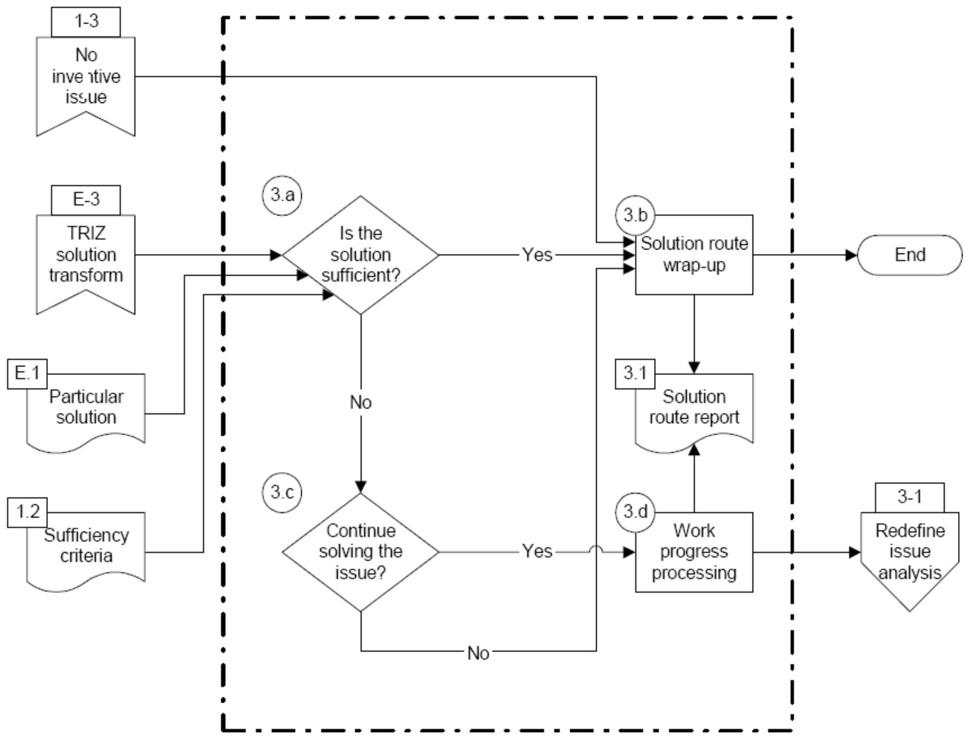


Figure 9: Solution analysis

How to Prevent Product Piracy using a new TRIZ-based Methodology

Günther Schuh[1], Christoph Haag[2]
[1]Laboratory for Machine Tools and Production Engineering, RWTH Aachen, Germany
[2]Fraunhofer Institute for Production Technology IPT, Germany

Abstract

In recent years, product and brand piracy has significantly gained importance and risen to a worldwide mass phenomenon. Companies are gradually facing up to the challenge and taking action. Besides legal measures, an increasing number of firms is also willing to implement strategic and technical measures into their organisations respectively products. But the potential of these approaches is so far only being exploited to a limited extent, mainly due to lacking knowledge regarding the functionality and benefits of technical know-how protection mechanisms.

Focusing on this issue, the paper introduces the so called Product Piracy Conflict Matrix (PPC Matrix). The PPC Matrix methodically resembles the well-established TRIZ Contradiction Matrix and is also based on Neemann's work (2007), who recently introduced a new approach for product-based imitation protection including a set of technical, strategic, organisational and legal instruments. The PPC Matrix combines both approaches to a new framework to help companies to find expedient measures against product piracy.

The article introduces the new methodology by giving detailed insights into its theoretical backbone, providing practitioner's guidance and outlining examples from industry practice.

Keywords

Product piracy, Product imitation, Technology know-how protection, Contradiction Matrix, Ideality approach

1 PRODUCT PIRACY AS A NEW CHALLENGE FOR COMPANIES

Product and brand piracy has significantly gained importance in recent years and risen to a worldwide mass phenomenon [1]. Companies are gradually facing up to this new challenge and taking action. Besides legal counteractions, an increasing number of firms are also trying to implement organisational or technical measures against product piracy [2]. Nevertheless, the potential of these approaches is so far being only exploited to a limited extent which can mainly be traced back to lacking knowledge regarding the functionality, benefits and application conditions of these new know-how protection mechanisms [3].

When it comes to identifying concrete protection mechanisms and implementing these into a running business, companies often face problems and conflicts, which seem insurmountable: on the one hand, a burdened company quests for powerful protection strategies for its product and brands. Yet on the other hand, companies are not willing to accept excessive modifications to their products and value chains. From a corporate point of view, a common requirement for instance is that the general product functionalities must not be noticeably affected by the implementation of a protection feature. In other cases, financial limitations, after sales service requirements or constraints by regulations have to be considered. Due to these restrictions, companies often face a "deadlock situation" when trying to install suitable measures against product piracy.

In order to overcome such conflicts, companies require systematic methodological support in finding appropriate measures that do not influence their value chains in a negative or harmful way. In line with this claim, the article introduces the so-called Product Piracy Conflict Matrix (PPC Matrix). This new problem-solving approach has been developed by the Fraunhofer Institute for Production Technology IPT based on insights from numerous consulting and research activities in the field of product piracy protection.

2 THE PPC MATRIX AND ITS THEORETICAL BACKBONE

The PPC Matrix has been designed as a methodical guideline for companies to select appropriate protection measures against product piracy. Contrary to other approaches ([2] [4] [5]) the PPC Matrix pays special attention to boundary condition within the value chain of a company, which may not be influenced in an undesired or harmful way by the implementation of protection measures.

The methodology primarily addresses professionals in R&D management who are searching for means to protect their products but yet have little experience in that issue. Also it can be helpful for experts who have already considered certain protection schemes but would like to double-check their selection in order to reduce the risk that a more appropriate measure might have been forgotten.

2.1 The Contradiction Table of TRIZ as a Methodological Frame

The basic idea of the PPC Matrix is derived from the contradiction analysis as a well-established method within TRIZ. The TRIZ approach relies on expressing a challenging problem as either a technical contradiction, for which solutions can be identified in a systematic way based on innovative principles. A technical contradiction exists, if improving a parameter "A" of a system causes a different parameter "B" to deteriorate, whereas a physical contradiction exists if some aspect of a product or service must simultaneously adopt two opposing states. Expressing the problem in question as a technical or physical contradiction is therefore a prerequisite to applying the contradiction table [6]. The analysis then relies on fitting the problem to a table of conflicts between 39 technical parameters and identifying solutions based on 40 innovative principles, which have proved successful in solving these conflicts. In this sense, the contradiction table represents a comprehensive data compilation of expert knowledge on the applicability of innovative principles in solving technical or design problems (for a more detailed description of the contradiction analysis see for instance [7]).

In certain cases, the contradiction table itself is already applicable and helpful in the context of product piracy protection. Yet in general, its direct applicability is limited, mainly due to two reasons:

- Users often fail in structuring and expressing piracy problems in terms of technical or physical contradictions due to lacking knowledge and experience. That is why more problem-specific guidance is required.
- Solutions against product piracy are clearly not limited solely to technical principles. That is why the scope of innovative solutions generated by the contradiction table is limited and thus inappropriate for piracy problems.

However, the issue of creating solutions against product piracy can as a whole be viewed as a physical contradiction, due to the already mentioned conflict: on the one hand, protection mechanisms are called for, yet on the other, persons responsible are not willing to take negative or harmful alterations to their product into account. In many workshops that Fraunhofer IPT has conducted with companies in different lines of industry, this conflicting situation represented a major restriction or even a knock-out criterion against the implementation of powerful protection measures. The idea of a problem-specific contradiction analysis arose from this insight.

2.2 The Analogy Between the TRIZ Contradiction Table and the PPC Matrix

Following the basic idea of the TRIZ contradiction table, the PPC Matrix is designed to identify standard solution principles against product piracy threats, for which suitable solutions must be identified. Therefore, the structure of the PPC Matrix is quite similar to the contradiction table. The rows contain actuating parameters or levers to implement protection mechanisms. The columns on the other hand represent a list of reactive parameters that could be harmfully affected by the actuating parameters. In short, the analogies between the traditional contradiction table and PPC Matrix can be described as follows:

- Conflicts between active and reactive parameters are recorded at the intersections of the rows and columns of the PPC Matrix.
- Standard solution principles within the PPC Matrix are based on a catalogue of protection measures as a research result of the Fraunhofer IPT [2] [8].
- The application of the PPC Matrix is embedded in a comprehensive problem-solving procedure that comprises an initial problem analysis and the identification of main conflicts and is followed by the development and validation of solutions based on standard principles proposed in the cells of the Matrix.

2.3 Design of the PPC Matrix

In contrast to the contradiction table, the PPC Matrix is designed in a non-symmetric way. Although several parameters can be found simultaneously in the columns and the rows of the Matrix, the structuring frameworks for the rows and the columns are different (Figure 1): Derived from a game-theoretical analysis, the parameters within the rows are classified according to the generic behavioural pattern of the imitator and original product manufacturer. On the other hand, the parameters in the columns are arranged according to the standard value chain of a company. These two basic structuring concepts will be described in detail in the following.

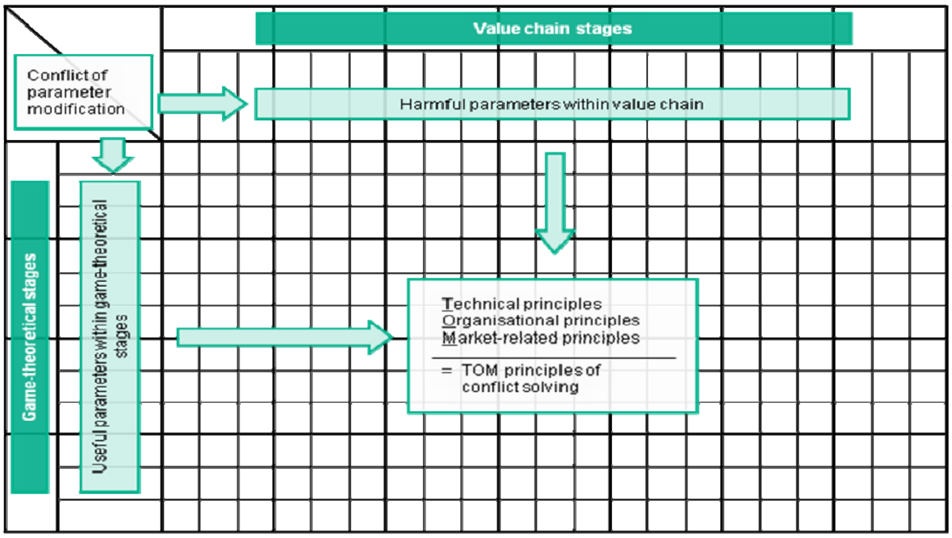


Figure 1: Concept of the PPC Matrix

2.4 Structuring the Rows Based on Game-theoretical Analysis

From a game-theoretical point of view, there are four more or less sequential stages which are suitable to generically describe the behavioural pattern of an imitator and thus, the stages of opportunities for an original product manufacturer to take counteractions [2]:

- Selection of a product to be copied
- Analysis of the product
- Reproduction of the product
- Marketing and sales of the imitation

The first decision an imitator has to make is the selection of the product he intends to copy. Needless to say, the imitator's decision mainly depends on the expected commercial benefits which are linked to the imitation. Hence, the initial selection and decision-making process of the imitator represents the first stage for the original product manufacturer to take action. By shifting certain parameters within the product design or business model (e.g. in terms of production techniques or after sales services), the original product manufacturer can deliberately lower the imitation attractiveness of his products.

After an imitator has decided to copy an original product, the second lever is to make the product analysis or reverse engineering as time-consuming and tedious as possible for the imitator. Various counteractions can be considered, yet most of them are directly affiliated to the product structure or design (e.g. increase of product complexity or limitation of product access).

If the imitator has succeeded in analysing a product, the third and subsequent stage is the reproduction (in terms of manufacturing) of the original product by the imitator. For the original product manufacturer, the according lever is to impede the imitator from actually realising a reproduction. At this stage, mainly measures related to supply chain management (e.g. limiting the access to essential suppliers or components) can be considered.

Finally, assuming the imitator has actually achieved in manufacturing a false replica, the remaining lever for the affected company is to hinder the imitator in bringing his imitation to the market and gaining market shares. Counteractions primarily apply either directly to the design of sales channels or to implementing appropriate authentication means.

These four stages represent a suitable classification framework for a generic list of actuating parameters companies can modify in order to implement protection measures. The according parameters represent the rows of the PPC Matrix.

2.5 Structuring the Columns Based on the Ideality Principle

According to “ideality thinking” as a central TRIZ principle, a technical sub-system should fulfil its desired functions without calling forth an undesired effect of the corresponding entire system. The TRIZ dictum says: effective technical solutions evoke maximal positive effects within a system and simultaneously limit possible negative effects to a minimum. The effectiveness E is a universal TRIZ ratio to evaluate the degree of ideality of technical system.

$$E = \frac{\text{Sum of the positive effects}}{\text{Sum of the negative effects}}$$

Metaphorically speaking, the ideal system provides a desired function without even existing [9]. Following this line of thinking in the context of product piracy, protective measures can be considered subsystems of an (already existing) system, i.e. of the value chain of the burdened product which has to be protected. Hence, an ideal measure against product piracy fulfils its desired function without bringing harmful effects into the value chain system it is supposed to protect. A full corporate value chain generally comprises seven stages [10]:

- Research & Development
- Procurement
- Production
- Distribution
- Marketing
- Sales
- Service

As illustrated in the introduction already, certain characteristics within the value chain may be influenced in a harmful or destructive way by the implementation of protection measures. This circumstance accounts for the conflict companies are faced with in the context of product piracy. Consequently, according to the notion of ideality, the PPC Matrix offers standard solution principles which enhance the positive (protective) effects and minimise the negative (value chain-modifying) effects.

2.6 The 26 TOM Principles

Based on the research results of Neemann, Fraunhofer IPT has compiled a list of 26 principles that can be applied to dissolve the described conflict. Neemann provides an even more comprehensive list of 42 principles. Fraunhofer IPT has used a number of workshops with companies from different industry sectors to test these principles. As an outcome of these workshops, 26 principles have proven to be highly promising solutions against product piracy. Three basic categories have been distinguished to classify these principles:

- Technical principles: they are directly integrated within the product as additional features or as modifications of existing product components
- Organisational principles: they can be implemented within the internal organisational structure, without considering external links to markets
- Market-related principles: they are implemented according to customer requirements and relationships, i.e. taking the market of the burdened product into account.

According to the initials of the three categories, the 26 principles against product piracy are labelled the TOM principles (Figure 2). In analogy to the 40 inventive principles of TRIZ, the TOM principles represent standardised mechanisms in an abstract form. This implies that a principle considered justified must be adjusted to individual problem characteristics, i.e. to product and corporate boundary conditions.

Technical principles:

T1	Fixed cost-intensive manufacturing
T2	Branded functionality
T3	Product (de-)activation
T4	Decomposition barriers
T5	Functional black boxes
T6	Fake black boxes
T7	De-standardisation
T8	Local increase of performance density
T9	Product authentication
T10	Product bundling

Organisational principles:

O1	Product certification
O2	Staff retention
O3	Codification of documents
O4	Proprietary development of production facilities
O5	Collaboration with imitator
O6	Chinese walls in the supply chain
O7	Contracted supplier relationships

Market-related principles:

M1	Lead time
M2	Release management
M3	Simultaneous market launch
M4	Price differentiation
M5	Product differentiation
M6	Shadow placement
M7	Mass customisation
M8	Extended life cycle services
M9	Establishment of industry standards

Figure 2: The 26 TOM principles for product piracy protection

One example for a technical principle is the principle of De-standardisation. Today there are numerous industry standards existing in order to ensure the exchangeability of components and to increase economies of scale. Engineering departments often try to achieve a maximum quota of standard components in their products, which can be easily purchased from catalogues. On the one hand, this proceeding reduces costs in purchasing and enables the integration of different products. On the other hand however, standardisation makes it easy for imitators to reproduce original products, because they can source standard product components on worldwide markets.

The principle of De-standardisation is based on the idea to focus not on existing standard material when constructing key components of a product but instead to design these components individually. The individualised components only deviate slightly from the standard component. The imitator does not notice the deviation of this particular component and uses standard material instead. As a result, the imitator's product does not run correctly or shows much lesser durability than the original product.

2.7 Industry example: Rolling bearing

For the bedding of a spindle, a machine manufacturer uses rolling bearings which have an external diameter slightly above the diameter of the industry's mainstream bearings. When trying to copy the machine, imitators with little technical capability will probably copy the diameter of the bore in which the outer ring of the bearing is located but will resort to the standard bearing, which they easily get on the world market.

Thus, the bearing fit will be loose and abrasion will accelerate. The imitator's machine will have much lower durability and accuracy whereas the imitator will probably never find out, where that comes from.

A sound example for an organisational principle is the proprietary development of production facilities. That is also an option to make the reproduction of the original product difficult for the imitator. In the first place, it reduces the risk of know-how outflow, which can take place when production facilities for a specific product are developed outside the own company. The developer of the facilities is willing to use the specific technologies or machinery also for other commercial purposes. Thus, he tends to sell his development to other companies. The special product-related know-how is not exclusively owned by the original product manufacturer anymore. This risk can be reduced by the proprietary development and maybe also manufacturing of production facilities. An expedient practice in terms of this principle is also the product-specific modification of standard machinery instead of the completely new development of the production facilities.

2.8 Industry example: Special production facilities at OSRAM

OSRAM is a market leading producer of lighting systems. OSRAM's special machinery which is necessary for the production of their product lines has always been developed and manufactured company-internal.

According to OSRAM, this procedure not only lowers the time-to-market of their products but also works as a powerful protection mechanism against product piracy. No other supplier has the technological capability to develop machines as capable as the OSRAM production facilities [11].

Finally, Mass Customisation is an expedient practice in terms of market-related principles. From the outset this mechanism lowers the imitation attractiveness by offering products that are specifically tailored to each customer but however derive from mass production.

Mass customisation is already well-established in the automotive sector, where customers have a wide scope to individually configure their own cars. However, mass customisation requires highly-flexible production facilities, which is the first reason why it can hardly be offered by most imitators. On the other hand, imitators would need infrastructure for direct customer contact to take individual orders from them. Most imitators flinch from building up this kind of infrastructural capacity to avoid fixed expenses.

2.9 Industry example: Tailored consumer goods for mass markets

The clothing and accessory producers Polo, Timberland und Longchamp allow customers on their companies' homepage to configure their ordered products after their own fancy. Customers have various degrees of freedom (e.g. for embroideries) and thus can individually create their own clothes [4].

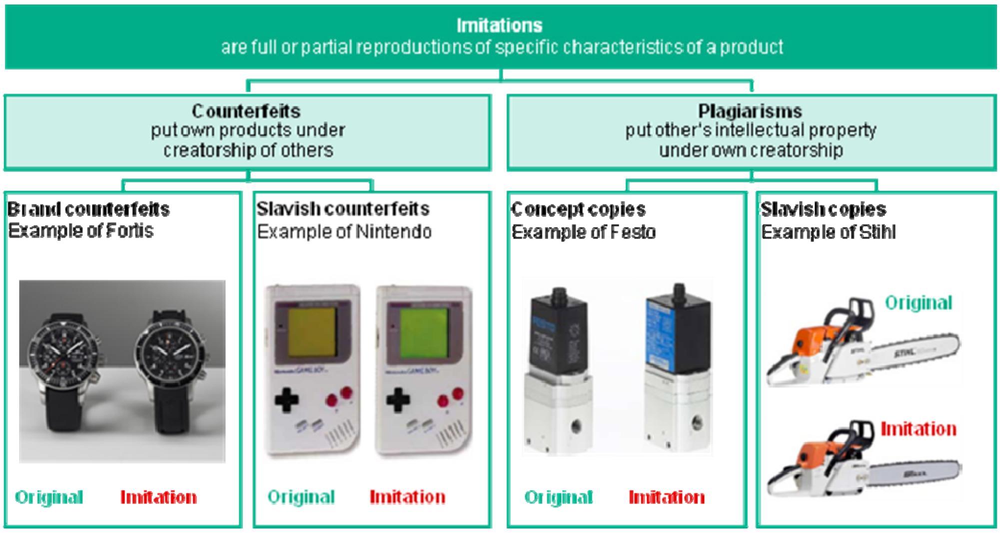


Figure 3: Generic types of product imitation (image source: www.plagiarius.com)

3 PRACTITIONER'S GUIDANCE FOR APPLICATION

The Fraunhofer IPT has also elaborated a user's guideline, how to apply the PPC Matrix and what critical factors to consider. A six-step procedure is suggested and will be introduced in the following.

3.1 Step 1: Piracy Problem Analysis

A detailed problem analysis is the first step to applying the PPC Matrix. During this initial phase, the company's specific situation must be investigated i.e. the actual or most likely imitation scenarios determined. The following categorisation of imitation types (Figure 3) gives companies guidance to clarify this issue:

Companies must get a clear idea about what kind of imitation they actually fear. Furthermore, there has to be considered, what kind and extent of commercial issues are implicated by these forms of imitations. For instance, concept copies will probably not result in unjustified product liability complaints. Only slavish counterfeits will do so and demand for appropriate counteractions. In other cases, when very simple and obvious brand counterfeits are reproduced by the imitator, this probably may not immediately end up in significant sales losses because the potential customers of the imitation are not the same as those of the original product; a decrease in brand reputation is much more likely to fear for this type of imitation scenario.

3.2 Step 2: Identification of Relevant Stages for Counteractions

As next step, the relevant (game-theoretical) stage for taking counteractions must be identified. Questions to ask in this context are: is the considered product highly attractive to be imitated? Has the product already been analysed by potential imitators resp. has technical know-how already left the boundaries of the company (e.g. due to personnel fluctuation, trade fairy appearances etc.)? Have concrete product imitations already emerged or are they however foreseeable?

Depending on how far the (expected) imitation process has already stepped ahead, companies have to define their appropriate stage for counteraction. When for example the product development has not been completed yet and no critical know-how has left the company so far, the product's attractiveness to be imitated can be reduced by certain technical and commercial characteristics so that imitators will not select the product for imitation purposes in the first place. However, when the product has been analysed by imitators already and reproductions of the original product are very likely to be proceeded, the appropriate stage to take counteractions would be the marketing and sales phase of the imitation.

3.3 Step 3: Selection of Appropriate Levers for Protection Mechanisms

The third step involves identifying those levers which are available for integrating protection mechanisms. In accordance to the stage for taking counteractions, the company must think about parameters in their own business to change, in order to prevent product piracy. This may include parameters like brand appearance, product complexity or even annual part volume.

Such useful parameters for modification are listed in the rows of the PPC Matrix. Needless to say, companies do not have to focus only on one parameter i.e. row of the PPC Matrix, but can also take three or four parameters into account. In this case the following steps would have to be conducted multiple.

3.4 Step 4: Identification of Fixed Parameters in the Value Chain

During the fourth step, the firm must consider the entire value chain and determine which phases are likely to be harmfully affected by modifying the selected parameters.

As taken as an example before, when decreasing the annual part volume in order to lower the imitation attractiveness of a product, the sales volume will decrease as well. It is easily foreseeable, that this kind of parameter modification will hardly be accepted because it might hurt the company's commercial performance even more than the appearance of product imitations itself.

The sales volume is included in the list of harmful parameter to be changed within the company's value chain, which constitute the columns of the PPC Matrix. The comparison of useful parameters against product

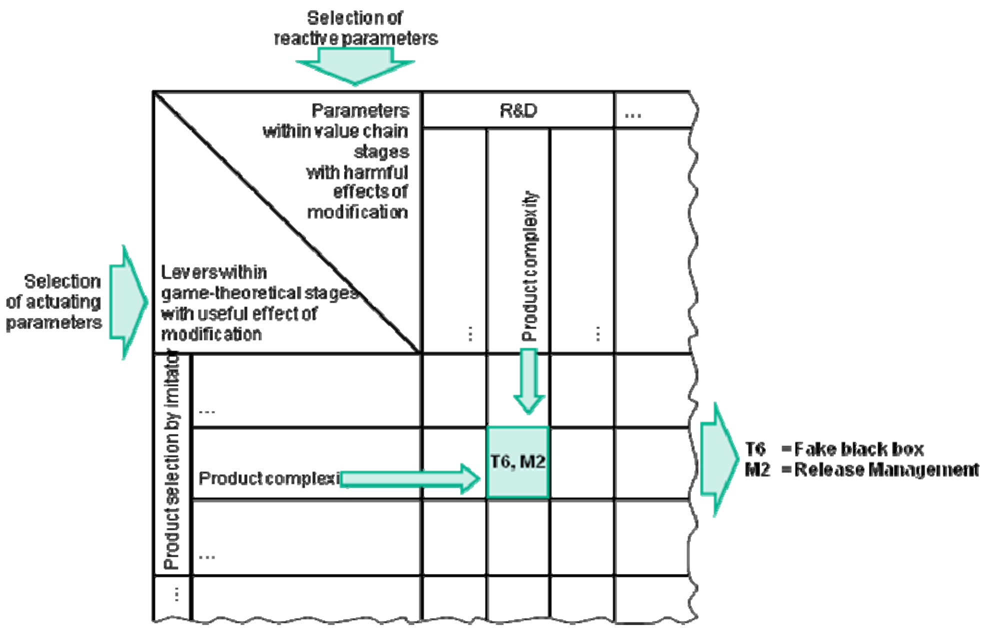


Figure 4: The 26 TOM principles for product piracy protection

piracy in the rows and harmful parameters of the value chain in the columns state the conflict which is tried to be solved in the following step.

3.5 Step 5: Determination of Appropriate TOM Principles

Within the fifth step, the core of the PPC Matrix is finally applied. First, the line containing the useful actuating parameter to implement a protection mechanism is selected. Then the column that corresponds to the harmful reactive parameter is indentified, which represents the fixed aspect in the value chain that is negatively affected by an alteration of the actuating parameter. At the intersection of the line and the column, the solution principles capable of solving the conflicting situation are indicated with their respective short name as shown in Figure 4.

There always can be more than one principle within an intersection. For each TOM principle a short description as well as application advices are given, so that the user can get a clear picture about the principle and its effect against product piracy.

3.6 Step 6: Evaluation of TOM Principles and Company-specific Adaptation

An identified TOM principle might be, but does not have to necessarily be, an appropriate measure for a specific case. Therefore in the next step it is inexpedient to evaluate a measure regarding its actual problem-solving potential for the particular product piracy scenarios.

For this last step all stakeholders that might be affected by the implementation of the measure have to be involved and asked about the principle's applicability from their point of view. After a principle has finally been approved from all experts as a suitable and applicable measure for the company to prevent product piracy, the technical, organisational or market-related adaptation of this principle can be initialised.

4 EXAMPLE FROM INDUSTRY PRACTICE

In the following, an example from Fraunhofer IPT's industry consulting practice will be introduced in order to point out the general proceeding of the PPC Matrix application. The company in this case, which will not be mentioned by name, was burdened by product piracy and asked for Fraunhofer IPT's support in that matter.

As a manufacturer of medical devices for various surgery applications, the company was going to release a new product in a few months. There was grave suspicion that the product could be slavishly imitated, i.e. identically replicated including the copy of the brand mark, by Chinese low-cost manufacturers for the fast growing Chinese market. As the product was still in its development phase, the existence of imitations could be excluded. Also there was little probability, that critical technical know-how of the product – especially about constructive lightweight solutions and a controlling panel device – had already left the boundaries of the company. Consequently, most relevance for taking protective action was given to the approach to lower the product's attractiveness for imitation.

After discussions with the sales department as well as R&D, the parameter „product complexity“ was determined as an essential useful parameter: By increasing the product complexity, the attractiveness towards Chinese product imitators was intended to be lowered. However, there were also restrictions stemmed from R&D: An increase in complexity should not postpone the completion of the development project and on no account have affect on other already set-up product functionalities. Additional functional elements were undesirable as the R&D department had already submitted a design freeze and was not willing to realise further design modifications or alterations. Hence, the parameter „product complexity“ – although identified as a useful parameter in the first place – also represented an essential fixed parameter because any modification of it would cause harmful effects within the value chain.

Using the PPC Matrix for this particular issue, the existing conflict can be described as illustrated in Figure 5. The resulting cell contains the two abstract mechanisms with the identification codes T6 und M2; these abbreviations correspond to the TOM principles „fake black boxes“ and „release management“.

Fake black boxes aim to make potential imitators believe that a black box contains a disclosed functionality. Yet in reality, the black box is a mock-up, furnished with all obvious external features (for instance electrical connections, pressure pipes etc.). Ideally, potential imitators are discouraged by the apparent complexity of the product, which would significantly impede product analysis. In general, the application of fake black boxes is limited to low-quality imitators, as most of them can be recognised by well-trained engineers who have in-depth

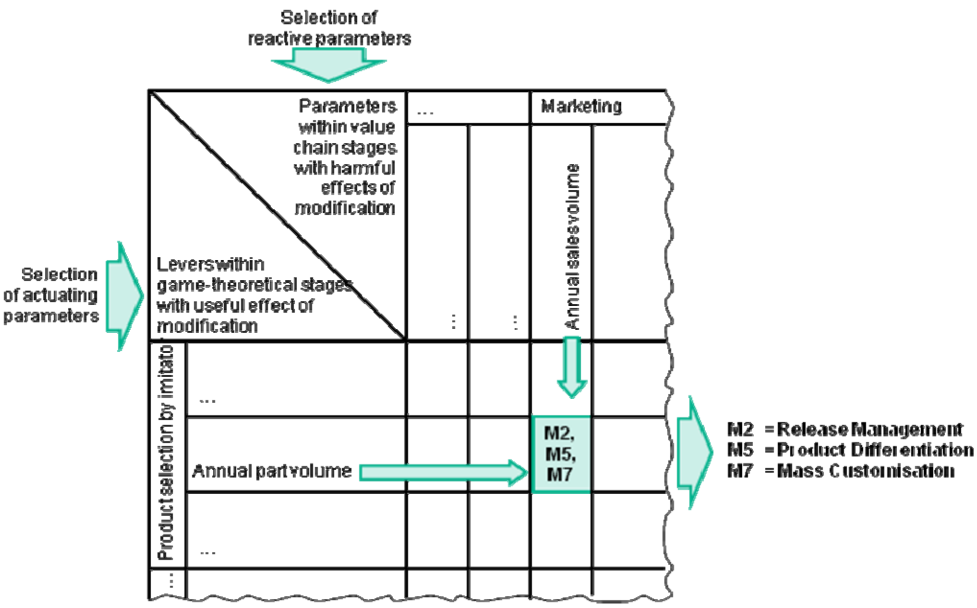


Figure 5: Exemplary application of the PPC Matrix

know-how concerning both the product structure and according production processes [2].

“Release Management” as a protection mechanism is based on a deliberate increase of the relative lead time, i.e. the product development time in relation to the product life cycle of the original product manufacturer. In practice, this can be achieved by combining incremental innovation steps to create a market-effective product release in the perception of customers. The individual releases must be submitted at relatively short intervals; thus imitators are deterred from analysing and reproducing the product by its high dynamics and complexity in R&D [2].

In our corporate example, the highest potential was allocated to the principle „fake black boxes“ and subsequently, more detailed feasibility checks were initiated. The R&D department was finally designated to implement the principle in close cooperation with all departments potentially affected by the product alteration. As it turned out, R&D was able to implement a fake black box in the product without touching the already set-up total product design. There is realistic hope, that the imitation attractiveness of the product thus has been lowered significantly by implementing the black box.

5 REFLEXION AND OUTLOOK

As described above, the PPC Matrix has proved successful in a number of consulting projects conducted by Fraunhofer IPT. First and foremost, the approach can be regarded as a basic framework for companies that so far have little idea concerning the range of solution principles and their application potential. Furthermore, the PPC Matrix can provide valuable guidance for companies in validating mechanisms previously identified.

Clearly, the Matrix does not claim to deliver „turnkey solutions“ for a concrete piracy problem; in analogy to the contradiction table, it generates ideas in the sense of abstract principles, stimulates creativity and forms the basis for further validation, implementation and from a more academic perspective, by analysing in detail the coherences and determining factors of protection mechanisms, the matrix represents an important step in structuring this novel field of research. In this sense, the matrix represents a comprehensive compilation of expert knowledge concerning the applicability of non-legal principles in preventing product piracy.

In the future, Fraunhofer IPT will continually supplement the 26 TOM principles and update the matrix accordingly. Although the set of principles can already be considered highly comprehensive, the initial set must be extended mainly triggered by experiences gained in concrete industrial applications. This process has not been finalised and will be continued on an ongoing basis, thus ensuring the up-to-date status and capability of the methodology.

REFERENCES

[1] OECD (2007) The Economic Impact of Counterfeiting and Piracy - Part IV: Executive Summary. OECD, Paris.

[2] Neemann, C. W. (2007) Methodik zum Schutz gegen Produktimitationen (engl: „Methodology for Protection against Product Imitations“), Shaker Publishing, Aachen.

[3] Krueger, J. and Nickolay, B. (2006) Marken- und Produktpiraterie 2006: Wahrnehmung von Marken- und Produktpiraterie und Akzeptanz technologischer Schutzinstrumente, Fraunhofer IPK, Berlin.

[4] Fuchs, H.J. (ed.); Kammerer, J.; Ma, X.; Rehn, I.M. (2006) Piraten, Fälscher und Kopierer: Strategien und Instrumente zum Schutz geistigen Eigentums in der Volksrepublik China. Gabler-Verlag, Wiesbaden.

[5] Specht, D.; Mieke, C. (2008) Strategien gegen Produktpiraterie – Schutzmaßnahmen setzen an in Forschung & Entwicklung, Produktion und Vertrieb, in: Wissensmanagement 2/2008, Büro für Medien, Augsburg.

[6] Terniko, J. et al. (1998) Systematic Innovation. An Introduction to TRIZ, CRC Press, Boca Raton.

[7] Pannenbaecker, T. (2001) Methodisches Erfinden in Unternehmen, Gabler-Verlag, Wiesbaden.

[8] Schuh, G.; Kreysa, J.; Haag, C. (2007) TRIZ-based Technology Know-how Protection: How to Find Protective Mechanisms against Product Piracy with TRIZ. In: Gundlach, C.; Lindemann, U.; Ried, H. (ed.): Current Scientific and Industrial Reality – TRIZ future 2007. Kassel University Press, Kassel.

[9] Orloff, M. A. (2003) Inventive Thinking through TRIZ, Springer-Verlag, Berlin-Heidelberg-New York.

[10] Mueller-Stewens, G. and Lechner, C. (2003) Strategisches Management, Schaeffer-Poeschel-Verlag, Stuttgart.

[11] Bopst, W.-D. (2003): Leading position through new technologies. Financial market days, Siemens-Osram, 12.5.2003. URL: http://www.siemens.com/Daten/siecom/HQ/CC/Internet/Investor_ Relations/WORKAREA/ir_ed/templatedata/English/file/binary/fmd_2003_osram_1073825.pdf [Date: 1.9.2006].

CONTACT

Christoph Haag

Fraunhofer Institute for Production Technology IPT

52074 Aachen, Germany

E-mail: christoph.haag@ipt.fraunhofer.de

Phone: +49 (0) 241 8904 275

FAX: +49 (0) 241 8904 6275

LOGISTIC SUBSTITUTION MODEL AND TECHNOLOGICAL FORECASTING

Dmitry Kucharavy, Roland De Guio
INSA Strasbourg - Graduate School of Science and Technology,
LGECO - Design Engineering Laboratory, France

Abstract

In this paper the application of several models, based on the logistic growth function (simple logistic, component logistic and logistic substitution models) in the context of technology change forecasting is discussed. The main idea of this paper is to revise existing models and arrange working hypotheses for future research. First, the features of a simple logistic model are presented, different types of competition are discussed and a component logistic model is briefly presented. Second, logistic substitution models in the context of long-term technological forecasting are reviewed. Third, some hypotheses about how to improve the reliability of the logistic substitution model for studying the technological future are proposed.

Keywords

Bi-logistic; multi-logistic; logistic substitution model; resource limitations; technology future study; logistic S-curve; socio-economic cycles.

1 INTRODUCTION

The whole purpose of science is to find meaningful simplicity in the midst of disorderly complexity.
Herbert A. Simon, Models of My Life (1991)

The main objective of scientific study is to reveal and describe regularities which can be used to predict the future. Among his many achievements, inventor and researcher, Galio Galilei (1564-1642), called the "father of modern science", made an excellent forecast about the periodic return and nature of a comet. That forecast was based on observations and a mathematical model. In fact, forecasting plays a significant role in the development of science as soon as it is employed as a method to verify proposed theories and hypothesis.

Our research on long-term technological forecasting is inspired by the description of "the lifeline" of technological systems from Altshuller [1] where contradiction models, S-curves, and the limitation of resources play important roles. Our former paper (2005) focuses on problems with stages of the generic forecasting process. The distinction between short-, medium-, and long-term forecasts, based on three phases of S-curves is also proposed [2]. One S-curve is typically divided into 3 phases as in figure 1: before point α, between points α and β, and after β. A short-term technological forecast is about one phase of an S-curve, while a medium-term forecast considers two phases. The scope of study for a long-term forecast is usually beyond one technology, since it studies at least three phases on an S-curve and may consider several growth processes and more than one system.

Our article for the ICED'07 conference [4] depicts theoretical and practical results from two forecasting projects. A critical-to-X feature merges qualitative and quantitative natures of long-term forecasting. This paper illustrates through case studies for energy technologies how the prediction of technological barriers can be facilitated by mapping the contradictions in combination with assessment of limiting resources.

In our paper for the TFC-2007 conference [3] emphasis on the definition of the growing parameters for many logistic growth models is made. To address the issue when there is no data for emerging technologies, the naïve and causal methods for long-term forecasting are discussed. The causal method is applied to adopt quantitative models for predicting the diffusion of new technologies. In particular, as a growing parameter for consecutive logistic growths it is proposed to apply the amount of knowledge in percent of readiness for the transition from exploration to experimentation towards exploitation phases.

In the present paper we develop the applications for reliable and reproducible long-term technological forecasting using the naïve method and logistic growth function. After revising the component logistic (CLM) and logistic substitution models (LSM) some hypotheses for improving their reliability are proposed. According to our findings these models can help cope with the problems of qualitative-quantitative forecasting described in previous publications [2, 3, 19].

The following section is a short history of particular logistic models and concepts of competition. The section 'Logistic Substitution Model' focuses on the questions: "How does LSM work?", "What are the known difficulties?", and "What can be done in order to improve reliability of forecasting with LSM?". The concluding remarks propose possibilities for further work.

2 LOGISTIC MODELS AND FORECASTING

"… with enough parameters anything can be fit…"

Most of the studies of technological changes are based on the application of logistic models and S-curves. However, not all S-shaped curves are logistic ones. Furthermore, there are symmetric and non symmetric logistic curves which are consequently classified as simple logistic functions or complex ones.

In the scope of our research, we apply the simple logistic S-curves due to the ease in interpreting the meaning of their parameters and the simplicity in estimating the parameters from their observed phenomena. Moreover, in numerous publications it was concluded that the other models of non-symmetric growth have limited application due to their complexity and low efficiency for technology forecasts [6, 7, 8, 9, 10].

The widespread practical application of the logistic function as a means to depict growth processes started with *An Essay on the Principle of Population* by the English economist Thomas Malthus (1766-1834). In 1825 Benjamin Gompertz published work developing the Malthusian growth model for demographic study (the law of mortality). The first reference to the logistic curve as a model of population growth can be found in the work of Pierre-Francois Verhulst (1838, 1845, 1847). In 1923 T.

Brailsford Robertson suggested using the function to describe the growth process in a single organism or individual. Raymond Pearl rediscovered the function (1924, 1925) and used it extensively to describe population growth, including human ones. During 1925 and 1926, while working independently, Alfred J. Lotka and Vito Volterra generalized the growth equation to quantify competition among different species and coined the predator-prey equations.

One of the earliest studies about technological substitution described by S-curves was done in 1957 by Zvi Griliches. Using concepts of Griliches in 1961, Edwin Mansfield developed a model to depict the rate at which firms follow an innovator. In the early 1960s, S-curves were regularly employed for technological forecasting [8]. The diffusion of the innovation theory, formalized by Everett M. Rodgers [18] in 1962, postulated that innovations spread in society in an S-curve.

A significant achievement was accomplished by J. C. Fisher and R. H. Pry (1970) in formulating the model for binary technological substitution as an extension of Mansfield's findings [12]. C. Marchetti proposed a logistic substitution model for describing technology substitution in the dynamics of long-run competition (1976-1979) by extensively using the Fisher-Pry transform [7]. In 1994 P.S. Meyer proposed the component bi-logistic growth model [5] Later on, a component logistic model with multi-logistics generalises this bi-logistic growth model [6]. The application of bi-and multi-logistics makes possible the description of complex growth processes through a family of simple logistic curves.

Logistic substitution and component logistic models in combination with the Fisher-Pry transform technique provide clear and suggestive outputs for supporting medium- and long-term forecasting of technology change [5-8, 11, 13-16].

2.1 Simple logistic model (SLM)

The natural growth of autonomous systems in competition might be described by logistic equation and logistic curve respectively. In the context of our proposed research, natural growth is defined as the ability of a 'species' (system) to multiply inside finite 'niche capacity' (carrying capacity [5], a physical limit of resources [1]) through a time period.

As soon as the function parameters can be calculated using a partial set of data (e.g. the efficiency of changes in the internal combustion engine over the last 20 years) it is possible to use the equation in a predictive mode (i.e. how much that efficiency will grow and when). Nevertheless, the availability of a reliable set of data is a principal limiting factor for S-curve model application in the technological forecast of emerging technologies.

For socio-technical systems the three-parameter S-shaped logistic growth model (1) is applied to describe continuous "trajectories" of growth or decline through time.

$$N(t) = \frac{\kappa}{1 + e^{-\alpha t - \beta}} \qquad (1)$$

Where N(t) – is the number of 'species' or growing variables in question; κ – is the asymptotic *limit of growth*; α – specifies[1] "width" or "steepness" of the S-curve (e.g., α=0.19 means approximately 19% growth per time fraction); it is frequently replaced with a variable that qualifies the time required for the "trajectory" to grow from 10% to 90% of limit κ: *(Δt)*[2] - is *characteristic duration;* β – specifies the time (t_m) when the curve reaches 0.5κ: *midpoint* of the growth trajectory (t_m implies symmetry of a simple logistic S-curve).

These three parameters κ, α, and β are usually calculated by fitting the data. The method used to fit S-curves on data aims at minimizing the next sum:

$$\sum_i \frac{(Ni - Di)^2}{Wi} \qquad (2)$$

Where Ni, Di and Wi are respectively, at times ti, which is the value of the function, the data value and the weight we may want to assign to the data.

The function is originally evaluated by assigning arbitrary starting values to the parameters of N. After that, an iterative search is performed to determine those values for which the sum becomes as small as possible.

There are diverse fitting techniques. For instance, the asymptotic limit of growth κ can be estimated such as expert judgment, when α, and β are optimized to minimize residuals.

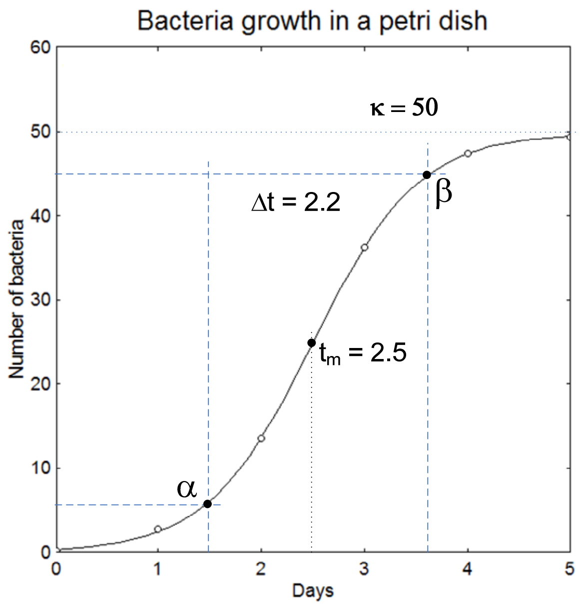


Figure 1: Growth of a bacteria colony consuming sugar and minerals in a closed Petri dish fitted to a logistic curve: limit of growth κ=50 species, characteristic duration Δt=2.2 days, midpoint t_m = 2.5 days.

For case N(t) << κ, the logistic model closely resembles exponential growth (3):

$$N(t) = e^{\alpha t + \beta} \qquad (3)$$

An equivalent form of logistic equation (1) for practical application can be defined as:

$$N(t) = \frac{\kappa}{1 + \exp\left[-\frac{\ln(81)}{\Delta t}(t - t_m)\right]} \qquad (4)$$

Empirical studies have shown that the characteristic S-shaped curve is present in thousands of growth and diffusion processes [7, 11]. Therefore, this model can be

[1] Where *e* - the base of the natural system of logarithms, having a numerical value of approximately 2.71828

[2] The decline can be described by a logistic with a negative Δt.

applied to both systems where the mechanisms of growth are understood and growing principles are hidden.

2.2 Technology diffusion and competition

Our working definition of *technology diffusion* is the following: technology diffusion is the process of obtaining (new) technology adapted through practical use. In the context of long-term technological forecasts, technology diffusion can be presented as a process of transition from invention to innovation [17, 18]. Therefore, such a transitional process from the first feasible prototype to the first regular product and new market creation takes time. For photography it took 112 years, for the steam locomotive – 55, for rolled wires – 47, for the lead battery – 79 and for arc welding – 49 years [17].

In the framework of the present research *invention* is defined as the result of engineering activities in a technological context which resolves contradictions between specific needs (how it was perceived) and known laws of nature. The output of the invention process is a feasible solution and working prototype, but not necessarily a patent[3]. *Innovation* is the result of socio-economic and technological activities. It produces added value because of an uncommon way of doing business. Thus, it seems meaningless to compare invention and innovation. They result from different activities and their values are measured by different parameters.

From invention to innovation, technology diffusion is a long and bumpy road full of uncompromising competition. It is a fact that hundreds of thousands of inventions have never become innovations. Furthermore, when innovation occurs, the long delay from invention to innovation makes it difficult to study the causality of the innovation process. Unfortunately, these facts are frequently ignored in studies about invention-innovation relationships.

Moreover, it is evident, that competition among emerging technologies plays a crucial role in technology diffusion. One of the basic assumptions for long-term forecasts that we apply is: all systems (super-systems, sub-systems) evolve under competition according to the law of logistic growth. Thus, mechanisms of competition should be divulgated and purposefully applied for technology forecasting in a reproducible way.

In his paper on the scientific approach of managing competition, T.Modis describes[4] six ways that two competitors, can influence each other's growth rate [13]: pure competition, predator-prey, symbiosis, parasitic (win-impervious), symbiotic (loss-indifferent), and no-competition.

Pure competition is when both species suffer from each other's existence because they use the same resources to survive. The traditional example of this occurs between rabbits and sheep. Each one decreases the growth of the other but at a different rate (sheep multiply more slowly than rabbits but eat more grass).

Predator-Prey competition is a relationship in which two 'species' interact as 'predator' and 'prey'. The predators flourish when there are abundant preys. However, ultimately, predators surpass their 'food supply' and decline. When the predator population is low, the prey population will increase once again. These dynamics go on in cycles of growth and decline. The classical example is the case of rabbit (prey) and fox (predator) populations. The Lotka-Volterra equations are usually applied to simulate the dynamics of this kind of competition.

Symbiosis is a situation where both species benefit thanks to their association. For instance, mobile phone sales trigger the increase of operators and new services and this escalation provokes sales of the latest mobile phone models.

Parasitic (win-impervious) is a relationship between two species in which one obtains some benefit while the other is unaffected. The classic example is from biology: remoras, which attach themselves to sharks and feed on their leavings without hindering their hosts. A market example is the increase of digital cameras and computers sales which prompt growth in the external hard discs market. However, the sale of external hard disks does not influence the sale of digital cameras.

Symbiotic (loss-indifferent) is a situation when one species suffers from the existence of another, which remains insensible to what is happening. A textbook case from biology is the shading out of one plant by a taller and wider one.

No-competition is a relationship between two species when there is no overlap in using resources to evolve. For instance, sales of coffee do not affect sales of tea in the same supermarket. Sales depend on seasonal variation rather on competition between two products.

In addition to two-competitor cases, the competition of one 'species' for resources (*Malthusian case*), such as *multiple competitors*, as well as a model of *indirect competition* (e.g. spatial competition when A interacts with B, and B with C, then C affects A through B) are revealed.

Given the number of various competition models it is not easy to subsequently build a practical instrument. Such a study becomes inadequately complex and time-consuming, with multiple opportunities for hidden errors and biases.

Therefore, problem can be formulated: it is necessary to take into account competition mechanisms that occur within technology diffusion among multiple competitors in order to consider intrinsic processes; but it is necessary to avoid the analysis of competition mechanisms, because it complicates applied models, and increases study costs. In addition, the complex models leave room for hidden errors, biases, and as a result, cause inadequate output.

2.3 Component logistic model (CLM)

If the data do fit well a large section of an S-curve, then one can argue for logistic growth… "if it walks like a duck and quacks like a duck, it must be a duck." T.Modis

As soon the logistic S-curve had been extensively applied to and studied in a wide range of socio-technical systems, the necessity of a feasible model to describe systems that experience two or more phases of growth became vital (medium and long term forecasting).

Starting with the assumption that the standard logistic S-curve describes one period ("pulse") of growth for a particular system, then obviously multiple growth pulses depict many systems [5]. Meanwhile, defining a system is a difficult task in itself. One of the fundamental ideas in the system approach is that all systems interact with their environment. In order to portray this phenomenon the system operator (multi-screen schema) must link super-systems, systems, and sub-systems as well as past, present, and future dimensions.

Indeed, a system is a demarcated part of the universe which is separated from the rest by an imaginary border. These artificial borders are unavoidable since to perceive

[3] "A patent is a government grant to an inventor assuring him the sole right to make, use, and sell his invention for a limited period." (Collins English Dictionary. 8th Edition first published in 2006 ©)

[4] It is referenced to the study of Kristina Smitalova and Stefan Sujan (1991).

or know anything, one must make this distinction. Nevertheless: How can we be sure about our delineation of a system? What are the criteria that justify the location of an artificial boundary?

To develop a system definition it is necessary to situate the boundaries and describe the characteristics of the system, the features of universe which affect the system outside of the system (super-system), and the interactions between universe and system.

Frequently, due to difficulties with the definition of the system, the time-series data cannot be cleaned and split properly. This leads to problems with fitting logistic S-curves to data. Before Perrin Meyer proposed bi-logistic and multi-logistic[5] models, complex multi-parameters functions were applied for the extrapolation of this sort of data [5, 6].

Problem

Prior to discussing the component model, let us appreciate the problem. The evolution of systems should be described by multi-parameter complex functions and curves, since the systems rarely follow a single S-curve trajectory due to *indigenous* complexity (e.g. systems including sub-systems and sub-processes; the irregularity of system parts evolution, etc.) and *exogenous* complexity (e.g. quasi-random behaviour thanks to multiple interactions with other systems, etc.). However, the evolution of systems should be described by (symmetrical) simple three-parameter logistic functions, to provide clear physical interpretations, to be comparable with other system evolutions, to decrease errors during forecasting, and to be applicable in practice.

Solution

The component logistic model describes the complex growth processes using a combination of simple three-parameter functions by applying bi-logistics [5] or multi-logistics [6]. The mechanism of combination resembles the 'nested doll' principle [1] and once again confirms the fractal feature concept of natural growth [20].

For instance[6], to study the dynamics of US Nuclear tests (source of data [21]) a single simple logistic does not provide an adequate level of residuals, while a bi-logistic growth curve fits data with acceptable residuals (see Figure 2).

Such a result was interpreted the following way: "…the fastest rate of growth (midpoint) of the first pulse occurred in 1963, following the Cuban missile crisis. While the first logistic pulse was largely the race to develop bombs with higher yields, the second pulse, cantered in 1983 and nearing saturation now (1994), is probably due to research on reliability and specific weapons designed for tactical use. The Bi-logistic model predicts that we are at 90% of saturation of the latest pulse. Processes often expire around 90%, though sometimes processes overshoot. The residuals show the extraordinary, deviant increase in U.S. tests after the scare of the 1957 Sputnik launch…" [5]

When reasonable interpretation is done, the application of component models provides suggestive and attention-grabbing results. However, our practical experience shows that experts might need several weeks to propose a realistic interpretation for obtained fits.

One of the remarkable characteristics of the component logistic model is its self-adjustment to a proposed definition of a system. Through the reduction of residuals and decomposition of an initial set of data by multi-logistic ones the initial definition of a system can be corrected and refined. In the proposed example (Figure 2) the initial system for nuclear tests was decomposed to nuclear tests for aircraft and for missile delivery and indeed they demonstrate different features and interactions.

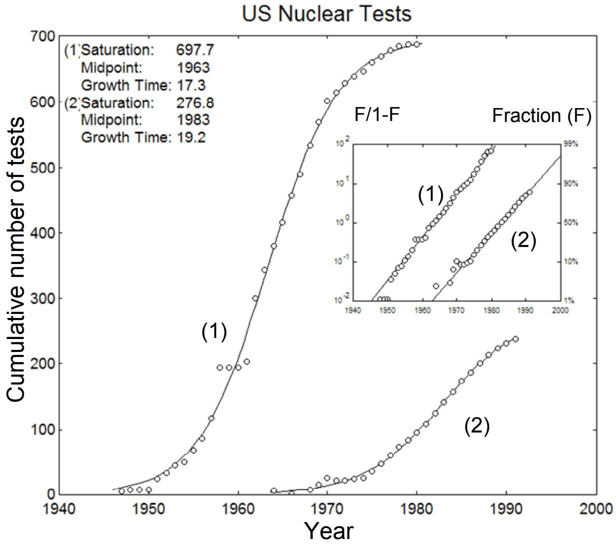


Figure 2: US nuclear weapon tests with a decomposed bi-logistic growth curve. The inset shows the component growth curves after using the Fisher-Pry transform. Source: [24].

3 LOGISTIC SUBSTITUTION MODEL (LSM)

"…no two people, working independently, will ever get exactly the same answer for an S-curve fit..." T.Modis

In their classic paper Fisher and Pry [12] proposed the substitution model of technological change based upon a simple set of assumptions. It was suggested, that the model could be applied for "…forecasting technological opportunities, recognizing the onset of technologically based catastrophes, investigating the similarities and differences in innovative change in various economic sectors, investigating the rate of technical change in different countries and different cultures, and investigating the limiting features to technological change." At first, proposed mathematical transform, decreases the number of parameters defining logistic growth and second, allows the comparison of growth processes with very different absolute values (e.g. growth of total length (for US) for canals - $7x10^3$km, and for roads - $6x10^6$km).

Most of the sources for LSM refer to the publications of C. Marchetti, and N. Nakicenovic [7, 22] issued in 1979. However, early traces of an application of the Fisher-Pry transform to study technology substitution under long-term competition are already in a 1976 publication [23].

The logistic substitution model *describes the competitors' niche market* (e.g. fraction of market share). The life cycle of competitive technologies is subdivided into three periods: growth, saturation and decline, where the growth and decline stages are logistic growth processes.

Problem

In order to provide long-range (over 50 years) forecasting in areas of the energy market, and energy use, the researchers faced with the problem of applying models which capture and simulate numerous relationships and feedback characteristics (complex ones), to represent, among other things, the activity of an economic system and to report competition phenomena. It was also necessary, however, to apply models with minimum

[5] For multi-logistic model growth is the sum of *n* simple logistics.

[6] This example is adopted from [5].

characteristics (simple ones), in order to provide a clear unambiguous interpretation and satisfy a 50 year forecast horizon.

Proposed solutions and results

For the purpose of dealing with long-term technological forecasting for energy systems, a basic hypothesis was formulated which stated that, “primary energies, secondary energies, and energy distribution systems are just different technologies competing for a market and should behave accordingly.” [7]

The authors emphasised three basic assumptions they applied to LSM [7, 22]:

1. New technologies enter the market and grow at logistic rates.
2. Only one technology is in the saturation period at any given time.
3. Declining technologies fade away steadily at logistic rates uninfluenced by competition from new technologies.

Nevertheless, two additional suppositions can be recognized as well:

4. There are n competing technologies ordered chronologically in the sequence of their appearance in the market.
5. A technology in saturation follows a non-logistic path that connects the period of growth to its subsequent period of decline.

A total of about 300 cases were examined from IIASA's Energy System Program using LSM for historical periods from 130 to 20 years ago. The report [7] description details the resulting model with comments for nine pages. Additional examples, graphs, and captions occupy sixty pages.

Descriptions of numerical methods for logistic substitution can be found in following publications from C. Marchetti, N. Nakicenovic, P. S. Meyer, J. W. Yung, and J. H. Ausubel [22, 6, 7]. There are also at least two non-commercial software packages [24, 25] for experimentation with LSM without the complications of equations and programming.

3.1 How does it work?

To illustrate how a forecast can be supported with LSM, the data of recording media sales in the US was fitted with the help of Loglet Lab software [24]. The latest data sets can be taken from http://www.riaa.com/keystatistics.php. However, in order to recognise the strong and weak points of LSM we will start with an old set of data, from 1998.

At first, initial data in millions of US dollars for vinyl record, cassette, and CD sales is represented as market shares using the Fisher-Pry transform. After that, the years between in which a logistic should be fitted are entered. These years are the assumptions about a period for Δt (see Fig. 1), based on the visual observation of transformed data. Linear behaviour corresponds to logistic growth or decline for the Fisher-Pry representation. In practice, assumptions about Δt and midpoint t_m can be done instead of a period evaluation.

As in any judgment, these assumptions contribute to the accuracy of a fit and future forecast. It was assumed that for vinyl a decline logistic should be fitted from 1977 to 1985, for cassettes a growth logistic is within 1977-1985, and for CDs a growth logistic is within 1987-1995 (Figure 3).

Note that the data sets for the early years of the CD and for the later years of vinyl do not follow the model. Based on the results of thousands of fits, such growth behaviour is usually irregular when a market share is less than 5% [26, 11, 20].

The obtained results strengthen the forecast about the growth of CD and the decline of cassette market shares. To convert this information into an absolute value in millions of US dollars, return to the initial data and fit them with the parameters learned from LSM.

The next step is to make an assumption about the next (new) technology, one for which there is not yet any data. Creating logistics for hypothetical technology demands supplying assumptions about a fourth saturation curve. At least two parameters should be defined: characteristic duration Δt and midpoint t_m to approximate when and how fast the technology will grow.

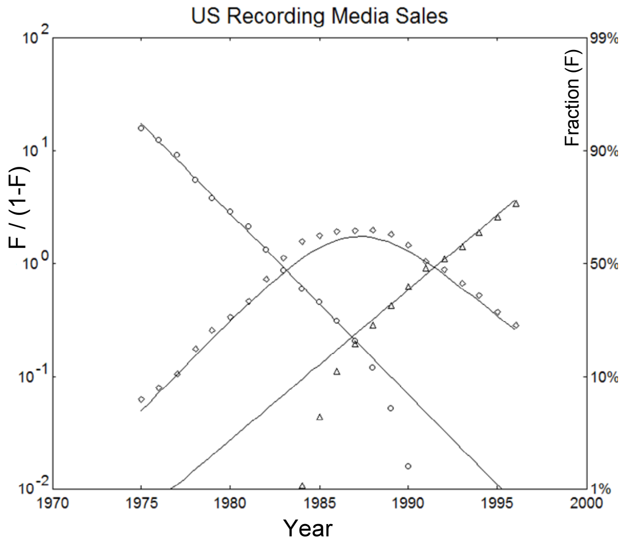


Figure 3: The recording media sales data with the logistic substitution model.

How can these two parameters be predicted? When the technology has already entered the market (passed 10% of market share threshold), the assumption about growth rate is based on the logistics for past technologies. For vinyl, cassettes, and CDs calculated Δt were respectively 12, 13, and 14 years. On Figure 4 the projected result of emerging technology #4 with Δt=14 and t_m=2005 is presented.

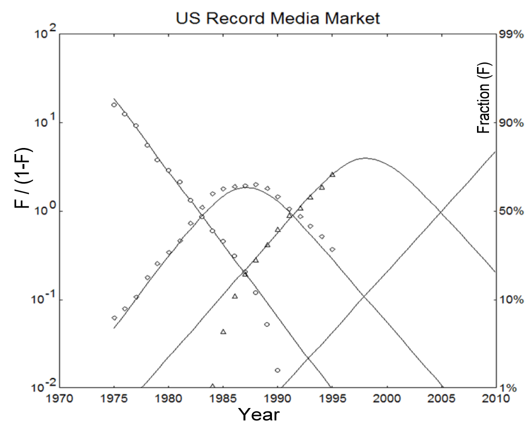


Figure 4: Anticipating the impact of new technology: the recording media sales data with a hypothetical fourth new technology.

In 1998, the DVD was chosen as the new technology and this turned out to be an incorrect prediction.

3.2 Known difficulties

To illustrate some known difficulties and ambiguities, let us compare diagrams reported in 1999 [6, 24, 26] with diagrams reported in 2007 [25] about the same topic.

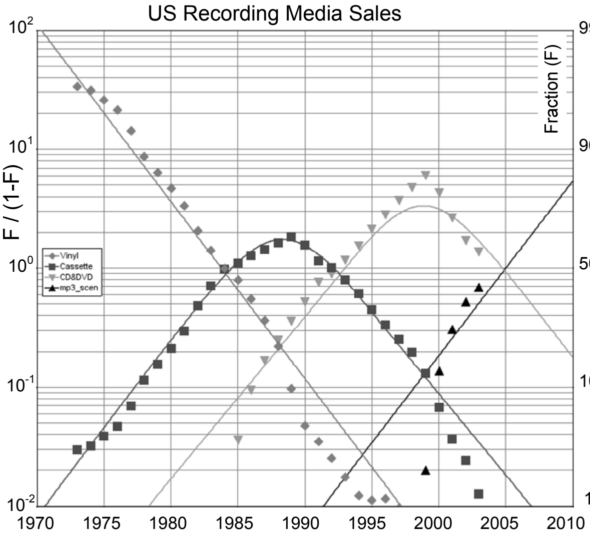


Figure 5: The recording media sales with MP3 data set (up to 2003). Source: [25].

The *first issue* is the definition of parameters for the hypothetic technology. In two papers published by the same authors in the same year, different assumptions were made about characteristic time Δt and midpoint t_m to describe logistic growth of new music technology. In Table 1 the second, third, and fourth columns represent the years of logistic decline / growth which were chosen as parameters for LSM.

	1999 [6]	1999 [26]	2007 [25]
Vinyl	1975-1985	1977-1985	1977-1988
Cassettes	1977-1985	1977-1985	1985-1999
CD	1988-1996	1988-1995	1986-2000
Hypothetic	2005-2018	1998-2012	1999-2016

Table 1: Variation of assigned parameters for logistic growth description.

The analysis of data from Table 1 once again confirms the absence of formal procedure to define the parameters for the given time periods.

The *second issue* is linked to the definition of the new technology itself. How is a prospective competitor defined in advance? In publications in 1999 the digital versatile disc (DVD) was a candidate. However, today MP3 technology is following the predicted growth curve, whereas the DVD is mostly used for video records, and not for music.

Another example to underline the second issue is the famous diagram "World – Primary Energy Substitution" which was made in 1979 [7]. In his 2002 book [11, p.164] Theodor Modis wrote "That turned out to be a most inaccurate forecast..." For instance, according to the world energy statistics [28] the nuclear primary energy supply in 2005 was about 6.3%[7], and combustible renewable & waste supply represents about 10%. Thus, the trajectory for nuclear energy evolution fell below what had been predicted.

[7] Fuel share of TPES. Total primary energy supply (TPES) is made up of indigenous production + imports - exports - international marine bunkers ± stock changes [28].

Even if LSM can predict logistic growth and decline, it is a challenging task for naming of a new technology within the long-term.

The *third issue* is about time-series data sets (selection, cleaning, transformation) and the assumptions made to fit logistics into data. In the second and third rows in Table 1 the same data were fitted with different assumptions. The primary question is: How can one have confidence in obtained fits? Unfortunately, the analysis of residuals is not allowed for LSM in referenced software [24, 25].

The *fourth issue* (but not the last) is about the interpretation of obtained results. LSM represents changes in competitor niches (e.g. changes in market share). On the other hand, the trustworthiness of a model depends on the initial estimations of niche capacities (κ) for each technology.

The difficulty for LSM is not building or running a model several times to get the best fit, but the interpretation of those obtained results, for the interpretation of plausible results do not always correspond to the actual future. Therefore, a formal mechanism is required to predict implausible events.

3.3 How to be more reliable

...the system had a schedule, a will, and a clock...

The working hypothesis to answer the *first issue* about the definition of parameters for logistic growth curves is based on studies about cycles in economic, technological and social environments [11, 29-36]. Detailed reviews of long economic cycles-waves, can be found in R. Ayres, *Technological Transformations and Long Waves* [39] and in documents from the NATO Advanced Research Workshop: *Kondratieff Waves, Warfare and World Security*, February 2005, Covilhã, Portugal[8].

Theodor Modis proposes a suggestive diagram (see Fig. 6) in his book [11]. A harmonic wave with a fifty-six-year time period in the upper part of the diagram represents deviations of the logistic growth of energy consumption in the US[9]. At the bottom, more than fifty growth processes are shown with their ceiling normalized to 100 percent. Most of the data for curves have been taken from Grubler's *The Rise and Fall of Infrastructures*. [37].

The growing parts of curves coincide with the upswing of the cycle indicating growth and prosperity, while saturation periods correspond to economic recession.

Data sets showing basic innovations [11, 17] represent regularity as well: the peaks in innovation correspond to valleys in energy consumption. Therefore, energy consumption resonates with making basic innovations[10].

The results in Figures 6 and 7 coincide with the conclusions about activities in social systems which were proposed in 1924 [29] and confirmed using extended data sets in 1936 [36] by A. Tchijevsky. These results are also in accordance with N. Kondatieff's concept of long waves in economics [30] and data about basic innovations collected by Mensch [17].

The hypothesis, which we are going to check in the coming future, defines logistic growth characteristics for LSM (characteristic time Δt and midpoint tm) in accordance with the "schedule" from the nearest environmental, social, and economic super-systems. The

[8] http://www.natoarw-kw.ubi.pt/scope.htm

[9] The periodicity in energy consumption was first observed by Hugh.B. Stewart [38].

[10] Cesare Marchetti first correlated Stewart's energy cycle with Mensch's basic innovations one [40].

surprisingly accurate predictions made using software based on knowledge about cycles TechSignal [44] give us confidence in our expectations.

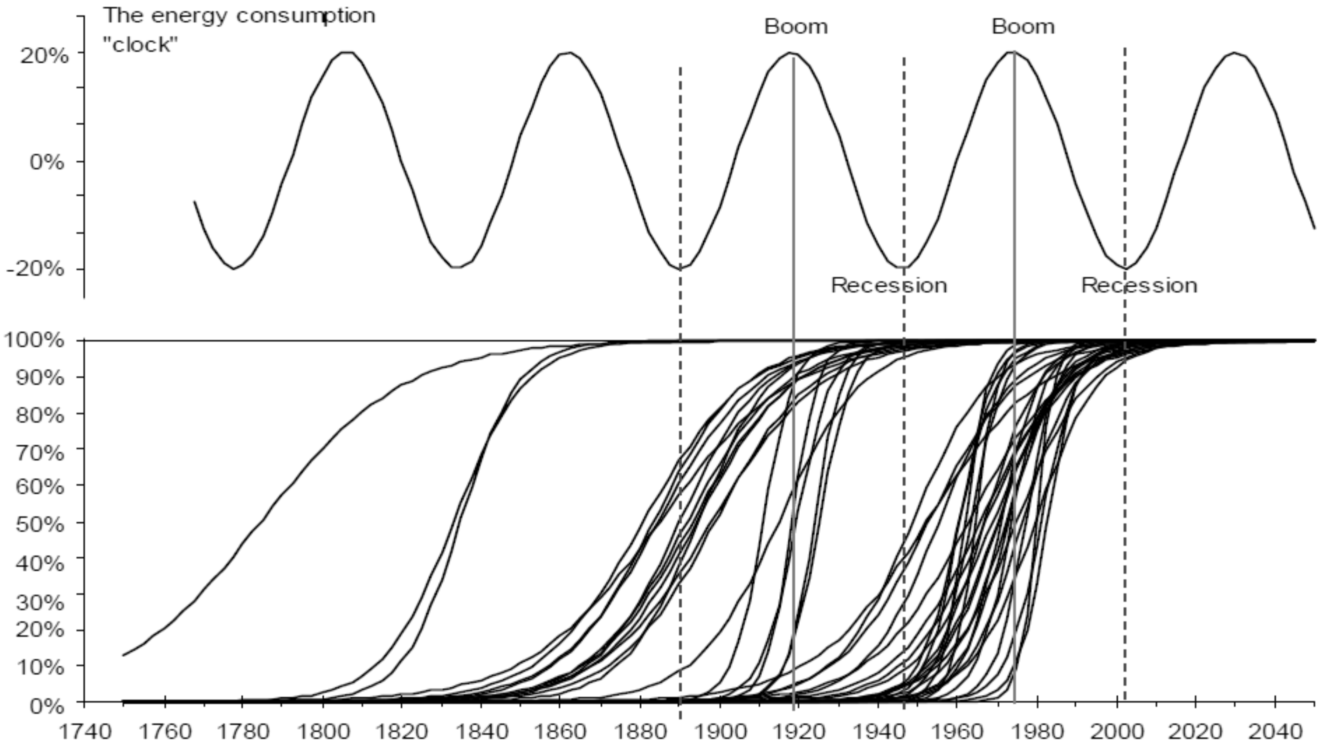


Figure 6: S-curves describing technological growth and substitution processes all normalized to reach 100% when they are completed. Adapted from [11].

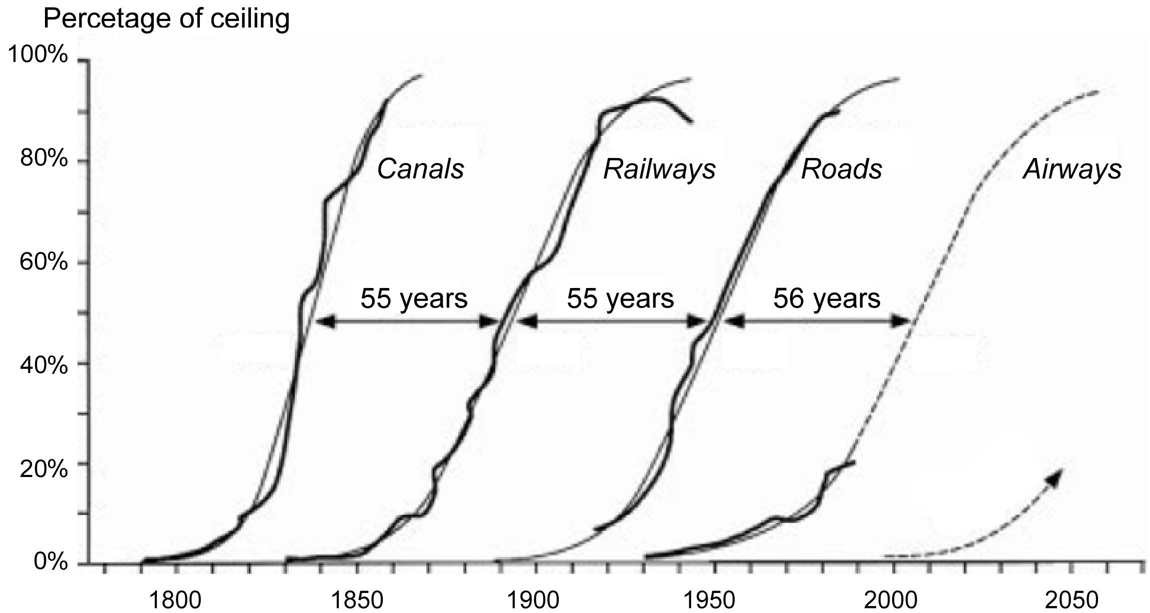


Figure 7: U.S. transport infrastructure. The growth in length of each infrastructure is expressed as a percentage of its final ceiling. The absolute levels of these ceilings in miles are different. Source [11, 37].

The *second issue* concerning the definition of prospective competitive technology can be addressed with the help of a genetic algorithm [41] and problems flow technology [42]. To identify the next generation of technology, techniques and models should be applied which are similar to the ones applied in inventive problem solving: the description of an X-element (ARIZ) [43], the Ideal Final Result (IFR) [1], and the element-name_of_feature-value_of_feature (ENV) model [42].

Progress regarding the *third issue* demands research about logistic growth models and the development of software which will facilitate LSM construction using a rigorous analysis of data and residuals.

Advancement on the *fourth issue* which concerns the interpretation and initial estimation of a ceiling for S-curves will come from analysis of limiting resources [19] and further development of the network of contradictions approach.

4 CONCLUDING REMARKS

In this paper we introduced the ‘direction through super-systems’ for problems of long-term forecasting of emerging technologies using CLM and LSM in the dimension of the naïve method. In further research, we plan to explore the 'direction through sub-systems' using the causal method based on logistic growth of knowledge within the 'invention-to-innovation' process [3].

Based on the application of laws of technical system evolution [1], logistic growth [11], and cycles [39] as main components, we have concluded that the basic patterns of technological changes are invariant. This application of knowledge about cycles and laws of logistic growth models (SLM, CLM, LSM) makes long-term technological forecasting possible as it soon helps resolve an incompatibility between cause-effect description (scientific) and the inadequate complexity of a model (practical).

The multi-screen scheme of thinking [1] in combination with the concept "competition is possible only in a common infrastructure" [37] makes possible the management of complexities of models by the synergy of CLM and LSM. When CLM allows the description of the logistic growth of a system from a viewpoint of sub-system evolution and endogenous competition mechanism, LSM provides a means for depicting technological change and performing long-term forecasting of socio-technical systems from super-systems and exogenous competition factor viewpoints.

For logistic growth models, the critical point for forecasting is the interpretation of results. For instance, in the case of CLM, it is a nontrivial task to recognize the essential underlying mechanism of obtained bi-, or multi-logistic growths. In one practical case it takes more than three weeks to understand the underlying mechanism of the constructed triple-logistic model. In the case of LSM, it is a challenging task to name the next technology. Even the time parameters of growth can be accurately identified.

Another remaining question: What are the regularities of evolution for systems which never show innovation? It is a well-known fact that before 'point α', systems do not display logistic growth behaviour (see Figures 3, 4, 5).

In conclusion, it is necessary to emphasis the crucial role of forecasters, since they play a decisive one. The reliable forecasting method alone is not enough for accurate long-term prediction. It will never be a "push-button" solution. Like any powerful tool, a method can produce a great outcome in the hands of the intelligent, but it may demonstrate misleading results in the hands of the inexperienced.

ACKNOWLEDGMENTS

This research was partially supported by European Institute for Energy Research (EIFER), Karlsruhe, Germany. We would like to thank our colleagues from the LICIA team of LGECO, INSA Strasbourg for constructive discussions. We also are grateful to all participants of seminar in Vinci, Italy at June 2008 for their goodwill, curiosity, questions, and helpful criticism.

REFERENCES

[1] G. S. Altshuller, Creativity as an Exact Science, Sovietskoe radio Publishing House, Moscow, 1979. p.184. in Russian.

[2] D. Kucharavy, and R. De Guio, Problems of Forecast, ETRIA TRIZ Future 2005, Graz, Austria, 2005. 219-235.

[3] D. Kucharavy, and R. De Guio, Application of S-Shaped Curves, 7th ETRIA TRIZ Future Conference, Kassel University Press GmbH, Kassel, Frankfurt, Germany, 2007.

[4] D. Kucharavy, R. De Guio, L. Gautier, and M. Marrony, Problem Mapping for the Assessment of Technological Barriers in the Framework of Innovative Design, 16th International Conference on Engineering Design, ICED'07, Ecole Centrale Paris, Paris, France, 2007.

[5] P. S. Meyer, Bi-logistic growth Technological Forecasting and Social Change, 47(1), (1994) 89-102.

[6] P. S. Meyer, J. W. Yung, and J. H. Ausubel, A Primer on Logistic Growth and Substitution: The Mathematics of the Loglet Lab Software, Technological Forecasting and Social Change, 61(3), (1999) 247-271.

[7] C. Marchetti, and N. Nakicenovic, The Dynamics of Energy Systems and the Logistic Substitution Model, International Institute for Applied Systems Analysis, Laxenburg, Austria. 1979.

[8] R. U. Ayres, What have we learned? Technological Forecasting and Social Change, 62(1-2), (1999) 9-12.

[9] N. Meade, and T. Islam, Forecasting with growth curves: An empirical comparison, International Journal of Forecasting, 11(2), (1995) 199-215.

[10] N. Meade, and T. Islam, Technological Forecasting -- Model Selection, Model Stability, and Combining Models, Management Science, 44(8), (1998) 1115-1130.

[11] T. Modis, Predictions - 10 Years Later, Growth Dynamics, Geneva, Switzerland, 2002. p.335. ISBN 2-9700216-1-7

[12] J. C. Fisher, and R. H. Pry, A simple substitution model of technological change, Technological Forecasting and Social Change, 3(1), (1971) 75-78.

[13] T. Modis, A Scientific Approach to Managing Competition, The Industrial Physicist, 9(1), (2003) 24-27.

[14] Grubler, A. (2003). *Technology and Global Change*. Cambridge, International Institute of Applied System Analysis. 453. ISBN 0521543320.

[15] J. H. Ausubel, and C. Marchetti, The Evolution of Transport, The Industrial Physicist, April/May, (2001) 20-24.

[16] C. Marchetti, Nuclear Energy and Its Future, Perspectives in Energy, 2, (1992) 19-34.

[17] G. Mensch, Stalemate in Technology: Innovations Overcome the Depression Ballinger Pub Co, Cambridge, Massachusetts, 1978. p.241. ISBN 088410611X

[18] E. M. Rogers, Diffusion of Innovations, 5th ed., Free Press, New York, 2003. p.512. ISBN 0743222091

[19] D. Kucharavy, and R. De Guio, Technological Forecasting and Assessment of Barriers for Emerging Technologies, IAMOT 2008, Dubai, UAE, 2008. p.20.

[20] T. Modis, Fractal aspects of natural growth Technological Forecasting and Social Change, 47(1), (1994) 63-73.

[21] Stockholm International Peace Research Institute Yearbook 1992, Oxford University Press, New York, (1992).

[22] N. Nakicenovic, Software Package for the Logistic Substitution Model, International Institute for Applied Systems Analyse, Laxenburg, Austria. 1979.

[23] C. Marchetti, On Hydrogen and Energy Systems, International Institute for Applied Systems Analysis, Laxenburg, Austria. 1976.

[24] J. W. Yung, P. Meyer, and J. H. Ausubel, Loglet Lab version 1.1.4. Program for the Human Environment, 1998. http://phe.rockefeller.edu/LogletLab/

[25] IIASA - Logistic Substitution Model II. Version 0.9.20, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, 2008. http://www.iiasa.ac.at/Research/TNT/index.html

[26] J. W. Yung, P. S. Meyer, and J. H. Ausubel, The Loglet Lab Software: A Tutorial, Technological Forecasting and Social Change, 61(3), (1999) 273-295.

[27] T. Modis, Strengths and weaknesses of S-curves, Technological Forecasting and Social Change, 74(6), (2007) 866-872.

[28] Key World Energy Statistics, International Energy Agency (IEA), Paris, France, 2007. 82. http://www.iea.org/Textbase/stats/index.asp

[29] A. Tchijevsky, Physical factors of the historical process, Kaluga, Russia, 1924. p.72. in Russian

[30] N. D. Kondratieff, The Long Waves in Economic Life, Archiv fur Sozialwissenschaft und Sozialpolitik, 1926 (vol 56, no 3, pp. 573-609, XVII(6), (1935) 105-115.

[31] J. A. Schumpeter, Business Cycles: A theoretical, historical and statistical analysis of the Capitalist process, 1939.

[32] H.-D. Haustein, and E. Neuwirth, Long waves in world industrial production, energy consumption, innovations, inventions, and patents and their identification by spectral analysis, Technological Forecasting and Social Change, 22(1), (1982) 53-89.

[33] T. Modis, Sunspots, GDP, and the Stock Market, Technological Forecasting and Social Change, 74(8), (2007) 1508-1514.

[34] E. R. Dewey, The Case for Cycles, Cycles Research Institute, 1967. 36.

[35] B. J. L. Berry, A Pacemaker for the Long Wave Technological Forecasting and Social Change, 63(1), (2000) 1-23.

[36] A. Tchijevsky, Earth Echo of Sun Storms, 2nd, Misl' (Thought), Moscow, 1976. p.376. in Russian.

[37] A. Grubler, The Rise and Fall of Infrastructures Dynamics of Evolution and Technological Change in Transport International Institute for Applied Systems Analysis IIASA, Laxenburg, Austria, 1990. p.305. ISBN 3-7045-0135-2

[38] H. B. Stewart, Recollecting the Future: A View of Business, Technology, and Innovation in the Next 30 Years, Dow Jones-Irwin, Homewood, Illinois, 1988. p.356. ISBN 1556231431

[39] R. U. Ayres, Technological transformations and long waves. Part I&II, Technological Forecasting and Social Change, 37(1&2), (1990).

[40] C. Marchetti, A Forecasting Model for Research and Innovation Activities in Selected Areas: A Support for Strategic Choices, International Course on Research and Innovation Management, UNIDO and ICS, Venice, 1991.

[41] D. E. Goldberg, The design of innovation: lessons from and for competent genetic algorithms, Kluwer Academic Publishers, 2002. p.248. ISBN 1-4020-7098-5

[42] N. Khomenko, and M. Ashtiani, Classical TRIZ and OTSM as a scientific theoretical background for non-typical problem solving instruments, 7th ETRIA TRIZ Future Conference, Frankfurt, Germany, 2007.

[43] G. S. Altshuller, To Find an Idea: Introduction to The Theory of Inventive Problem Solving, 2nd, Nauka, Novosibirsk, 1991. p.225. ISBN 5-02-029265-6. In Russian

[44] TechSignal, Foundation for the study of cycles, Inc., Albuquerque, New Mexico, 2001. http://techsignal.com/

CONTACT

Dmitry KUCHARAVY

LGECO / INSA Strasbourg

24, Bd de la Victoire, 67084 STRASBOURG, FRANCE

Phone: +33 (0)3 88 14 47 10

Fax: +33 (0)3 88 14 47 99

E-mail: dmitry.kucharavy@insa-strasbourg.fr

URL: http://www.insa-strasbourg.fr/triz/

Design Methodology for Hybrid Production Processes

Fritz Klocke[1], Andreas Roderburg[1], Christoph Zeppenfeld[1]
[1]RWTH Aachen University, Laboratory for Machine Tools and Production Engineering WZL, Germany

Abstract

Current developments of hybrid production processes or production systems exceed the performance in manufacturing. Most of these developments have in common that they have mainly been found intuitively. Up to now the development of new hybrid production systems leads to high amounts of operative planning. The challenge is to develop a systematic and scientific approach for aggregating, describing, explaining and combining single processes. This paper introduces a systematic approach of the design methodology for developing hybrid production processes. In terms of identifying hybrid process solutions as part of an innovation process, the applicability of different TRIZ tools is shown concerning the specific requirements of manufacturing processes development.

Keywords

TRIZ, hybrid processes, hybrid production, manufacturing processes, grinding, grind-hardening

1 INTRODUCTION

The manufacture of innovative products often fails due to technological limitations of today's production systems and processes. The hybridisation of manufacturing processes can help to break the limits of today's production systems and to realise innovative products. Thus developments of new hybrid manufacturing technologies arouse high expectations.

Previous developments of hybrid machining processes mostly base on intuitively or randomly found solutions. As yet a methodology for the systematic development of hybrid machining technologies does not exist. But as known from other scientific disciplines, a big part of solutions can not be found effectively without a methodological approach [1] [2] [3] [4]. Hence it can be assumed, that up to now the full potential of hybrid technologies is not exploited by far.

2 HYBRID PRODUCTION PROCESSES

2.1 Ontology of hybrid production processes

Within hybrid production processes different forms of energy or forms of energy caused on different ways respectively are used at the same time at the same zone of impact. Hybrid production processes are also defined as the combination of effects that are conventionally caused by separated processes in one single process at the same time [5].

The realisation of hybrid production processes bases on two approaches. By the integration of specific forms of energy in the work area of the process the machinability of the workpiece material is improved or the process mechanisms as well as the process characteristics are improved itself.

For the realisation of these approaches, one or more supplementary forms of energy have to be coupled into the existing process. For this purpose several different forms of energy combinations are possible consisting of e.g. thermal, mechanical or chemical energy, although the technological advantage and the possibilities of realisation must be considered [6].

2.2 Potentials of hybrid production processes

For the majority of companies in production industry – especially in high wage countries – innovation is one of the most important factors of success. Concerning this matter it is not only the product idea that contributes to a higher success, but also the capability of optimal production processes. In this context optimal means most efficient, flexible and stable at the same time. Broad manufacturing process know-how is necessary to run a technology near its limits of performance. However the full use of today's manufacturing technologies by means of conventional optimisation in most cases does not lead to a leap of performance. Hybridisation of conventional technologies is a way of reaching new technology capabilities in production systems. Figure 1 shows how hybrid processes can improve a production in terms of process chain shortening or the realisation of new product qualities.

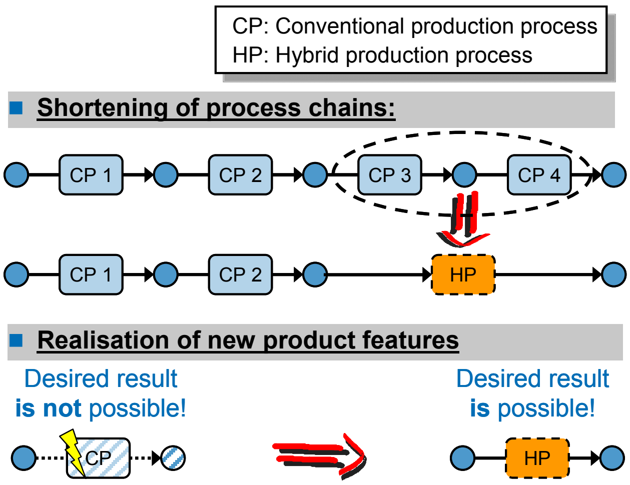


Figure 1: Aims of hybrid production processes

By the described technology integrations the process chain can be shortened due to the substitution of several processes by a single hybrid process. Further this can lead to a reduction of planning operations that are necessary to synchronise several processes in a process chain, even though a hybrid process may be more complex and may cause more requirements concerning process stability. Nevertheless a second aim of developing hybrid processes is to realise new product qualities. For example by hybridisation a conventional process can be enabled to machine new materials that according to the state of the art could not be machined by the conventional process yet. Based on these new production capabilities innovative products could be realised, that could not be produced (economically) due to the technological limitations of today's production technologies.

3 METHODOLOGY DEVELOPMENT

The research and development of production technologies often focuses on single production processes concerning specific applications. This profound research is very specialised and vital for the understanding of the mechanisms of known production processes. The knowledge about the mechanisms of single technologies enables these production processes to be adapted and optimised for a wide field of specific product requirements. According to the s-curve theory the possibility of process improvement decreases after a specific time considering single processes respectively – in this state the technology is optimised near to its limits. In the case of conventional, widely investigated manufacturing technologies, production research often focuses on adapting the known technologies for new applications such as the machining of new workpiece materials. On the other side more capable and efficient manufacturing technologies have to be developed. Assuming that the possibilities of hybrid production technologies is not utilised by far, the development of new inventive production technologies has to consider and combine the mechanisms of different single processes. For this purpose the integration of profound process knowledge from different production technology disciplines is necessary. In order to provide the broad field of necessary knowledge, it has to be compressed in an abstract way to get new ideas, which is the first step of inventive solutions.

The aim of the herein described scientific work is to develop a systematic tool for:

- optimisation of technology chains based on technology profiles
- describing and explaining of technology limits
- generating inventive solutions e.g. in terms of hybrid production technologies

TRIZ and the steps of hybrid production process design

To find inventive (hybrid) process solutions, different steps have to be proceeded. Figure 2 shows a general structure of the methodology and its similarities to the general TRIZ algorithm.

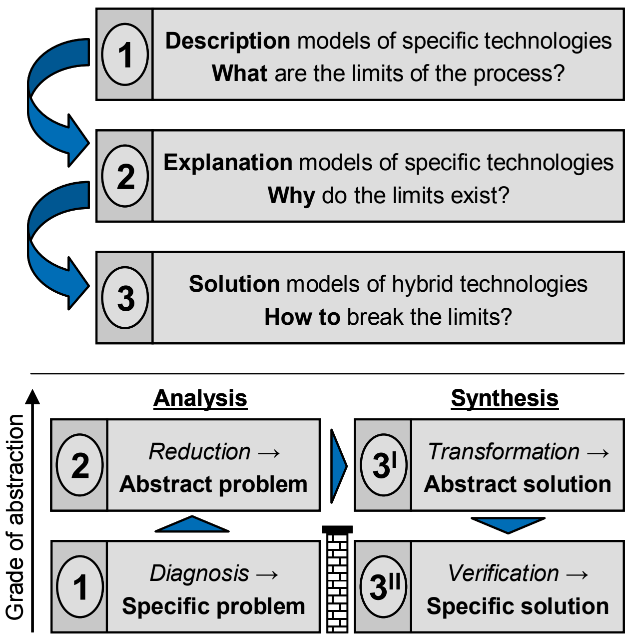


Figure 2: Steps of the design methodology for production processes and similarities to general TRIZ algorithm

The herein presented approach bases on the assumption, that a new process solution only can be developed if the limits of a technology are known as well as their reasons and that they can be described. The limits of technologies can be characterised in terms of problems, while a problem is defined as a contradiction. Thus in the first steps of the methodology the problems of today's technologies must be analysed systematically. TRIZ provides several methodological tools for the purpose of analysing problems. In accordance with the TRIZ methodology the technology limits are described in terms of standard problems through abstract physical or technical contradictions. By means of TRIZ, standard solutions can be identified for standard problems (e.g. by contradiction matrix, separation principles, standard solutions for substance field models) [7] [8] [9] [10].

Based on an aggregation of solutions and mechanisms of known production processes – single and hybrid processes as well – analogies can be provided to support the search for a specific solution. E.g. if a local heating of the work piece surface layer is required the use of laser beams is a specific solution as it is known from laser-supported turning or laser-supported incremental sheet metal forming.

3.1 Description level – Identification of limits

Technology capabilities can be described by several criteria composed of output quantities or output characteristics, which are related to the resulting workpiece, the tool wear or the productivity, see Figure 3. While the tool wear and the productivity primarily are economical evaluation criteria, the workpiece results are technological criteria.

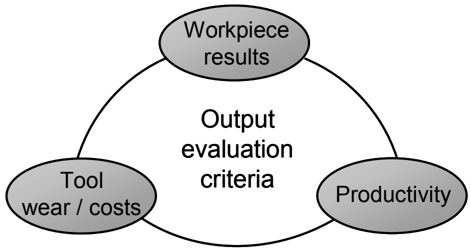


Figure 3: Evaluation criteria of a manufacturing process

The single manufacturing process can be described in terms of a black box by its input and output parameters, see Figure 4. This kind of description model reduces the complexity of a manufacturing process. In manufacturing research the correlations between input and output parameters of a specific process are often described by empiric-analytical models, which are based on experimental investigations. The results of these investigations are used for the purpose of process chain generation. In a process chain the workpiece state output of one single process is the workpiece state input of the following process until the desired workpiece condition is reached.

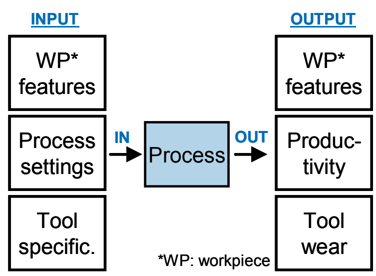


Figure 4: Black box model of a production process

The description of the workpiece state before and after the manufacturing process classifies the workpiece characteristics into macro geometry, surface topography, surface layer and bulk features. In the first procedures of the herein introduced methodology a technology is described concerning the results of workpiece surface topography and the influence on the workpiece material characteristics. For this purpose a workpiece element is defined. The difference between the states of the workpiece element before and after a manufacturing process describes the manipulation of the workpiece by the process. Hence, for the use of process chain generation the considered technology is sufficiently described by the change of the workpiece element characteristics. Figure 5 shows an example of a workpiece influenced by a grinding process. The surface layer consists of a re-hardening zone and an annealing zone. This manipulation is also known as "grinding burn".

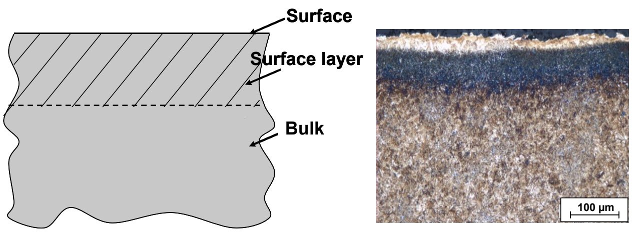


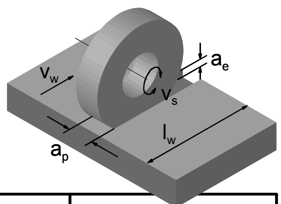
Figure 5: Workpiece model and surface layer analysis micrograph of a ground workpiece

In general, technological limits derive from a matching of required product results and technology capabilities. The realisation of some requirements is often directly opposed. The better the one criterion the worse gets the other one. In most technologies characteristic conflicting process output criteria are e.g. accuracy and productivity or tool wear and productivity. The below example of a conventional grinding process illustrates the above described context.

In the below example the assumed object is to optimise a conventional grinding process. A capability profile of the grinding process shows the following relation tendencies between some important output parameters of a grinding process:

Grinding - Conflicting output criteria

+ improving feature
— worsening feature



Surface Roughness	Process time / Productivity	Risk of grinding burn
+	—	constant
+	constant	—
constant	+	—

Figure 6: Characteristic conflicting output criteria of a grinding process

If the surface roughness of the grinding process should be improved e.g. the infeed speed can be reduced, which causes longer process times and thus leads to a lower productivity. If the productivity should be constant, the surface roughness can be improved e.g. by a higher cutting speed or by the use of another grinding wheel specification that features a lower grain size. Both lead to a higher risk of grinding burn.

As shown in the above example undesirable process outputs and generally conflicting outputs are aggregated for many different manufacturing technologies. This is the basic for a broad description of limits in production technologies.

3.2 Interpretation level – Reasons for limits

While the above described first step of the methodology features a phenomenological/descriptive view, in the following step the interrelationships of the process are considered by means of causes and effects. The change of view from the phenomenological to an interpretational view is also expressed by the terms that are used within the process models. Within the description level the terms of input and output mainly have been used. Within the interpretation level technology outputs are understood as effects at the end of a cause-and-effect chain. Hence, the production process is no longer described as a black box, but it is characterised by a cause-and-effect chain as shown in Figure 7.

Compared to the descriptive process model in Figure 4 the process is divided into two sub-models. The first sub-model *"Interaction" is technology specific*. It represents the mechanisms of interaction between the production system elements such as the interactions between tool and workpiece. Within these interactions energies are transmuted. E.g. the kinematic energy of a moving tool or workpiece are transmuted into work of friction and deformation, thus lead to mechanical and thermal energy as an effect of the interaction. The effected energies are defined as process characteristics. As a function of place and time these process characteristics describes the production process in a technology unspecific way without the need of profound information about the process input parameters. The technology unspecific process characteristics are vital for a common semantic for the purpose of comparing and combining different technologies.

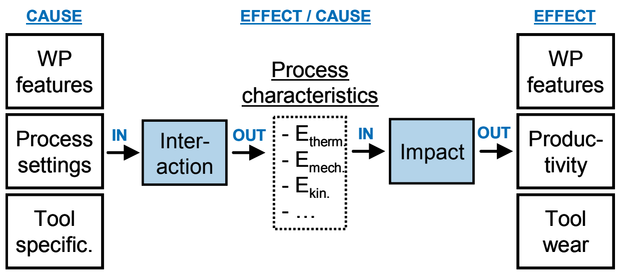


Figure 7: General interpretation model of a manufacturing process

In opposite to the sub-model "Interaction", the second sub-model *"Impact" is technology unspecific*. It represents the impact of the process characteristics on the process results such as the workpiece features and the tool wear. Within this sub-model the process characteristics are the root causes of the results.

It has to be remarked that Figure 7 shows a reduced model in order to clarify the idea of the model. In case of applying to a specific technology problem, it can be adapted or added by further cause and effect elements. E.g. the influence of specific machine specifications, supplies such as lubricants and external disturbances is not considered. Also the feedback of tool wear is neglected in this model, because in this case it is presumed that the principles of physical mechanisms do not change while tool wear appears.

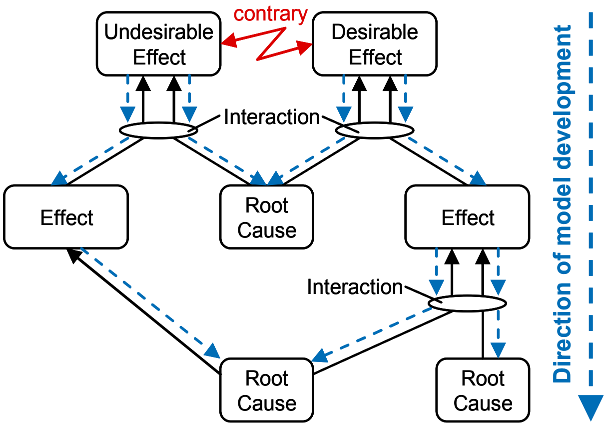


Figure 8: General model of cause-and-effect relations according to the Theory of Constraints [11]

In order to improve the technology by means of major changes of the manufacturing system instead of optimising the existing system by a compromise between process settings, the undesirable process results have to be traced back to their physical mechanisms and root causes. The cause-and-effect chains of specific undesirable effects such as high tool wear or subsurface damages of the workpiece can be described according to the "Theory of Constraint (TOC)" [11], see Figure 8. The construction of this model emanates from the undesirable and desirable effects that represent the contrary output criteria of the considered technology. The advantage of this diagram is the transparency of the cause-and-effect relationships. In many cases the real root causes are not identified. Instead of this the system is tried to improve by changing parameters that do not have a main impact on the undesired result or parameters that are effects of the real root causes itself. Additional by means of weighting the cause-and-effect relationships it is possible to identify the core problem, which features the main impact on the undesired effect.

3.3 Design level – Breaking the limits

Today's manufacturing technology research and development often focuses on the optimisation of single processes for specific applications by means of changing the tool specification and process setting parameters. This kind of process improvement is represented by the conventional optimisation approaches, see upper part of Figure 9. The *need for radical changes* of technologies cannot be achieved by these approaches.

Though the mechanisms of single technologies today are profoundly investigated and modelled in detail by several experts, interdisciplinary solutions are found rarely. The reasons are the limited individual knowledge concerning other disciplines or technologies respectively as well as psychological barriers (psychological inertia vector). In order to increase the probability of interdisciplinary solutions in production technology research and development a link of different technology models is vital. As mentioned above the technology unspecific process characteristics are used in this approach as a common semantic and interface respectively for different technology models.

After applying and executing all conventional optimisation approaches, the lower part of Figure 9 illustrates another way in order to achieve a radical improvement in terms of clearly enhancing the technical limits of a known process.

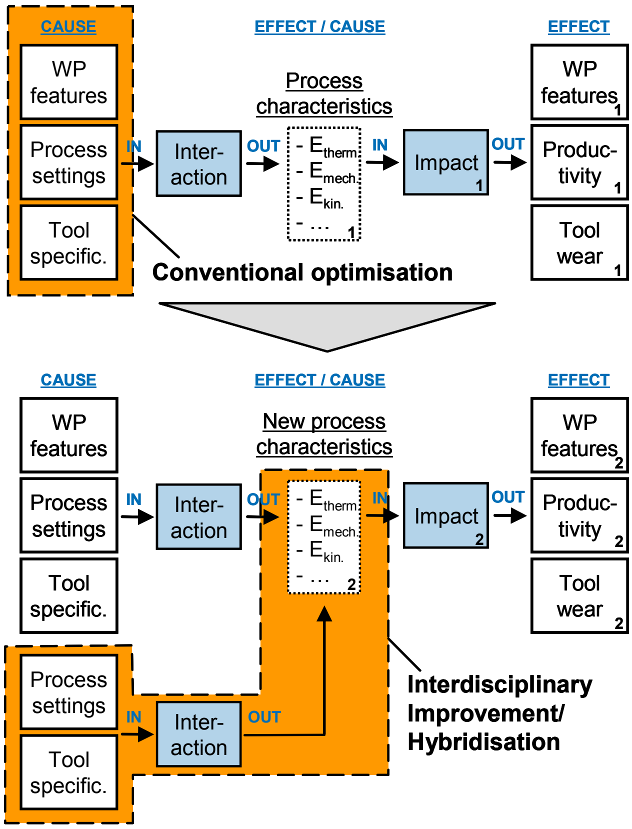


Figure 9: Illustration of conventional optimisation vs. interdisciplinary improvement of production processes

Assuming the possibilities of conventional optimisation is nearly exploited; the process can only be improved by changing the composition of process characteristics by external (energy) sources. This integration is based on an interaction of the added technology and the workpiece or the conventional process as well.

Another possibility of finding hybrid solution is to analyse the resources of process chains in terms of cause-and-effect relations. Based on this, a process chain may be improved by integrating single processes or the impacts of several processes respectively in one technology.

The above described design level of the methodology provides a way to find hybrid production technology solution. The general structure of this approach is based on the principles of TRIZ. Furthermore several tools of the TRIZ methodology have to be integrated to the introduced procedure in order to provide an effective applicable way that can extend the capabilities of technology development in production research.

4 INTEGRATION OF PRODUCTION PROCESS DESIGN AND TRIZ

The basic correspondences between TRIZ and the steps of hybrid production process design have been shown above, see Figure 2. The parallels between TRIZ and the introduced production process design methodology show a high potential for the use of TRIZ within this context. The main parallels are shown in the following [7] [8] [9] [10].

Interdisciplinary solutions

For the purpose of finding hybrid solutions the combination of different technology models is necessary. Due to the psychological inertia vector (PIV) the non-methodological problem solving process mostly focuses on a small field of possible solutions, which is limited to the technological knowledge of the individual person. An interdisciplinary solution often is outside of the focus of solution that is determined by the PIV. Such an inventive solution has to be found systematically, e.g. supported by several TRIZ tools.

The ideal solution

Both TRIZ and the hybrid production process design methodology aim at the "ideal solution" instead of accepting early compromises. In order to achieve a technology improvement with higher ideality compared to conventional optimisation, at least two conflicting output criteria of the manufacturing system have to be improved at the same time.

Analogies

The analogy approach bases on the assumption, that most problems already have been solved in other disciplines or another context respectively. Hence, new solutions often can be found based on analogue solution principles that have been realised in other technical areas. This implies an aggregation of known solution and an extracting of solution principles. In the field of manufacturing technologies, existing technology database systems can help to analyse existing solutions in order to find solutions for unsolved problem. In terms of an efficient production process design methodology technology only limited knowledge can be given und thus must be provided purposeful.

Abstraction

Known specific solutions can be used to identify standard solution strategies, that can be used to find a solution for another specific problem. The linking of solution and problem is enabled by an abstract modelling of the specific problem. This origin idea of TRIZ is followed by the herein introduced modelling of single processes. The problem of a technology is described in an abstract manner by process characteristics based on their physical mechanisms. In a next step the solutions are generated on this abstraction level as described in Chapter 3.3.

In literature TRIZ is described as a methodology, consisting of different method tools. Figure 10 summarises several TRIZ tools as they are used for problem solving in a broad field of applications.

Systematic	Knowledge	Analogy	Vision
Innovation Checklist	Physical Effects	40 inventive Principles	S-Curve
Ressource Checklist	Internet Search	Contradiction Matrix	Laws of Evolution
Ideality	Patent Search	4 Seperation Principles	
Operator MTC		Substance-Field-Model	
Miniatur Dwarfs			
Problem Formulating			

Figure 10: TRIZ tools overview [12]

Concerning the integration of TRIZ and the introduced methodology of production process design, the applicability of several TRIZ tools is evaluated by means of known hybrid production processes. Hereby the physical mechanisms of single processes are considered and process solutions are developed by the help of TRIZ tools respectively.

In the following the application of the above described methodology in combination with several TRIZ tools is exemplified by the technology evolution from grinding to grind-hardening as a new hybrid application of the grinding process.

4.1 Grind-hardening

Grinding is generally used as a finishing process of hard materials due to its high dimensional and shape accuracy, although grinding can be used for high stock removal rates as well.

Identification of limits in grinding

In grinding of hardened steel, undesirable effects can appear near to the ground surface such as crack formation, workpiece material structure transformation, modification of hardness progression, and residual tensile stress. As mentioned in chapter 3.1 the workpiece material structure transmutations – also called grinding burn - can be divided in a white etching re-hardening zone and an annealing zone, see Figure 5. The annealing zone features a lower hardness than the bulk material. The re-hardening layer is harder and more brittle compared to the bulk material. The generally conflicting output criteria of a grinding process concerning grinding burn have been shown in Figure 6.

Reasons for limits of grinding

The progression of temperature over the time is the main influence factor of dimension and modality of the surface layer. The temperature progression can be characterised e.g. by the maximum temperature and time period of thermal impact [13]. Figure 11 shows the cause-and-effect relationship of the grinding process regarding the above mentioned undesirable effect of grinding burn, that occur if the productivity is raised to a critical point, while the surface roughness and tool wear is constant.

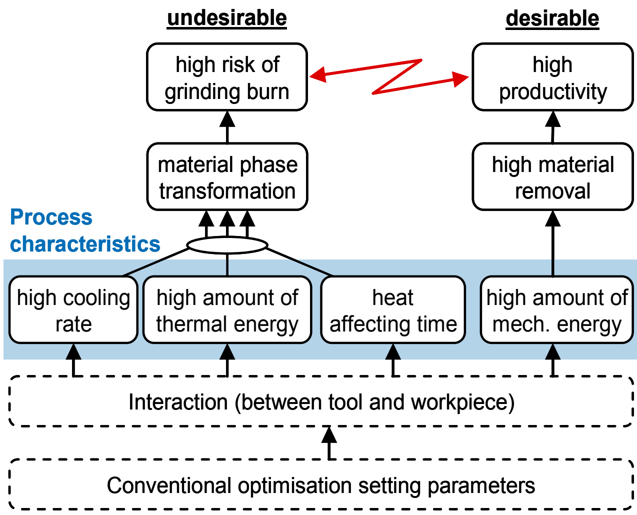


Figure 11: Cause-and-effect model of a grinding process

It is assumed, that all conventional optimisation approaches according to Figure 9 are exhausted, so that the root causes in terms off setting parameters are not considered in Figure 11. In a first step it is also sufficient not to regard the interaction of tool and workpiece. Instead the first object of process improvement is the level of process characteristics, which are assumed to result from the process interactions. In opposite to the other system and process setting parameters, the initial workpiece material features have turned out to be important information, which has to be considered on every abstraction level of the process model. It is a crucial fact that the effects of interaction as well as the effects of process impact, such as material structure transmutations, depend on the initial material state in a great extent.

Breaking the limits of grinding

In order to find a solution for the above described problem in terms of TRIZ, the first step is to define the problem in form of a contradiction. In Figure 12 the reduced substance field model of the grinding process depicts the problem.

Between the grinding wheel and the workpiece a mechanical field is generated effecting the desirable chip formation and thus the material removal. A thermal field is generated as a second field that causes the undesirable effect of thermal workpiece surface damages.

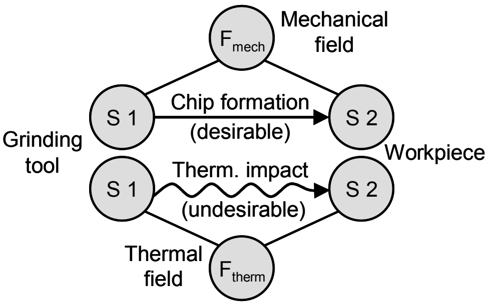


Figure 12: Reduced substance field model of a grinding process

Due to physical laws in conventional grinding the amounts of thermal and mechanical energy are correlated, both are affected by the total amount of process energy. The use of standard solutions has brought out some known solutions such as using cooling lubricants. Cooling lubricants can improve the ratio between the mechanical and the thermal fields. Up to now no other solution was found to resolve this relation. Thus the problem can be described by a *physical contradiction*:

- Process energy must be high.
- Process energy must be low.

A possible solution is to apply the principle of separation in time. While in a rough machining process the productivity is high, a damaged surface layer can be compensated by a finishing process afterwards. This solution is well known and probably the most applied one in industry, but it is not a hybrid process solution. To find another solution for this particular problem is a big challenge for future research.

Another approach is to change the view of examination to the *superior system* of process chains. As long as there is no specific application to be considered, it is appropriate to describe a process chain, which is commonly linked to grinding technologies. Grinding is mostly used for hard machining and thus the grinding process very often follows a heat treatment process. Here the heat treatment is applied in order to harden the surface layer. Hence, the considered process chain consists of soft machining, followed by heat treatment (e.g. induction hardening or laser hardening), and followed by grinding for hard machining. The heat treatment processes cannot easily be integrated into the production line. For this reason the heat treatment process involves some more processes due to transport and cleaning operations that are time and cost consuming, see Figure 13.

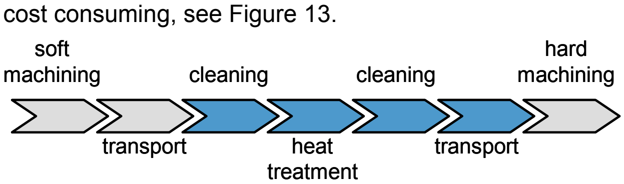


Figure 13: Conventional process chain commonly linked to a grinding process

By an expansion of the above shown cause-and-effect description to the process chain, the TRIZ tools "Innovation Checklist" (ICL) and "Resource Checklist" (RCL) respectively can be used. In terms of this process design methodology not the technologies but their abstract cause-and-effect relationships are considered as the resources of a process chain. Within the considered process chain an accumulation and comparison of cause-and-effect models of all participating technologies shows a common cause-and-effect relationship shared by the grinding and hardening process as shown in Figure 14.

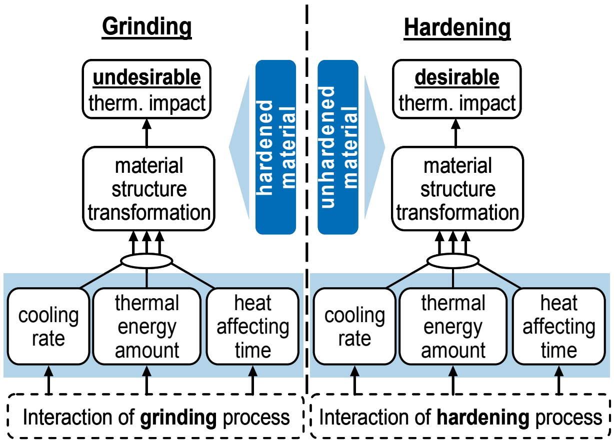


Figure 14: Common cause and effect relationship shared by grinding and hardening processes

Concerning the thermal aspects of the processes the same process characteristics determine the thermal impact onto the workpiece surface layer. While the effect of material structure transformation in grinding leads to undesired grinding burn, the material structure transformation in hardening causes the desired process result. The crucial difference between the two technologies is that the initial state of workpiece material of a grinding process is a hardened material, but in hardening the material is unhardened before. Using the principles of ICL/RCL it can be concluded, that grinding of hardened material can lead to undesired grinding burn, but in grinding of unhardened materials it may be possible to use the heat progression for the purpose of surface hardening [14]. Figure 15 shows the principle of grind-hardening.

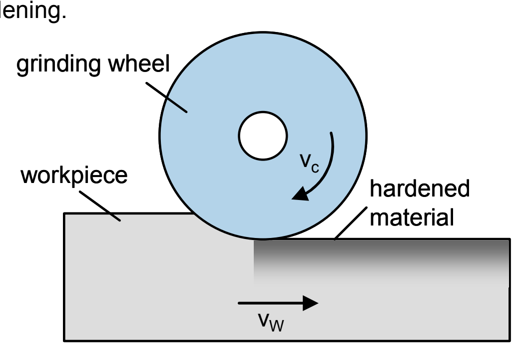


Figure 15: Principle of grind-hardening

As primary experimental investigations already has shown, the heat generated in grinding can be utilised for thermal induced surface hardening effect up to mm-scale. They have shown that the metallurgical effects in grind-hardening are comparable to those of conventional surface hardening technologies such as laser and induction hardening [14] [15] [16] [17] [18].

By the use of grind-hardening a separate hardening process can be substituted and therewith involved time and cost consuming transport and cleaning processes get unnecessary, see Figure 16.

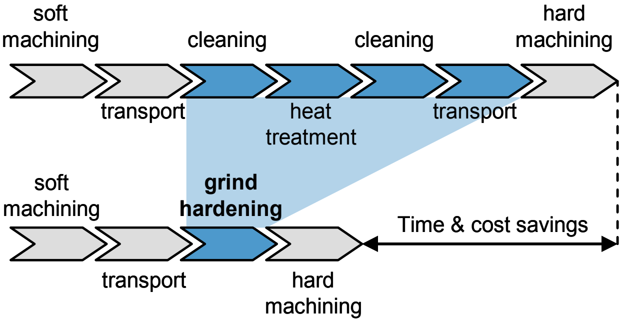


Figure 16: Shortening of process chain by grind-hardening

Thus a new application of grinding technology was found in using the thermal source of a grinding process for surface material hardening.

5 SUMMARY

This paper introduced a systematic approach of a design methodology for developing hybrid production processes that can clearly enhance the capability limits of today's production technology systems. According to the principles of TRIZ the herein introduced approach consists of three steps. First generally technology capability limitations (problems) have to be found in terms of contradictions. Secondly specific limits must be traced back to its physical causes by exploring cause-and-effect relations. A technology unspecific description of the process characteristics is used to find abstract solutions. These abstract solutions are the origin for the integration of different technologies and thus for new approaches in terms of breaking the limitations of single technologies by radical changes. TRIZ provides several method tools that support the search for inventive (hybrid) production process solutions and that have to be integrated respectively.

As illustrated in the use case of grind-hardening the introduced systematic approach supports the technology development in terms of generating new ideas and solutions for enhancing the limits of today's production technologies.

ACKNOWLEDGMENTS

The authors would like to thank the German Research Foundation DFG for the support of the depicted research within the Cluster of Excellence "Integrative Production Technology for High-Wage Countries" [19].

REFERENCES

[1] Altschuller, G.: „Erfinden – Wege zur Lösung technischer Probleme“. (Ed.): Thiel, R; Patzwaldt, Berlin: Verlag Technik, 1984

[2] Klein, B.: „TRIZ/TIPS – Methodik des erfinderischen Problemlösens“. München: Oldenbourg Wissenschaftsverlag, 2002, ISBN 3-486-58083-3

[3] Orloff, M. A.:, 2002: „Grundlagen der klassischen TRIZ – Ein praktisches Lehrbuch des erfinderischen Denkens für Ingenieure“. Berlin: Springer-Verlag, 2002, ISBN 3-540-66869-1

[4] Zobel, D.: „TRIZ für Alle“. Renningen: expert Verlag, 2006, ISBN 3-8169-2396-8

[5] Feinauer, A. et al.: „Werkzeugmaschinen für die Produktion von morgen im Spannungsfeld: flexibel und einfach, schnell und genau.“ In: Eversheim, W. et al. (Ed.): Wettbewerbsfaktor Produktionstechnik. Aachener Werkzeugmaschinen Kolloquium 2005. Aachen: Shaker, 2005, pp. 373-409

[6] Eversheim, W.; Klocke, F.; Pfeifer, T.; Weck, M. (Ed.): „Hybride Prozesse – Neue Wege zu anspruchsvollen Produkten.“ In: Aachener Werkzeugmaschinen Kolloquium. Wettbewerbsfaktor Produktionstechnik. Aachener Perspektiven. Aachen: Shaker, 1999, pp. 243-278

[7] Orloff, M. A.: “Inventive Thinking Through TRIZ: A Practical Introduction”. 1st Ed., New York: Springer-Verlag. 2003, ISBN 3540440186

[8] Altshuller, G.: “The Innovation Algorithm: TRIZ, Systematic Innovation and Technical Creativity.” Worchester, Massachusetts: Technical Innovation Center. 1999, ISBN 0964074044

[9] Altshuller, G.: “And Suddenly the Invenor Appeared: TRIZ, the Theory of Inventive Problem Solving.” Worchester, Massachusetts: Technical Innovation Center. 1996, ISBN 0-9640740-2-8

[10] Altshuller, G.: “40 Principles: Triz Keys to Technical Innovation.” Worchester, Massachusetts: Technical Innovation Center. 2002, ISBN 0964074036

[11] Dettmer, H. W.: “Goldratt's Theory of Constraints – A Systems Approach to Continuous Improvement.” Quality Press, 1997, ISBN 0-87389-370-0

[12] Jantschgi, J; Shub, L.: „TRIZ – Innovativer Irrgarten der Werkzeuge“, In: Gundlach C. et al: Innovation mit TRIZ – Konzepte, Werkzeuge, Praxisanwendungen. Düsseldorf: Symposion, 2006, pp. 59 – 73, ISBN 3-936608-74-1

[13] Nachmani, Z.: “Randzonenbeeinflussung beim Schnellhubschleifen”, Dissertation at RWTH Aachen University, Aachen: Apprimus Verlag, 2008, ISBN 978-3-940565-07-5

[14] Brinksmeier, E.; Brockhoff, T.: „Advanced Grinding Processes for Surface Strengthening of Struktural Parts“, In: Machining Science and Technology, Volume 1, Issue 2, pp. 299 – 309, Taylor & Francis, 1997, ISSN 1091-0344

[15] Brockhoff, T.: “Surface Hardening by Using Advanced, Grinding, Technology”, In: Abrasives Magazine, December/January 1997/98, pp. 10 - 11 and 32 – 37

[16] Brockhoff, T.: “Grind-Hardening: A Comprehensive View”, Annals of the CIRP Vol. 48, Nr. 1, pp. 255 – 260, 1999, ISSN 0007-8506

[17] Brockhoff, T.: „Schleifprozesse zur martensitischen Randschichthärtung von Stählen“, Dissertation at University of Bremen, Aachen: Shaker Verlag, 1998, ISBN 3-8265-6020-5

[18] Stör, R.: „Untersuchung und Entwicklung des Innenrundschleifhärtens“, Dissertation at University of Bremen, Aachen: Shaker Verlag, 2008, ISBN 978-3-8322-7107-7

[19] www.production-research.de

CONTACT

Andreas Roderburg

Laboratory for Machine Tools and Production Engineering
RWTH Aachen University

52074, Aachen, Germany

E-mail: A.Roderburg@wzl.rwth-aachen.de

Phone: +49 241 8028187

Searching for Similar Products through Patent Analysis

P.-A. Verhaegen[1], J. D'hondt[1], J. Vertommen[1], S. Dewulf[2], J. R. Duflou[1]
[1]Katholieke Universiteit Leuven, Mechanical Engineering Department, Belgium
[2]CREAX N.V., Belgium

Abstract

During problem solving, TRIZ users map a specific problem to a generic problem, solve it via TRIZ tools, and map back to a specific solution, a process relying heavily on their TRIZ skills. To aid less skilled users, a methodology and algorithm are proposed that, through identification of specific word categories in patents, analysis of term-term correlation data, and data mining techniques, automatically identify similar products, and properties relating or differentiating products. This algorithm can quantifiably guide creativity efforts and aid in patent portfolio management.

Keywords

Systematic Innovation, TRIZ, Creativity, Patent Analysis, Data mining

1 INTRODUCTION

1.1 Patent Portfolio Management

In 2007, the United States Patent and Trademark Office (USPTO) granted over 150 thousand patents [1], and categorized each patent in a hierarchical system based on topic or technological area. These schemes, such as the US or IPC patent classification schemes, allow to search for patents related to an application area, e.g. IPC groups A45B 11 to A45B 19, A45B23 and A45B25 all relate to patents covering umbrellas.

Hundreds of companies' portfolios increase by 40 to over 3000 patents per year [1], complicating efficient and effective portfolio management, and demanding tools and techniques enabling the detection of market opportunities outside the application area of the organization's own technology, as well as the identification of possibilities to license in complementary technology.

While commercially available patent databases offer full text and more specific search features based on different patent fields, such as citations, applicant, inventor or issue date fields, these functionalities do not directly allow a company developing umbrellas to search for market opportunities, or to identify complementary technology.

This research facilitates reaching these two objectives by proposing automatically identified similar products, and the properties relating or differentiating these products.

1.2 TRIZ

TRIZ is the Russian acronym for the Theory of Inventive Problem Solving, and encompasses a series of tools and a methodology for generating innovative ideas and solutions for problem solving. It was formed through the manual analysis of what TRIZ practitioners estimate to be one and a half to three million patents, from which forty thousand innovative patents were withheld and their applied innovative solutions were mapped onto a small number of extracted inventive principles.

TRIZ is based on three postulates [2] [3]:

- The Postulate of Existing Objective Laws states that engineering systems evolve according to a set of laws;
- The Postulate of Contradictions states that, in order to evolve, an engineering system has to overcome one or more contradictions; and
- The Postulate of the Specific Situation states that the problem solving process should take into account the specific problem peculiarities.

Derived from this patent analysis and based on the postulates, a set of TRIZ tools was conceived, of which the most popular are [4]:

- The Contradiction Matrix to solve technical contradictions;
- The Separations Principles to solve physical contradictions;
- Substance-Field (SU-Field) modeling and the Inventive Standards to transform technical systems;
- ARIZ as a list of logical procedures for eliminating contradictions; and
- TRIZ Trends as a system of laws that govern engineering system evolution.

TRIZ incorporates the idea of mapping a specific problem to a more general problem specification, solving this generic problem via the TRIZ toolset, and mapping back the generic solution to the specific problem. This enables TRIZ users to benefit from the generalized inventive solutions outside their fields of knowledge, but also relies heavily on the user's TRIZ skills. As TRIZ users are interested in analogous inventions in other fields, or technological areas, that solve the same contradictions, the analyses can not easily be automated by simple search functionalities for other patents based on the IPC classes or patents fields.

Instead of requiring the user to map to and from the generic TRIZ solution space, the proposed algorithm directly relates products with other products from other technological areas with similar product properties, and assumes that the observed contradictions are solved in products with similar properties.

The following section gives an overview of related research on data mining of the structured and unstructured fields of patents, and on innovative idea generation. The third section describes the proposed methodology, while the fourth illustrates this methodology with a case study. The final section formulates the conclusions.

2 RELATED RESEARCH

Research has been conducted to automatically infer structure from non-text patent fields. Citation analysis permits functionalities such as the identification of major competitors, the construction of technology indicators, and documentary search possibly identifying related technologies and applications [5]. This analysis is based on references given by the applicant, optionally for the European Patent Office, and screened by the patent office, thus basing any further analyses on already known product or technology relations, and excluding e.g. new applications domains. In addition, most patents never get cited or only begin to get cited after several years[6].

Patent text fields, such as the title, summary, description or claims fields, contain vital information about the patent, and can be subjected to text mining techniques, which extract relevant information from less structured textual data through use of keyword extraction, pattern recognition, linguistic analysis, and statistical techniques. A series of text mining techniques for patent analysis is presented and evaluated in [7].

In [8], Yoon and Park propose a network-based analysis as an alternative to citation analysis. This methodology is based on keyword extraction and linking patents based on the occurrences of these keywords, instead of citations between patents. It allows users to visually identify patent network structure, such as central patents, or disjoint groups.

[9] proposes a case-based reasoning methodology and product innovation retrieval system (PIRS) for retrieving similar products based on 87 user-centered design (UCD) attribute dimensions. The technique relies on a large database of products scored on these attributes, a manual process performed by UCD experts. The functions of the identified products are candidate ideas for the product under investigation. Compared to the methodology proposed in this research, the PIRS system can not retrieve products which are not interactively analyzed and inserted into a database. The use of the UCD attributes furthermore causes products similar only in functionalities to be retrieved.

In [10], Yoon and Park describe a morphological analysis methodology based keyword dictionary developed by text mining patent and factor analysis on the terms. The morphology of all patents is identified, and technology gaps within a product or technology can be identified.

The commercially available Goldfire InnovatorTM from Invention Machine [11] has a semantic engine to infer Subject-Action-Object (SAO) from plain text sentences in patents and queries and offers several TRIZ inspired idea generating functionalities based on an indexed database of these SAOs.

Other research by Cascini [12][13] describes algorithms to automatically analyze patent text fields revealing the invention’s components, architecture, and positional and functional interrelations, and aiding in identifying the solved TRIZ contradictions.

Research by He Cong and Loh Hang Tang [14] proposes a text based expert system which allows classifying patents according to TRIZ inventive principles. Similar research by the same authors [15] proposes an automatic patent classification system based on clustering to categorize patents in TRIZ inventive principles, and evaluates the performance of different clustering algorithms on the selected text features.

Other research by Cavallucci [16] proposed and validated the possibility to incorporate the eight original Altshuller's laws of development in the design process on a manifold case study. Based on TRIZ and domain knowledge, the conclusions concerning the development potential can be translated into specific directions for future improvements of the manifold.

In [17] and [18], Mann and Dewulf propose the concept of evolutionary potential, which is similar to the approach proposed by Cavalucci [16], but using more specific TRIZ trends or lines of evolution allows for a more actual and specific categorization.

Later research in Directed Variation by Dewulf [19] suggests depicting the product on a radar plot of property spectra, instead of trends or lines of evolution, e.g. rigid, jointed and flexible are all properties of the spectrum flexibility. While classical TRIZ assumes the evolution usually occurs in a certain direction along the trends, Directed Variation regards changes of properties towards both directions in a spectrum as variations to ensure certain functionalities of a product, e.g. for the surface spectrum, evolving towards the flat property can decrease resistance, while evolving towards the protruded side of the surface spectrum can increase grip or allow faster cooling. The radar plot of property spectra of a product, or product DNA, can be compared to the DNA of other products to find similar products. Figure 1, copied from this research, compares the product DNA of sugar and dish washing tablets, graphically illustrating the similarity and dissimilarity among the products, potentially inspiring the creativity of engineers.

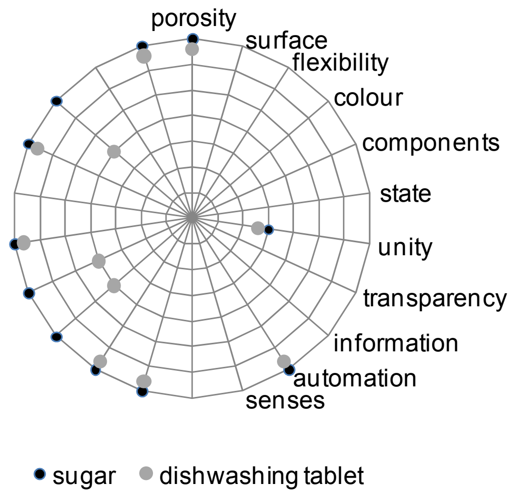


Figure 1: Product DNA comparison of sugar and dishwashing tablets [19]

Dewulf also identifies the link between adjectives and product properties, and between verbs and product functions. This research builds further upon this idea, proposing a method for automatic extraction of product properties and automatic comparison of products, and suggesting directions for creative efforts. This enables the discovery of market opportunities outside the application area of the organization’s own technology as well as the identification of possibilities to license in complementary technology.

3 METHODOLOGY

This research proposes an algorithm and framework that, through patent analysis and identification of word categories, can extract information concerning the properties of a given product or product family, which in turn allows to identify properties relating or differentiating two products. Other functionalities based hereon are the finding of similar products. These algorithms can assist in steering the creative efforts of the R&D department in a formalized and quantifiable manner, and aid searching for market opportunities, or identifying complementary technology in the context of patent portfolio management.

3.1 Gathering Properties

Currently several modules of a test platform have been implemented, some of which have been graphically depicted in Figure 2.

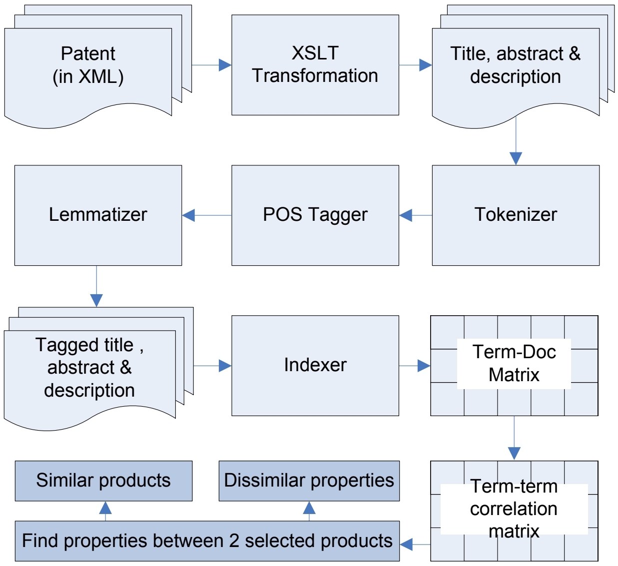


Figure 2: Modules of the platform

Patents written in English are converted into structured XML files, which are fed into a XSLT transformation module retaining only certain patent sections for further processing. Some patent sections contain specific numerical or textual information, such as patent number, date of application and authors. Other, more narrative, patent sections are the title, the abstract, the claims, the background, the summary and the description.

[15] indicates the importance of including the titles and abstracts in the automatic classification of patents, while the summary section gives only marginal improvements. Other research shows that the inclusion of a certain number of words or lines of the description, applications and/or claims can be beneficial to patent classification [20][21]. In the proposed approach, only the title, the abstract and the description sections are retained, although the additional benefit of processing the claims section too will be analyzed at a later stage. For most patents, the title and the abstract are available in English, which is not always the case for the other patent sections, such as the description section.

The XSLT transformation concatenates the text contained in the title, abstract and description fields and pipes this text on a per patent basis to the tokenizer module, which splits the text into a set of tokens to be interpreted by a Part-Of-Speech (POS) tagger. The tokenizer recognizes a manually assembled list of multi-words, e.g. 'de facto', which are then regarded by all subsequent step as being one word.

A TnT Tagger [22] is used to POS tag the text to the CLAWS5 tag set. This tagger is trained on a different set of patents in order to adapt the configuration files to the specific language used in patents. The trained tagger proves to correctly tag a word in more than 95 % of the cases. This 5 % error includes a number of words incorrectly tagged as adjectives which should have been identified as nouns that modify other nouns, or attributive nouns or noun adjuncts [23]. This misclassification occurs when the tagger encounters constructions such as 'loudspeaker system', 'textile cover', 'volume control', or 'earphone jack'.

It should be noted that [7] describes a method 'Keyword and phrase extracting' which allows for the identification of multiword phrases, based on the assumption that these multi-words would occur several times in the document. However, currently such a functionality is not implemented and further research will evaluate the usefulness of further decreasing the number of errors due to such misclassification.

The stream of tokens is then run through a rule based lemmatizer described in [24], which allows to normalize these words based on the given POS tag to the form used as the headword in a dictionary, e.g. 'cooled' and 'cooling' both map to 'cooled'. This step maps some misspelled word suffixes to a common lemma, but the main advantage of this strategy over the use of a Porter stemmer [25], which removes the word's suffixes, is that the resulting terms and further analyses are easier to interpret by humans.

3.2 Property Selection

Currently, only nouns and adjectives are withheld for further processing. However, no filtering is done to extract only relevant adjectives or nouns. In a later stage of this research only selected adjectives will be processed through a property selection phase explained below. The result of this step is a list of adjectives and nouns as input for the indexer.

[19] defines a property as 'what a product is or has', its attributes. This is mainly expressed in adjectives and is related to physical parameters. Examples of properties are hollow, smooth, transparent, strong, and flexible. These are all generic, in contrast to product specific attributes, for example light weight or inspectable. These product specific attributes are related to functional requirements. A generic property such as hollow can lead to a product specific property as light weight, just as transparent can lead to inspectable. The link between adjectives and properties was further examined by the authors in [26].

Currently, only adjectives are processed in the property selection phase as it is assumed that adjectives can express system properties [19] and that adjectives are less domain specific than nouns. Further research will investigate the effects of including other word categories, such as verbs.

As a prerequisite for this research, the authors validated the possibility to identify clusters of adjectives which relate to the same generic product property. From a sample of 22684 non-chemical patents, randomly selected from the entire USPTO utility patent database using a random number generator, the process described in previous section produces a list of 81750 adjectives, of which 69260 only occurred in a single patent, and are discarded for further processing. The remaining 12490 adjectives are run though a Porter stemmer [25] resulting in 10361 different stems. A Porter stemmer was preferred over a lemmatizer because this analysis is only performed once by TRIZ experts, and the results are never interpreted by the users of the system.

A 10361 by 22684 term document matrix is constructed, weighted with a Term Frequency Inverse Document Frequency (tf-idf) scheme [27], and normalized to account for different patent text lengths. A singular value decomposition (svd) step [28] is performed to reduce the number of dimensions before clustering. Most related research uses a value around 300 as a rule of thumb for the number of reduced dimensions for a similar sized collection [29]. Through experimentation, this value was set to 1000 to ensure enough discriminatory power through the explained variance, possibly leading to over fitting the model, which is less an issue as the results are manually analyzed by TRIZ experts as explained below. The terms are then grouped by clustering to 700 clusters, a value experimentally determined through sweeping this variable.

Table 1 shows the first 5 clusters with the contained adjectives. These results can be used as an aid to manually identify adjectives that describe system properties. This manual step, currently being performed by TRIZ experts, is still needed because the results are too noisy for full automatic extraction.

Cluster Number	**Clustered adjectives (or noun adjuncts).** Related terms are in *Italic*	**Relationship**
1	Teletypewrite, *prefinished*, *preparatory*, *preassembled*	Preliminary action
2	Degaussed, *activated*, *deactivated*, *deactived*	Activation, time segmentation
3	Boss, *multilayered*, *layered*	Layered
4	Dislodged, bumper, cental[1], radiated	(Cars)
5	*Seam*, *ring*, *weak*	Segmenting, or attaching

Table 1: Examples of adjective clusters, manual identification of related adjectives and description of the relationship

It can be seen that cluster 4 relates to certain car parts, and not to a generic property, which can be detected in the manual step. The adjectives or noun adjuncts from this cluster should therefore not be withheld for further processing.

As stated in the first paragraph of this section, the research on this adjective or property filtering is not yet concluded. Therefore, no filter is currently applied and all adjectives are input to the processing in further steps. In a later stage the results from the clustering and manual verification will be used to identify the adjectives relevant for further processing.

Besides adjectives, and to allow product or technology identification, mostly expressed by nouns, this word category is also processed in further steps. Further research will examine the possibility to only retain nouns occurring in the headings of the IPC class hierarchy, such that nouns directly indicate a product, or technology.

3.3 Term-term correlation matrix analysis

A slightly modified open source program Lucene [30], that only indexes a given list of adjectives and nouns and outputs results in human readable format, implements the indexer module of the test platform. These data are then read into a term document matrix A [27], in which each element A_{ij} represent the number of times term i occurs in patent j. From this, the term-term correlation matrix C is calculated as AA^T, in which C_{ij} is the sum, over all patents, of the product of the number of times a term i and the number of times a term j occurs in a patent.

Given two nouns that characterize two different products or product families, the term-term correlation matrix allows looking up adjectives which co-occur with these two nouns. These adjectives directly interrelate these two products, or product families. This methodology is illustrated by the term-term correlation matrix in Figure 3. The matrix elements ‘X’ indicate that the adjective co-occurs with Noun 1 and Noun 2, linking the Product 1 with Product 2 through this shared adjective.

It is at least equally important to find the property dimensions differentiating the two products. By looking at the differences in term-term correlations of an adjective with the product nouns, this methodology can be used to highlight the differences between the two products. This information can be used to transfer knowledge from one product to the other.

Given the assumption that adjectives relate to generic product properties, this technique allows to automatically calculate the degree of closeness of two products along these property dimensions. As rough indication the sum of the term-term correlations of all adjectives with the two nouns or products can be calculated.

As can be seen from the case study in the next section, some identified adjectives, or noun adjuncts, do not relate to generic product properties and should not be included in the analysis. This adjective filter, or property selection, explained in Section 3.2, should allow filtering the adjectives based on relevance to generic product properties.

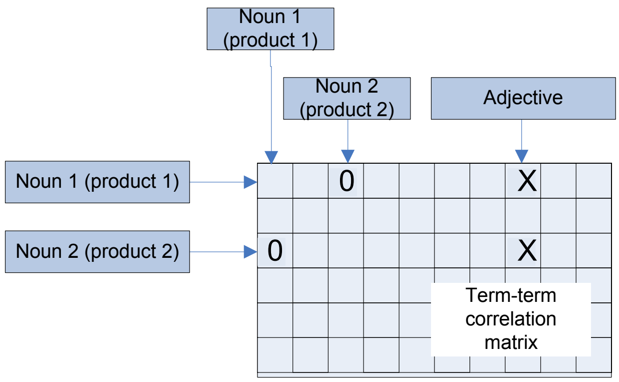


Figure 3: Term-term correlation matrix used to calculate the similarity between products

This methodology can also be used to find products related to Noun 1 or Product 1. Looping over all different nouns, or products, permits comparing the closeness figures of different products, and finding related products in large patent databases. Adding the constraint that the two selected nouns may not co-occur in any of the patents, which is illustrated by the ‘0’ elements in the term-term correlation matrix of Figure 3, this allows to find directly unrelated products in different technological areas having similar product properties. Depending on the size of the patent database this constraint can be implemented by a threshold value different of zero.

The methodology infers a link between two not directly related products. Such a higher order co-occurrence can also be found by techniques such as singular value decomposition, but these techniques complicate the interpretation of the property dimensions as these are linear combinations of the adjectives. In this light, Section 3.2 can be seen as a manual step to ease this interpretation.

4 CASE STUDY

To illustrate the proposed methodology a random set of 64529 patents are selected from the USPTO utility patent

[1] Analysis of the patents reveals that «cental» does not refer to the weight unit, but should be interpreted as a misspelled version of the word «central».

database using a random number generator. The title, abstract and description sections are tokenized, lemmatized and POS tagged, and the identified adjectives and nouns, collectively called terms, are stored in an index file associating them with the patents in which they are found. Because the researchers have little background in the chemical domain, terms and patents from this domain are discarded, and not processed. The index file is imported in a term document matrix A, from which the term-term correlation matrix C is calculated.

The product toothbrush is selected for analysis, and based on the term-term correlation data a list of similar products is determined. “Similar” to be loosely interpreted as products with the same properties.

Table 2 shows the results of this analysis. The value in the second column is the sum of the term-term correlations of adjectives in patents in which both products occur.

Product	Sum of adjective correlations	Number of noun-noun co-occurrences in an online database
Bristle	11317	5636
Bag	**9010**	**798**
Brush	8885	10345
Needle	**8604**	**591**
Tissue	8350	2384
Jaw	8167	647
Vessel	8145	829
Ink	**8108**	**375**
Stem	7640	1243
Food	7635	3011
Mold	7584	1427
Shutter	**7480**	**73**
Lid	**7407**	**786**
Mouth	7336	5468
Probe	**7292**	**464**
Neck	7207	2956
Chair	7085	144
Workpiece	**7042**	**120**
Anchor	**7018**	**671**
Brace	7015	142

Table 2: 20 Products most similar to toothbrush

Rows in bold indicate that the product does not co-occur with the word “toothbrush” in any patent from the database applied, e.g. the word “bag” does not co-occur with “toothbrush” in any patent, while the word “bristle” co-occurs at least once in a patent in the database applied. This research assumes that the nouns not co-occurring with the product, toothbrush in this example, represent products from other technological areas, and can therefore generate the most innovative ideas.

As a reference, the third column shows the co-occurrences of the word “toothbrush” with the other products in an online patent database [31]. This indicates that, in general, the bold products identified as most innovative indeed co-occur less with the word “toothbrush” in the online database.

Following this methodology, the shutter product seems most likely to inspire creative ideas, as it does occurs with the same properties, but occur relatively little with the product toothbrush. The Table 3 indicates the adjectives co-occurring with toothbrush and shutter.

Adjectives	Term-term correlations between		Min of co-occurrence s
	toothbrush	shutter	
Pulsating	1216	1269	1216
Oscillating	659	1530	659
Rotative	456	404	404
Protruding	324	2679	324
Displaceable	304	360	304
Retracted	217	3760	217
Foreign	162	232	162
Coiled	184	155	155
Collapsed	140	151	140
Insertable	228	136	136
Detachable	119	498	119
Aesthetic	114	226	114
Replaceable	114	169	114
Reversible	288	112	112
Decorative	114	110	110
Reusable	114	90	90
Thermoplastic	152	89	89
Absorbent	80	120	80
Component	76	208	76
Translucent	76	154	76

Table 3: 20 most co-occurring adjectives

This list of adjectives can be used in support of a directed knowledge transfer between a shutter and a toothbrush, e.g. making the toothbrush pulsating, oscillating or rotating.

It is also possible to search for similar products along a certain property dimensions, a functionality also offered by simple property keyword searching against a patent database. The database applied indicates the products, or technologies, mostly related to the oscillating property are software, flowmeter, shutter, toothbrush, bristle, cleansing, piston, discriminator, diaphragm, metering, flashlight and headbox. These results are consistent with the results of Table 2, and Table 3.

5 FURTHER RESEARCH

The results from the preliminary processing described in Section 3.2, and the results from the analysis in Table 3 indicate that the adjectives do not all relate to properties. The semi-automated step to identifying adjectives describing system properties must be completed, in order to filter adjectives for further processing. This should result in more relevant similarity analysis.

The result from Table 2 also indicate that nouns are not always indicative of products. Further research will examine the possibility to only retain nouns closely related to a technology, a product or a subsystem of a product, e.g. nouns occurring in the headings of the IPC class hierarchy.

6 SUMMARY

By means of a case study comparing the toothbrush product to other product in the database, it was shown that the proposed methodology allows to automatically find products similar to the toothbrush product, and list these in order of relatedness.

It was also shown that further analysis of the term-term correlation data of adjectives and nouns permits finding properties co-occurring with both products, or only one of both, enabling the extraction of properties relating, respectively differentiating the products.

By looping over different extracted nouns, the proposed methodology furthermore allows to automatically search for products related via a specific property. This was demonstrated by the identification of products closely related to the given toothbrush product along the oscillating property dimension.

REFERENCES

[1] United States Patent and Trademark Office, 2008, Patenting by Organizations 2007.

[2] Khomenko, N., Ashtiani, M., 2007, Classical TRIZ and OTSM as a Scientific Theoretical Background for Non-Typical Problem Solving Instruments, Proceedings of the TRIZ-Future Conference, 73-80.

[3] Altschuller, G S., 1984, Creativity as an Exact Science - The Theory of the Solution of Inventive Problems, Gordon and Breach Science Publishers, New York.

[4] Savransky, S. D., 2000, Engineering of Creativity: Introduction to TRIZ Methodology of Inventive Problem Solving, Boca Raton, Florida.

[5] Michel, J., Bettels, B., 2001, Patent citation analysis: A closer look at the basic input data from patent search reports, Scientometrics, 51/1: 185-201.

[6] Karki M.M.S., 1997, Patent Citation Analysis: A Policy Analysis Tool, World Patent Information, 19/4: 269-272.

[7] Tseng, Y.-H., Lin, C.-J., Lin Y.-I., 2007, Text mining techniques for patent analysis, Information Processing and Management: an International Journal, 43/5: 1216-1247.

[8] Yoon, B., Park, Y., 2003, A text-mining based patent network: Analytical tool for high-technology trend, Journal of High Technology Management Research, 15: 37-50.

[9] Wu, M.-C, Lo, Y.-F., Hsu, S.-H., 2006, A case-based reasoning approach to generating new product ideas, The International Journal of Advanced Manufacturing Technology, 30: 166-173.

[10] Yoon, B., Park, Y., 2005, A systematic approach for identifying technology opportunities: Keyword-based morphology analysis, Technological Forecasting & Social Change, 72: 145–160.

[11] Goldfire Innovator, Invention-machine.com. Available from http://www.invention-machine.com

[12] Cascini, G., Russo, D., Zini, M., 2007, Computer-Aided Patent Analysis: Finding Invention Peculiarities, Monterrey Nuevo León, Mexico.

[13] Cascini, G., Russo, D., 2007, Computer-Aided Analysis of Patents and Search for TRIZ Contradictions, International Journal of Product Development, 4/1-2: 52-67.

[14] He, C., Loh H. T., 2008, Grouping of TRIZ Inventive Principles to facilitate automatic patent classification. Expert Systems with Applications, 34/1:788-795.

[15] Loh H. T., He, C., Shen, L., 2006, Automatic classification of patent documents for TRIZ users, World Patent Information, 28/1:6-13.

[16] Cavallucci, D., 2002, Integrating Altshuller's Development Laws for Technical Systems into the Design Process, Annals of the CIRP, 50/1:115-120.

[17] Mann, D., 2002, Better Technology Forecasting using Systematic Innovation Methods, Technological Forecasting and Social Change, 70/8:779-95.

[18] Mann, D., Dewulf, S., 2002, Evolutionary-Potential in Technical and Business Systems, The TRIZ Journal.

[19] Dewulf, S., 2006, Directed Variation: Variation of Properties for New or Improved Function Product DNA, a Base for 'Connect and Develop', Proceedings of the ETRIA TRIZ Future Conference, Kortrijk, Belgium.

[20] Larkey L.S., 1999, A patent search and classification system, Proceedings of the fourth ACM conference on Digital libraries, ACM Press, New York, US., 179-187.

[21] Fall, C J, et al., 2003, Automated Categorization in the International Patent Classification, SIGIR Forum, ACM Press, 37/1:10-25.

[22] Brants, T., 2000, TnT - A Statistical Part-Of-Speech Tagger, Proceedings of the Sixth Applied Natural Language Processing Conference ANLP-2000, Seattle.

[23] Noun Adjunct., Wikipedia, available from http://en.wikipedia.org/wiki/Noun_adjunct.

[24] Carl, M., Schmidt, P., and Schütz, J., 2005, Reversible Template-based Shake & Bake Generation, Proceedings of Workshop Example-Based Machine Translation, MT Summit X, Phuket, Thailand.

[25] van Rijsbergen, C. J., Robertson, S.E., Porter, M.F., 1980, New models in probabilistic information retrieval, British Library Research and Development Report, 5587.

[26] Verhaegen, P.-A., Vertommen, J., D'hondt, J., Dewulf S., Duflou, J., 2008, Relating Properties and Functions from Patents to TRIZ trends, CIRP Design Conference 2008: Design Synthesis, Twente.

[27] Baeza-Yates, R. A., Ribeiro-Neto, B., 1999, Modern Information Retrieval, Addison-Wesley Longman Publishing Co., Inc., Boston, MA.

[28] Berry, M. W., Dumais, S. T., O'Brien, G. W., 1995, Using Linear Algebra for Intelligent Information Retrieval, SIAM Review, 37/4: 573-595.3

[29] Berry, M. W., Dumais, S. T., Shippy, A.T., 1995, A Case Study of Latent Semantic Indexing, Technical report, UT-CS-95-271, Knoxville, TN, USA.

[30] Apache Lucene, available from http://lucene.apache.org.

[31] Micropatent, Thomson Reuters, available from http://www.micropatent.com.

CONTACT

Paul-Armand Verhaegen

Katholieke Universiteit Leuven, Centre for Industrial Management

E-mail: paularmand.verhaegen@cib.kuleuven.be

Phone: +32 (16) 322567

Industrial & Practitioner Papers

Teaching TRIZ within Siemens

Dr.-Ing. Robert Adunka,
Siemens AG, Industry Sector, Industry Automation Division, Strategic Tasks 2 / Technology, Germany

Abstract

Within Siemens 163 people had an introduction to TRIZ with at least a half-day seminar. There are 41 people that had a Basic training for five days. The Basic Training is the equivalent to the MATRIZ Level 1 Certificate. Just eight people have taken the Advanced Course (equals MATRIZ Lv 2) up until now.

All those participants gave a feedback on the TRIZ tools they learned about on the course in a very comprehensive survey. They also judged the examples that were used within the course to illustrate the different teaching topics.

This paper shows the outcome of feedback given by 191 engineers on different TRIZ tools. It will elaborate on the examples used and how the understanding of the examples could be linked to the topics taught. It will also show how the tools build upon each other and how many days were spent teaching these topics. Therefore this paper will give TRIZ-teachers hints, on how to build up their lectures and which topics they should teach first.

Keywords

Siemens, Innovation Tool Academy, Teaching TRIZ

INTRODUCTION

In the TrizFuture conference in 2007 I elaborated on the 'Invention on Demand' workshops and how they lead up to the foundation of the Innovation Tool Academy [1].

This paper builds upon facts that were described in detail then [1]. It shows how the Innovation Tool Academy evolved from the foundation and what restructuring it went through based upon feedback from the participants of the courses.

For those not familiar with the facts presented then [1] a short summary of the 'Invention on Demand' workshops and the first layout of the Innovation Tool Academy will be described in the first two paragraphs of this paper.

INVENTION ON DEMAND

To prove that methods for the conceptual design of products could be used with the product range of Siemens Industry Automation and Drives Technology Divisions a workshop concept was launched consisting of three types of workshops. These workshops were customized to the expected needs of the divisions. The 'Invention on Demand' workshops could be subdivided into Solutions on Demand, Innovation on Demand and Patents on Demand workshops. Each of those workshops had a different set of methods recommended for this kind of workshop and a different goal attached to it.

After one year of Invention on Demand workshops, it was proven, that the proposed methods worked and that the employees of Siemens attach importance to the methods. To further bring methodical product development into the area of conceptual design, one step forward within the company, it was proposed to teach more people the methods which were used in the workshops.

Therefore the methods and their usage was investigated and it was found, that many methods are out of the TRIZ toolbox or were based on TRIZ. It was recommended to try to teach the employees of Siemens a modern TRIZ toolbox. Based on this decision, the Innovation Tool Academy was founded.

INNOVATION TOOL ACADEMY

The Innovation Tool Academy should teach the employees all the necessary tools to help them to work on innovative tasks better. It should help the participants to facilitate Invention on Demand workshops by themselves.

To do all that, the basic structure of the Innovation Tool Academy was developed. The foundation of the Innovation Tool Academy should be the comprehensive TRIZ toolbox. Based on these methods, other methods should follow one by one to fill in the knowledge gaps. Orientation for the selection of the methods for the completion of the Innovation Tool Academy could be found in the three types of Invention on Demand workshops and the experience from those workshops.

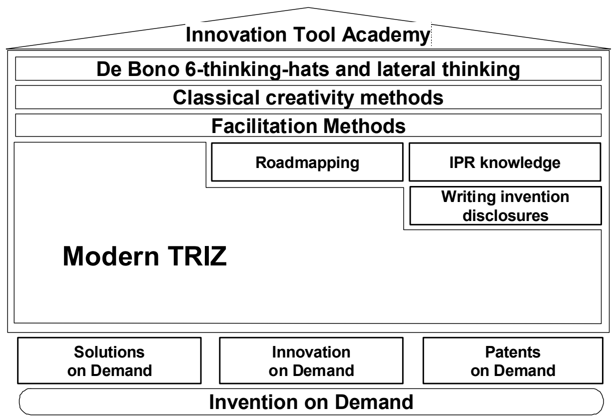


Figure 1: Basic Structure of the Innovation Tool Academy

For the modern TRIZ-lectures we choose a four course layout: one introduction course running for half a day, a basic and advanced course running for five days each and a professional course, that should run three times for five days. After each of the courses starting from the basic course, a test should prove that the knowledge is absorbed well.

Up till now, 163 people passed through the introduction course, 41 went on through basic and from those 8 passed through the advanced course. The feedback that was collected from those participants of the courses made it necessary to restructure the initial layout of the Innovation Tool Academy.

In the next section of the paper, the feedback and conclusions will be explained in more detail.

FEEDBACK AND LESSONS LEARNED

There were two introductory courses initially. One ran for half a day and was meant for managers and another one ran for one and a half days and was meant for engineers. After the initial round of introduction and basic courses it became clear, that the one and a half day format was not needed. This format just explained the function analysis and the inventive principles in a little more detail and showed a few more tools. It was too little to really teach the topic and it was too much time for just information on the topics. Therefore the decision was made to use the introductory course as a purely informational course that should give the participants an overview of the methods so that they can then decide for themselves, if they want to attend the basic course or send their engineers to attend the basic course (in the case of the managers).

From all of these introductory courses 144 feedbacks were received. These feedbacks came from 163 participants of the workshops. Methods that were only shown in the introductory course for engineers are not considered in the feedback.

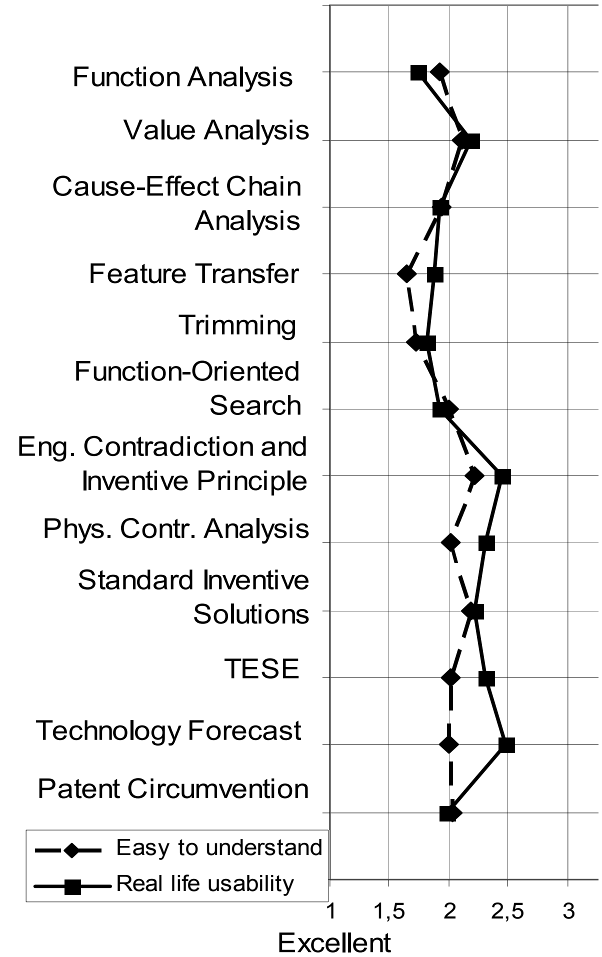


Figure 2: Feedback of the introduction courses

Within the feedback questionnaire two questions were always asked for each method. The first question was “How easy were the tools to understand?” and the second question was “Do you think the tools could be used in real life problems?”. The participants were asked to grade the answers with a “1” as the best mark and “6” as the worst mark. This range was chosen because it is a well known ranking system used in German schools.

As it can be seen from figure 2 the average mark given by the participants lays around “2”. Function Analysis, Trimming, Cause-Effect Chain Analysis and Feature Transfer were getting pretty good marks. What came as a surprise is that the engineering contradiction as well as the physical contradiction with their resolution in the 40 inventive principles and the separation principles didn’t get the best marks and didn’t stir up the enthusiasm of the participants as it could be expected from previous literature [2].

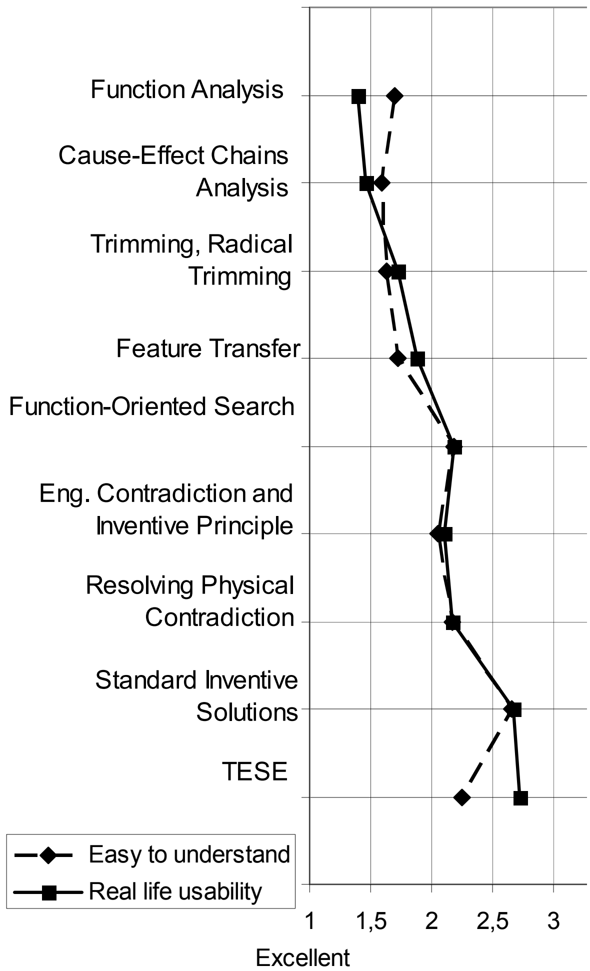


Figure 3: Feedback of the basic courses

From the basic course were received 39 feedbacks out of 41 participants (see figure 3). As in the introductory course, the Function Analysis also got good marks. This method was seen as a basis for other methods to build upon. The introductory topics in the basic course were the Standard Inventive Solutions and the Trend of Engineering System Evolution. Those topics were only introduced to the participants with some examples. They are main topics in the advanced course. They were rated even worse than in the introductory course. Also they were rated not as well as in the advanced course.

Up to this survey, only one advanced course had taken place with 8 participants from which 8 feedbacks were gathered. Within the advanced course the participants expected more sophisticated methods than in the basic course. The Pragmatic S-Curve Analysis and the ITA Benchmarking didn’t fit into this picture. The introduction to ARIZ was also too short for the participants.

In figure 4 the average marks for the different methods taught in the advanced course can be seen. The only really good marks were given for the Standard Inventive Solutions part of the course.

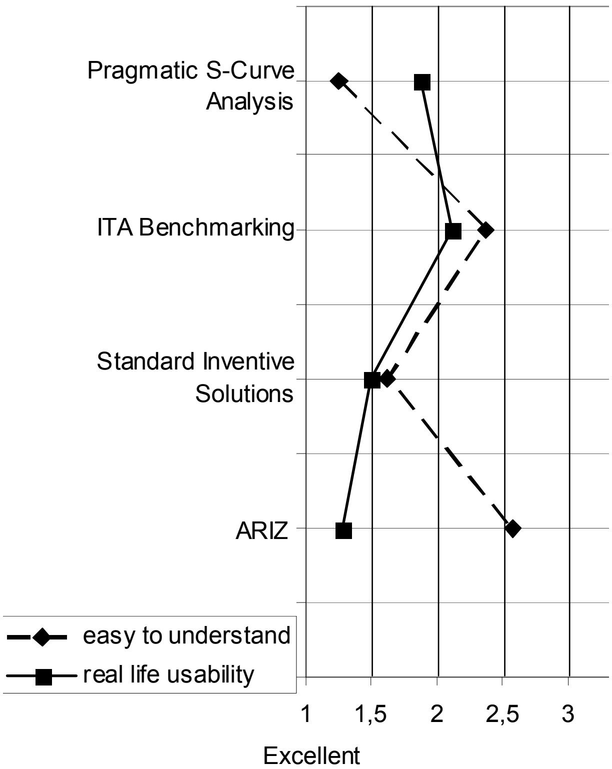


Figure 4: Feedback of the advanced course

Within the feedback questionnaire a mark was given for every example we used in the lecture. There were always at least two examples for every TRIZ tool within the course. One example was a generic example and one example was a Siemens-relevant example. The examples were a mix from simple and complex examples out of the field of mechanics, electronics and electro-mechanics. The question "Were the examples understandable?" was asked.

From this question and the feedback we got from it, it couldn't be determined if simple or complex examples are better. There was also no relevance detectable according to the field those examples came from. Mechanic, electronic or electro-mechanic examples were rated equally.

What gave more hints to the use of examples was the free form comment field. People mentioned that they wanted to see more examples from the software development field and from Siemens-internal workshops.

Generally speaking it can also be said, that good examples are more important in the introductory and basic courses. The more advanced the participants are, the less important are the examples.

After the advanced course, it was clear, that this course had to be restructured. The professional course also wasn't accepted in its initial layout. Therefore those two courses were reconsidered and a new layout for the courses was developed.

To do this, we first looked through the different topics and determined which topic contains a knowledge that is a prerequisite for another topic. If the participants don't get this knowledge first, then the following topic wouldn't make sense to them. Then we had to consider all the topics for the different MATRIZ-Levels. As the Innovation Tool Academy attached their certificates to the MATRIZ-certificates we didn't want to loose that. This also led to the requirements for the accreditation of a MATRIZ-Certificate, which is in the case of the level 3 certificate not only based on the topics taught. At last we looked to the needed time to teach the different topics.

Out of those influencing factors, a new layout and structure of the Innovation Tool Academy was constructed. The current curriculum of the academy has the old basic course, a reworked advanced course and several smaller advanced and expert topics instead of one big block of a professional course.

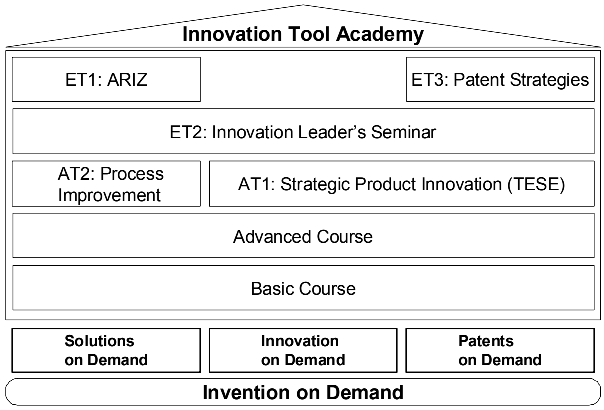


Figure 5: Current curriculum of the Innovation Tool Academy

This means that for the achievement of the "expert creative analyst" certificate, the participant has to take part in five days worth of advanced and expert topics. For the internal certificate it was the best solution and consistent with the other two levels. For the MATRIZ Level 3 certification, it was not sufficient. For this certification, the participant has to go through a certification process, in which he passes the basic and advanced courses as well as the advanced topic 1, expert topic 1 and expert topic 2. On top of that, he also has to document and present a TRIZ-Project, do a presentation on the methods itself and do some small further development on the methods.

The new layout of the Innovation Tool Academy now also gave us the possibility to customize the taught topics for different roles within our company. We can now recommend for a product engineer to go through the basic, the advanced and then take the ARIZ-course on top of that. For an innovation manager it even makes sense to deal first with the course on "Strategic Product Innovation" before he moves on to the advanced course (figure 6).

CONCLUSION

The participants of the courses evaluated the methods within the TRIZ toolbox as good to excellent applicable to their daily work. This was clearly shown by the feedback we received from the people who participated in the courses.

We also saw that management attention is good but not sufficient. We have to find ways to make them want the methods within their group.

The MATRIZ certificate was a very good thing within Siemens as it is an internationally recognized certificate that helps us to judge the TRIZ knowledge of employees.

The layout of the courses has to follow the culture of the company. If culture and courses do not fit, less people will attend the courses.

Our goal is to get the right ideas in less time. With a good TRIZ-knowledge this goal is reachable.

REFERENCES

[1] Adunka R., "Lessons Learned in the Introduction of TRIZ at Siemens A&D", Proceedings of the TrizFuture conference 2007, Frankfurt, 6-8 November 2007, published by kassel university press GmbH, Kassel, ISBN 978-3-89958-340-3.

[2] Shub L., "Rote Karte für die Matrix", QZ Jahrgang 52 (2007), Carl Hanser Verlag, München, 2007.

CONTACT

Dr.-Ing. Robert Adunka
Siemens AG
Industry Sector
Industry Automation Division
Strategic Tasks 2 / Technology
Gleiwitzer Str. 555
90475 Nürnberg
E-Mail: robert.adunka@siemens.com
Phone: +49 (911) 895-2824
FAX: +49 (911) 895-4554

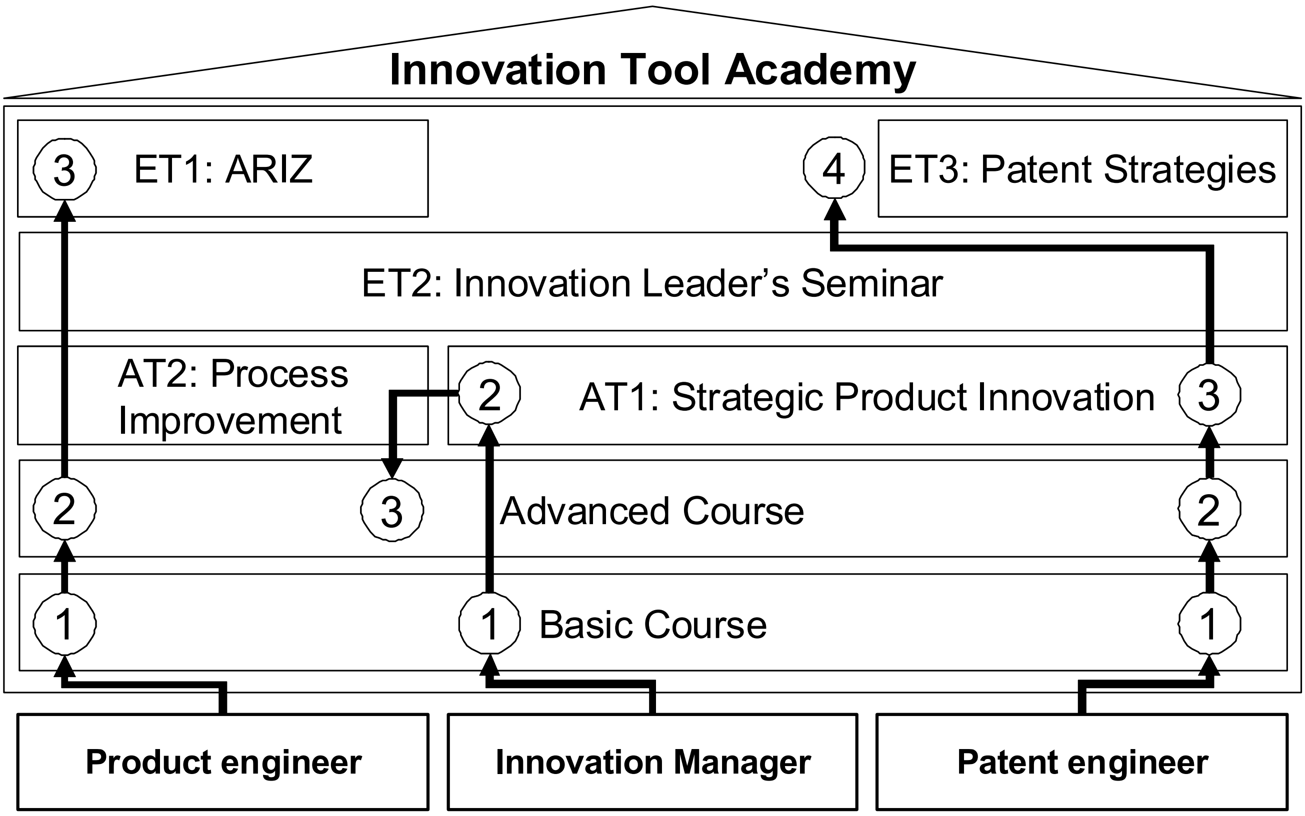


Figure 6: Different paths for different roles

Cognitive Foundations of TRIZ Problem-Solving Tools

Iouri Belski[1], Ianina Belski[2]
[1]Royal Melbourne Institute of Technology, Australia
[2]TRIZ4U, Australia

Abstract

This paper considers the cognitive foundations of TRIZ tools. It analyses reasons for the effectiveness of TRIZ tools in directing users to achieve superior solutions. General human inefficiencies in problem solving are considered. Differences in problem solving between discipline experts and novices are discussed. The cognitive bases for application of the systematised Substance-Field analysis, Method of the Ideal Result, Situation Analysis, the 40 Innovative Principles as well as the Contradiction Table are considered. Opinions of both experts and novices on the effectiveness of TRIZ problem solving tools are presented.

Keywords

Cognition, TRIZ, Problem solving, Creativity, Idea Generation

1 INTRODUCTION

Creative problem solving is normally considered to be a mental process which involves generation of new ideas or concepts to resolve existing problems.

Creativity and problem solving has been extensively studied by scientists belonging to various research fields ranging from behavioural and social psychology, to engineering design. Unlike many phenomena in science, creative problem solving does not have an explanation which is accepted by most members of the scientific community. Numerous existing models attribute creativity to various sources, including chance, personality traits, mental illness and even divine intervention. Some of them believe that it is a trait people are born with, and conclude that creativity skills cannot be enhanced by learning a creativity technique [1]. Most researchers, however, believe in purely psychological roots of creative thinking and problem solving and agree that a person can enhance his creative ability by acquiring some suitable methods and techniques. Some of these techniques include Brainstorming, Synectics, the Lateral Thinking techniques of Edward de Bono, and the tools of Theory of Inventive Problem Solving (TRIZ) [2].

The fields of science and engineering heavily depend on the creativity of engineers and scientists. Simonton [3] has shown that some of the major scientific advances of the 20th Century can be attributed to the creativity of individual engineers and scientists. Accordingly, engineering accrediting bodies consider an ability to problem solve as an exceptionally important skill for engineers of the 21st Century [4].

Many leading engineering companies have invested considerably into enhancing the problem solving abilities of their staff and have trained engineers and scientists in numerous creativity tools. Since their discovery by the western world in the early 1990s, TRIZ problem solving tools have gradually started gaining followers among engineers and are considered by more and more corporations as the tools that their engineers must know well [5, 6].

Usually TRIZ experts and TRIZ teachers explain the tools' efficiency in terms of a reduction in the psychological inertia [7] of a user. Although such an explanation may be valid, it neither describes how the tools of TRIZ really reduce psychological inertia, nor does it clarify the significant discrepancy in the perceptions of TRIZ practitioners of the effectiveness of different TRIZ tools in resolving real problems [8].

On these grounds, it is of interest to investigate the reasons behind the effectiveness of various TRIZ tools and to further clarify how these tools really work. In order to be effective, any creativity tool must somehow influence the operation of the human brain at the time of idea generation. Thus, it is necessary to consider models of human memory and specifically focus on the stage of information retrieval. It is the effectiveness of information retrieval which is likely to be affected by the creativity tools and thus may make human idea generation more efficient.

2 PROBLEM SOLVING AND MEMORY

2.1 Models of memory

Memory is normally defined as the human ability to store, retain, and subsequently retrieve information. Numerous models of memory have been presented by researchers. The *multi-store model* proposed in 1968 by Atkinson and Shiffrin [9] is represented in Figure 1.

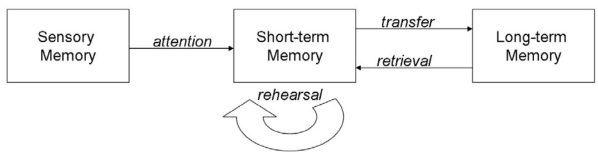


Figure 1: The *multi-store model* of memory.

Although the multi-store model of Atkinson and Shiffrin has been criticised for being too simplistic, it is sufficient to offer some insights into the reasons behind the efficiency of TRIZ tools.

There are several ways to classify memory. From the information processing perspective, science identifies three main stages in the formation and retrieval of memory [10]:

- *Encoding* or *registration*, which includes processing and combining of received information.
- *Storage,* which results in the creation of a permanent record of the information encoded in the previous stage.
- *Retrieval* or *recall*, which is related to retrieving the information stored during the previous stage.

Indeed, all three main stages listed above are of importance in the human ability of creative problem solving. Nevertheless, the stage of retrieval plays the most important role during the application of various creativity tools. A practitioner normally utilises creativity tools to recall some useful information from his or her memory in order to generate suitable ideas to resolve the problem. Inefficient encoding and storage can result in the absence of necessary information in long-term memory.

2.2 Cues and rehearsal in idea generation

Appropriate information is normally retrieved in response to some cue or cues, which a practitioner 'puts' into his short-term memory storage. These cues are basically used to search the long-term memory database for information which is related to the cues. If such information is found, it brings possible analogies to the mind of a practitioner which can result in novel solution ideas. This process of retrieval and idea generation can be expressed by the model depicted in Figure 2 (sensory memory is not relevant for the discussion on retrieval and will not be considered further).

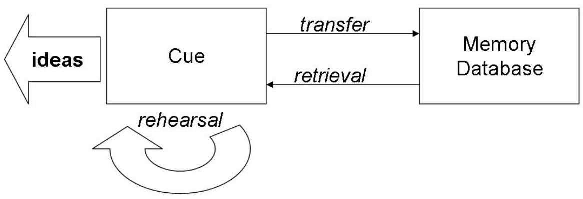


Figure 2: A model of idea generation.

The model in Figure 2 basically suggests that a problem solver tries to search his long-term memory database to find appropriate information which is helpful in resolving the problem. The search is based on cues which a user holds in his short-term memory. These cues are transferred from the short-term memory to the long-term memory to be compared with items in the memory database and to identify useful analogies, which will be retrieved back to the short-term memory as possible solution ideas. This database search is usually not very effective. Therefore, in order to recall more efficiently, a problem solver reminds himself of the cues again and again (rehearses) until some suitable information is found in long-term memory.

This model also identifies two essential ingredients for a practitioner to generate ideas efficiently:

- Firstly, information from which the idea can be drawn must be present in the long-term memory database of a problem solver. If such information is absent it cannot be retrieved, so a solution idea cannot be generated.
- Secondly, the cues used by a practitioner must be effective to ensure not only that appropriate analogies are found in the long-term memory database, but also that these suitable solution ideas are identified within acceptable time.

The cues employed by a problem solver's short-term memory are usually related to both the problem encountered and the creativity technique utilised during the problem solving process. Indeed, efficiency of the cues is affected by the mental and psychological state of the user as well as by his thoughts at the time of problem solving. In order to evaluate whether a creativity technique is efficient, it is necessary to eliminate those human effects. In other words, in order to judge a technique it is necessary to concentrate specifically on two kinds of cues:

- Cues which a user associates directly with the problem itself; and
- Cues which are suggested to him by the creativity technique as additional to the cues directly associated with the problem.

Under this assumption, we can re-draw the model of idea generation presented in Figure 2 to include the relevant cues, as presented in Figure 3.

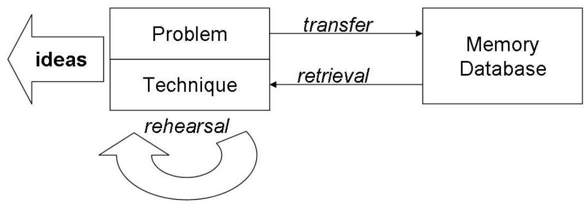


Figure 3: Cues and idea generation.

2.3 Cues and short-term memory overload

The storage capacity of short-term memory is small, so any problem solving methodology must not overload its existing storage limit with cues. In 1956, George Miller evaluated a forward short-term memory span to be equal to the magical number seven (approximately seven items plus or minus two) [11]. More recent research has shown that although Miller's evaluation is reasonably accurate, the number of items held in short-term memory can be significantly influenced by various effects [12].

Some authors have also suggested that new items added to short-term memory can cause decay of old items which are already held in short-term memory [13]. This decay is somewhat similar to interference. When a number of items are held in short-term memory at the same time, they compete with each other for retrieval. Newly added items interfere with the old ones and may even fully force them out of short-term memory storage.

These findings explain the inefficiencies associated with the method of trial and error. Normally, when no creativity tool is in use, such as when a user deploys the trial and error approach, cues stored and handled by short-term memory are likely to be solely related to the problem itself. Information that the user has about the problem is usually pretty general, unstructured and unfocused. Information about the problem can easily contain significantly more data then what the small storage capacity of short-term memory can handle efficiently for retrieval. This can cause short-term memory overload, resulting in a practitioner's loss of focus in trying to resolve too many problems at once.

Also, random thoughts can easily enter short-term memory and interfere with the problem cues. As a result, a problem solver may lose track of the problem and be carried away by new thoughts that are beyond the problem he wishes to resolve.

Based on the existing research into memory storage and recall we can conclude that unclear cues, interference from random thoughts, and excess information about the problem may be considered as the main reasons for why the trial and error method is inefficient.

To be successful in helping a practitioner, methodology intended to foster good creativity needs to overcome these problems. It must provide a practitioner with only several strong cues and at the same time ensure that the short-term memory of a problem solver is never overloaded during the idea generation (retrieval) process.

2.4 Creativity methodology and rehearsal

The low storage capacity of short-term memory is not the only challenge for the problem solving and idea generation process. The information storage time of short-term memory is also short and is unlikely to exceed 10 seconds. Researchers have limited the duration of short-term memory storage to between 2 to 30 seconds [14].

This limits the duration of a single retrieval period to only a few seconds. Such a short time may be insufficient to perform a thorough search of the long-term memory database. As a result, some important information which is stored in long-term memory and that can otherwise help resolve a problem, may be entirely lost. The situation is further complicated by the interference effect. New cues degrade the outcomes of recall of old cues by pushing the latter out of short-term memory. Thus, it is of importance to protect the older cues. This can be achieved by rehearsal or by directing attention to the older cues [13].

An effective problem solving methodology needs to take into account the short duration of a single retrieval interval and somehow make it last longer. This can be achieved by appropriately manipulating the natural process of rehearsal and recall.

The rehearsal process during retrieval, when deployed without a proper problem solving methodology, is unstructured. Usually this makes the duration of one cycle of information retrieval significantly shorter than would be theoretically possible [15]. This can significantly deteriorate the memory database search time. Moreover, a practitioner using trial and error does not normally continue reinforcing idea retrieval by rehearsing the cues again and again. Cues might re-appear in short-term memory at unexpected times for an unplanned search. The latter can be successful and bring superior solution ideas. Nevertheless, the outcome of trial and error idea generation is unpredictable.

Human thoughts are usually unstructured. Although this stochastic tendency can be helpful ‘in jumping outside the box’ on rare occasions, it usually hinders rehearsal. In light of this, it is possible that some creativity techniques may influence the rehearsal process by ensuring that the strong cues stay in short-term memory for as long as required to bring appropriate information out of long-term memory storage. This is likely to impact on the outcomes of the problem solving process and make it more effective in discovering appropriate analogies.

2.5 Experts and short-term memory limitations

The model of retrieval of information from long-term memory storage presented in Figure 3 needs some adjustment to explain the problem solving performance of subject experts. Ericsson and Kintsch [17] suggested that long-term memory can significantly improve the operation of short-term memory and minimise its limitations for experts. In their opinion, the extensive knowledge base of an expert helps in creating long-term memory schemas, which significantly increase the potential of short-term memory. Numerous experimental results support this concept, arguing that an expert effectively utilises his extensive experience, which is stored in his long-term memory, to enhance the operations of his short-term memory [18, 19].

As a result, limitations of the short-term memory of a subject expert can be practically eliminated [20]. This means that a subject expert resolving a problem can assess and search his long-term memory storage very effectively even without a proper problem solving methodology. Although experimental results support this effect, they also warn that short-term memory restrictions disappear only when information directly related to the area of expertise is accessed. In other words, when an expert is faced with a problem which requires knowledge from outside of his area of experience, long-term memory schemas are likely to be absent. Thus, the advantages created by the schemas of his expert knowledge practically disappear.

Every professional is an expert in some areas. Therefore, due to fewer limitations in his short-term memory, he usually achieves significantly better results while solving problems in his own area of expertise. As discussed, when a professional faces a problem from outside his expertise, he is likely to lose the advantages that his knowledge usually provides to short-term memory. Under these circumstances, one would assume that a professional would perform at the same level as a novice, proposing some reasonable solution from outside his area of expertise. This expectation seems theoretically sound, but hardly happens in practice. Usually, experts that must solve problems outside of their expertise perform significantly worse than novices. Instead of considering wide solution options, limited only by their general knowledge, they usually reinforce their own expert experience onto problems from other knowledge areas. This behaviour results in solutions which closely relate to their expertise. Moreover, experts consider their ideas of high quality even when those solution ideas are clearly inefficient and impractical.

2.6 Experts, novices and the human knowledge map

We have just found an explanation for a well known fact. Namely, that mechanical engineers offer mechanical solutions for problems which await electrical answers and vice versa – electrical engineers only think of electrical solutions to every problem they encounter. Experts’ long-term memory schemas force the short-term memory to always operate under the influence of extensive expert knowledge. Thus, short-term memory operates without much limitation, but predominantly searches the database of long-term memory which is occupied by expert knowledge. This situation can be further illustrated with the help of a human knowledge map pictured in Figure 4.

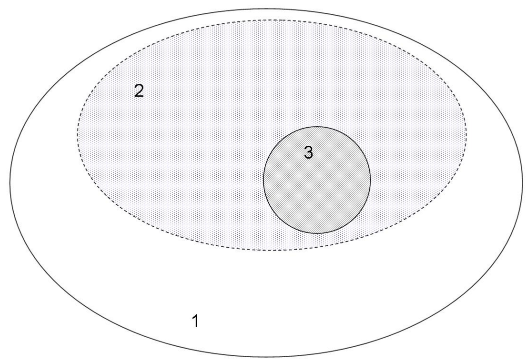


Figure 4: Map of human knowledge: (1 – all human knowledge; 2 – all knowledge acquired by an individual; 3 – expert knowledge possessed by this individual).

The knowledge map in Figure 4 consists of three main areas, which can be viewed as three sets representing different categories of human knowledge. The larger ellipse, identified as set “1”, symbolises all the knowledge produced by humans so far. The smaller ellipse of set “2” depicts the knowledge gained by a professional during his years of study and experience. The circle, assigned as set "3", stands for all the expert knowledge of this particular professional. Under such postulation, all the expert knowledge of the professional (set "3") is a subset of his general knowledge (set "2"), which is, in turn, a subset of all human knowledge (set "1").

A novice who is trying to resolve a problem without any problem solving methodology is likely to propose solution ideas which are based on his general knowledge. If the knowledge areas employed to produce such ideas were identified and mapped graphically using the representation in Figure 4, those knowledge areas would be spread pretty evenly over the smaller ellipse of set "2". Novices are not biased by their knowledge. They are likely to propose solutions using all the knowledge they possess.

Solutions suggested by an expert are usually biased towards his professional field. As we have discussed, expert knowledge can significantly enhance the operation of short-term memory, and so, experts are likely to generate solution ides more efficiently than novices. Those solution ideas, however, tend to occupy the knowledge area inside or in close proximity to the circle-set "3" depicting their expert knowledge. Early career professionals are likely to suggest ideas which are spread further from set "3". Very experienced professionals who have successfully reached the level of experts, on the other hand, are unlikely to propose ideas from outside of the circle-set "3" of their professional knowledge. Such problem solving behaviour can result in the inability of some experts to generate winning ideas beyond their area of expertise. Thus, many experts often apply the same collection of basic solutions to every problem encountered. This is no longer acceptable. More and more engineering solutions today are based on knowledge from more than one area of expertise; more than one discipline. Therefore, it is expected that an expert must be capable of looking beyond his knowledge when solving problems.

3 TRIZ PROBLEM SOLVING TOOLS IN RETRIEVAL

3.1 Effectiveness of problem solving techniques

This brings our discussion back to the need for effective problem solving methodologies. It is of interest to discover how these methodologies can help in searching the database of long-term memory for appropriate information on two levels of expertise: both for a novice and for an expert.

On the novice level of expertise, creative methodologies need to help a user whose retrieval is affected by severe limitations of short-term memory to overcome those limitations. This demand is threefold:

- Firstly, the methodology needs to ensure that the problem is understood very clearly and is represented in short-term memory by only very few simple cues.
- Secondly, the methodology is expected to supply a practitioner with some additional cues which make the long-term memory search extremely efficient.
- Thirdly, it must properly organise rehearsal to ensure that the relevant cues are kept in short-term memory for sufficient time to allow for a thorough search of the long-term memory database.

On the level of an expert, appropriate problem solving methodologies are expected to help an expert to 'lose' some of his expertise and to exploit his knowledge beyond the area of expertise while generating ideas.

Let us consider how the TRIZ tools of Situation Analysis, 40 Innovative Principles and the Contradiction Table, the Method of the Ideal Result as well as systematised Substance-Field Analysis address the above-mentioned concerns.

3.2 Experts and novices: practical evaluation

Once it is recognised that problem solving methodologies need to resolve different issues for experts and for novices, it is necessary to evaluate the usefulness of TRIZ tools by focussing separately on how a methodology influences members of each group, respectively. Experimental evaluation of the influence of any problem solving methodology on a user is not easy to carry out. Measuring changes in the short-term memory limitations of a practitioner while he resolves some real engineering problem is complicated. In this study, we attempted to make judgements about the effectiveness of TRIZ tools based on opinions provided by TRIZ learners. Those opinions have been collected over the past four years through surveying university students, engineers and scientists who were learning the tools.

Undergraduate students, most of whom started university directly after completing high school can be considered as novices. Few of them worked as professionals, and so had not been able to build up a sufficient base of expert knowledge and experience. Practicing engineers and scientists fit well into the definition of experts. It is noteworthy that significant differences in experience did exists between professionals, whose years of employment in industry ranged from 3 to over 15 years. Therefore, the current data, which does not discriminate explicitly between professionals' years of experience, will only identify the tendency. Nevertheless, even with a very broad definition of 'experts', we are likely to be obtain some interesting results.

The experimental data presented below has been derived from the opinions of nearly one hundred university students who took the TRIZ course at RMIT [21], and from the feedback of over three hundred engineers and scientists, who have participated in TRIZ4U training programs [8]. Students were asked to reflect upon the usefulness of every individual tool separately after they had learnt this tool and applied it to some challenging problem. Engineers were requested to identify the tools they found most useful and to explain why the tools they had chosen were useful to them.

3.3 Situation Analysis

Given that short-term memory is susceptible to becoming overloaded, it is important to ensure that the problem is stated clearly and understood. Numerous authors have reported on the importance of a proper understanding of the problem [20, 21]. It has also been found that many TRIZ practitioners see the Situation Analysis (SA) phase as essential [22].

Most TRIZ professionals conduct situation analysis before they start applying a formal problem-solving tool to generate ideas. Usually, the situation analysis procedure requires a user to answer a set of predefined questions. These questions are intended to examine the user's assumptions on the situation under consideration and to help him in identifying the problem(s) which really need resolution. When well conducted, situation analysis clarifies the problem so a practitioner is able to visualise it clearly.

For a novice, this means that the problem is stated concisely and, as a result, it does not occupy all of the available space in his short-term memory. Accordingly, some space in short-term memory is left for other cues, which can be brought in by a problem solving technique.

An expert conducting a situation analysis procedure is typically able to strip off unnecessary details from the problem. This allows an expert to deploy his expert knowledge schemas and to suggest a number of good solution ideas before any problem solving methodology is used. The fact that experts propose solutions when they understand a problem is well know and supported by human wisdom: *understanding the problem helps a user to proceed confidently towards a solution*.

When university students were asked about the usefulness and efficiency of Situation Analysis, over 90 percent of them expressed their positive opinion of the tool. Many students stated that it helped them to clarify the situation and to understand the problem better, and have accepted the tool as given. The following quotation is a good overall representation of their opinion:

> *"Situation Analysis provides a clear picture of the problem that we need to solve".*

As previously stated, most of the students had not been working professionally before they commenced university education. They had not yet solved company problems using accepted rules of the engineering profession. Accordingly, they may have concluded that professionals use this kind of situation analysis, and so, they were willing to use a similar tool.

The opinions of practicing engineers were significantly different to those of the students. Just over two thirds of the experts explicitly identified Situation Analysis as one of the most useful tools. Those who mentioned the tool were in most cases more excited about its impact on their problem solving than were the students. The following are some opinions provided by the experts:

> *"… it makes me realise that my "real" problem might not be the "real" problem. Only after applying SA did we realise what the "real" problem was".*

> *"… normally we never go through situation analysis to better understand the problem. With this tool, however, we more clearly understood the main problem".*

> *"What I found most useful was SA – the tool, which actually stopped me from jumping into problem solving. Instead, I analysed the situation first".*

As expected, the experts were able to generate numerous solution ideas when they conducted the situation analysis procedure. Moreover, those ideas, as a rule, were closely related to their field of expertise. The one-third of engineers who had not chosen SA as a useful tool were somewhat confused when requested to challenge the original problem formulation. They had spent years working in industry and had learnt not to challenge the problem statements provided to them by their managers. Nevertheless, they indicated that the experience of conducting situation analysis had made an impact on them, and they would try the tool again to see whether it would be helpful in future.

Although more university students accepted the situation analysis procedure, they generated significantly fewer ideas to resolve their problems than did the engineers. This fact supports the expected difference in the impact of situation analysis on novices and experts.

Overall, the situation analysis procedure seems to suit both novices and experts. Given that the SA procedure does not require too much time, it is highly recommended for use by both experts and novices.

3.4 40 Innovative Principles and the Contradiction Table

The 40 Innovative Principles [7] present a set of hints which are derived from thousands of successful technical solutions. The Principles offer cues related to the principle's name. Its body helps a practitioner to imagine various ways of utilising the suggested action. This is likely to make the cues stronger. Stronger cues are expected to lead to more solution ideas. Figure 5 depicts the way in which the 40 Principles are used in searching the long-term memory database.

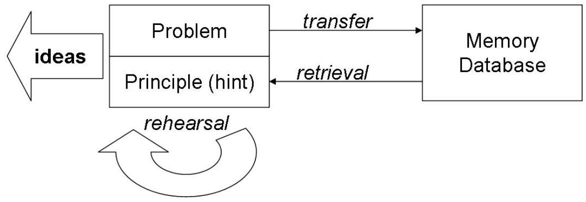


Figure 5: Cues during idea generation with the 40 Principles.

It is important to note that the cues related to the problem which short-term memory keeps during the idea generation with the 40 Principles, are not significantly altered by the methodology. Therefore, these cues can be lengthy and can overload short-term memory, minimising the positive role of the 40 Principles. While deploying the 40 Innovative Principles, a practitioner rehearses the search of the long-term memory database by sequentially concentrating on one principle at a time until all the 40 Principles are considered.

The 40 Principles can be used separately but yield better solutions when used together with the Contradiction Table (CT). The Contradiction Table offers the practitioner an opportunity to model the problem, and in this way identify the principles which have been most successfully used in the past to resolve problems containing the same technical contradiction as the one under consideration.

The short-term memory of a practitioner using the CT with the 40 Principles is likely to be less overloaded than would be the case if the 40 Principles were used alone. The former case requires the user to consider less than 10 principles, not 40, as in the latter case. Consideration of fewer principles reduces the pressure upon short-term memory as well as interference between the principles (cues). This usually results in more efficient ideas being achieved when both the CT and the 40 Principles are used together.

Students evaluated the 40 Principles and the Contradiction Table as the easiest tools to learn. Their opinion of the effectiveness of the tools, however, was not that positive. Only around 20% of students thought that the tools were effective. They found the 40 Principles and the CT to elicit fewer solution ideas, compared to the Method of the Ideal Result and Substance-Field Analysis. The following quote represents the opinion of many students:

> *"…using the CT helps to focus on basic principles, that at first glance do not seem relevant to the system at hand. But careful consideration of what these principles mean helps to come up with creative ideas that I would not have thought of otherwise".*

Engineers reacted more positively towards the tools and were able to generate many more solution ideas when applying them. Just over 50% of them chose the CT and

40 Principles as the most efficient tools. Most of the engineers liked the fast pace with which they were able to generate suitable ideas when applying the CT:

> *"… it applied well in my work and it easily provided solution principles to solve problems".*
>
> *"The Contradiction Table and 40 Principles have been extremely useful as I face many technical problems at work and this tool provided a shortcut solution to the problems".*

Further comments and discussion identified the major obstacle that was faced by practically all the students and numerous engineers while applying the 40 Principles and the Contradiction Table. In their studies, students had not come across enough examples of technical solutions which could illustrate the operation of individual principles. Thus, they did not have enough illustrations of real solutions in their long-term memory database to establish vivid analogies of what the principles were really recommending. Hence, many of the principles appeared to the students as empty suggestions which lacked technical meaning. Engineers with less than three to five years of practical experience reported similar problems, only to a lesser degree. Professionals with experience exceeding 10 years were the only group who reported being comfortable with the tools.

Overall, the 40 Principles and the Contradiction Table have not been evaluated highly by novices. Experts were significantly more positive about using the tools.

3.5 Method of the Ideal Result

Method of the Ideal Result (MIR) has been developed by one of the authors [22]. MIR is based on the TRIZ notion of the Ideal Ultimate Result (IUR).

It has been found that when engineers face problematic situations and need to devise some improvements, two main issues are especially challenging. They are [22, 23, 24]:

- to identify the most problematic issue to focus on during the improvement
- to be able to utilise the resources which are available, almost for free.

The first part of MIR is designed to aid users in pinpointing the very element upon which to focus. The second part of the MIR procedure helps a user to identify the resources available, and consider how these resources may be used in improving the situation.

Overall, MIR helps a user to accomplish the following:

- to identify the direction towards an effective and simple solution and to formulate the Target Task (TT) – the goal, which is as close as possible to the IUR and is achievable
- to separate different areas of improvement, and to identify the elements one must focus upon to deliver the most efficient improvement
- to recognise all the resources at hand
- to sift through all the available resources, with the aim of seeing whether they may help in improvement

The analysis component of the MIR solution process identifies the Target Task, which acts as a cue in short-term memory. Resources play the role of additional cues, which ensure that the database of long-term memory is searched well (see Figure 6).

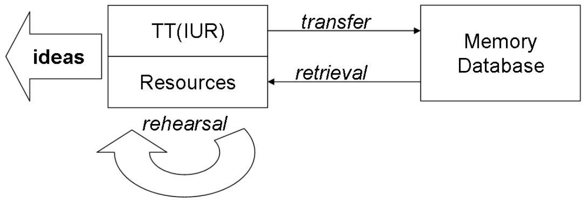


Figure 6: Cues during idea generation with MIR.

As depicted in Figure 6, the Target Task formally replaces the problem cues in short-term memory. This means that when the Target Task is formulated correctly, it is likely to occupy significantly less space in short-term memory than would the unstructured problem cues. Moreover, as the resources are considered in MIR idea generation individually, the short-term memory is never overloaded. This fact, together with the rehearsal based on sequential consideration of the resources, suggests that the MIR procedure is very effective in generating ideas.

The expectation that MIR would be efficient was supported by the opinions of both students and engineers. Both novices and experts had similar responses. Just over half of them identified MIR as an efficient problem solving tool.

The following are some of their opinions:

> *"After conducting the MIR I was able to see the problem clearly and identify several resources that I wouldn't look at before. This has decreased the level of complexity of the problem".* (Student)
>
> *"MIR helps to identify what is ideal and what tasks are essential and help solve problems".*
>
> *"MIR is a bold concept helping participants to make bold ideas to solve the root problems".*
>
> *"Method of Ideal Result - helps to focus thoughts on what the sought-after solution should be".*

Overall, both novices and experts evaluated MIR as an efficient way of solving problems, and they planned to utilise this tool in future.

3.6 Substance-Field Analysis

Substance-Field (Su-Field) Analysis represents any natural and man-made system as a set of interacting elements – a set of *substances* interacting with each other by means of *fields*, which are generated by the substances. Substances and fields in Substance-Field Analysis are not equal in representing systems – substances describe real system elements, and fields show the interactions between these elements. Nevertheless, both substances and fields are represented in a similar manner – by circles. This ensures that vastly different real systems are modelled in a similar way – by means of *circle-substances* and *circle-fields*. Such generalisations enable a practitioner to represent complex systems by simple structures. This allows a user to consider different systems in a uniform way and to apply similar rules to resolve dissimilar problems.

Su-Field Analysis models a system through a set of interconnecting substances and fields. This converts the real task into its Su-Field model and helps to clearly identify the *conflict zones* of the system. These conflict zones are broken down into *conflict triads.* Five model solutions are considered for every conflict triad. The eight fields of MATCEMIB (Mechanical, Acoustic, Thermal, Chemical, Electric, Magnetic, Intermolecular, Biological) are then used to "translate" model solutions into real solutions. [25]. Figure 7 depicts the cues which are used for searching long-term memory in Su-Field.

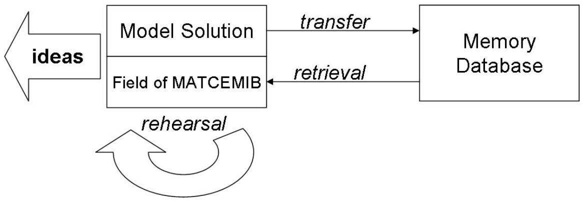


Figure 7: Cues during idea generation with Su-Field.

The problem cues during Su-Field idea generation are represented by five model solutions. They are used one at a time, and so do not occupy much space in short-term memory. Additional cues are represented by the "fields" of MATCEMIB, which are considered one at a time. This ensures that short-term memory is not overloaded and results in a very efficient rehearsal procedure, which is able to thoroughly search the database of long-term memory.

The opinions of both novices and experts on the effectiveness of Su-Field were overwhelmingly positive. More than 70% of students and almost 80% of engineers identified the tool as very effective. As expected, the reasons for its effectiveness were somewhat different.

Some students' opinions are presented below:

> *"After conducting this method of Substance Field Analysis, I now have a wider perspective".*
>
> *"…consider all aspects of the problem, and look at it from the winning side and the losing one".*
>
> *"…actually helped a lot in identifying the more promising solutions".*

Engineers expressed similar opinions. They were also very excited about applying Su-Field in failure analysis and Failure Prevention. The following are some of their judgements:

> *"Su-Field Analysis is a perfect birds-eye view of the situation and helps in spotting the problem".*
>
> *"Su-Field helps me to think and solve problems systematically".*
>
> *"Substance-Field Analysis applies both in solution development and product failure, which surprises me as we always learn to develop the solution rather than the failure".*

The efficiency of Su-Field Analysis was evaluated by both experts and novices as the highest of all the tools considered. Discussions with both groups helped to identify an important difference in its influence on experts and novices. Novices stated that they like the way Su-Field guides them through the eight fields of MATCEMIB and ensures that they do not forget to consider something. Experts, on the other hand, stated that Substance-Field Analysis forced them 'outside the square' of their professional knowledge. Many of them mentioned that this was the very reason that made them unhappy when applying the tool to resolve their first exercise. Nevertheless, once they trialled the tool in solving their work problems, they became very happy with it because of the variety of ideas it helped them to generate.

4 SUMMARY

Human thoughts are usually unstructured. Short-term memory has a low storage capacity and short duration of time for which it stores information. These characteristics significantly complicate the efficient retrieval of information from long-term memory storage during idea generation. When a professional solves a problem within his area of knowledge, the limitations of short-term can be practically eliminated. Although this is helpful when the problem requires a solution within the field of expertise, it often biases an expert who is asked to solve foreign problems, as he suggests solution ideas that are entirely confined to his area of expertise.

An effective problem solving methodology can significantly improve the outcome of idea generation. For the novice, creative methodology can help in retrieval by overcoming the limitations of short-term memory. It can also help an expert to 'lose' some of his expertise and to exploit his knowledge beyond that expertise while generating ideas.

The TRIZ problem solving tools discussed in this paper help a user to overcome these inefficiencies by

- Representing a problem in short-term memory by only very few simple cues.
- Supplying a practitioner with some additional cues which make the long-term memory search extremely efficient.
- Organising rehearsal to ensure that the relevant cues are kept in short-term memory for sufficient time to allow for a thorough search of the long-term memory database.
- Forcing a user to shift his focus from the field of his profession during problem solving.

Different TRIZ tools address the inefficiencies of short-term memory and the expert "biasing" effect differently. Thus, the help these tools offer operates differently on novices and on experts. The current investigation into the cognitive foundations of the TRIZ problem solving tools attempted to comprehend the ways in which different TRIZ tools work in practice. We have identified that the tools of Situation Analysis and Substance-Field Analysis have been rated by both novices and experts as most effective. The Method of the Ideal result has been evaluated by both groups as of medium to high effectiveness in resolving problems. The tools of 40 Principles and the Contradiction Table received a low mark from novices and a medium to high mark from experts. The diversity observed in these evaluations is due to significant differences in the ways that novices and experts solve problems.

REFERENCES

[1] Taylor, C.W. (1988). "Various approaches to and definitions of creativity", in ed. Sternberg, R.J.: *The nature of creativity: Contemporary psychological perspectives*. Cambridge University Press.

[2] Nickerson, R.S. (1999). "Enhancing Creativity", in ed. Sternberg, R.J.: *Handbook of Creativity*. Cambridge University Press.

[3] Simonton, D.K. (1999). *Origins of genius: Darwinian perspectives on creativity*. Oxford University Press.

[4] National Academy of Engineering (2005). *Educating the engineer of 2020: adapting engineering education to the new century*. National Academies Press.

[5] Adunka, R. (2007), Lessons learned in the introduction of TRIZ at Siemens A&D, *Proceedings of the triz-future conference*, Frankfurt, Germany.

[6] Conley, D. W. (2007), Intel Corporation's Expert TRIZ Field Guide, *Proceedings of the triz-future conference*, Frankfurt, Germany.

[7] Altshuller G., "Creativity As An Exact Science", Gordon & Breach Science Publishing House, New York, 1984, ISBN 978-0677212302.

[8] Belski,I.,(2005). The Role Of Practice In Mastering TRIZ, *Proceedings of MATRIZFest*, St. Petersburg, Russia, June.

[9] Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory : A proposed system an dits control processes. In W. K. Spence & J. T. Spence (Eds.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 2, pp. 89-195). New York: Academic Press.

[10] Ashcraft, M. H. (2006). Cognition (4th ed.) New Jersey: Pearson Education.

[11] Miller, G. (1956): "The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information", *Psychological Review*, vol. 63 pp. 81–97

[12] Poirier, M., & Saint-Aubin, J. (1995). Memory for related and unrelated words: Further evidence on the influence of semantic factors in immediate serial recall. *Quarterly Journal of Experimental Psychology*, 48A, pp. 384–404.

[13] Oberauer, K., & Kliegl, R. (2006). A formal model of capacity limits in working memory. *Journal of Memory and Language*, 55, 601-626.

[14] Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences*, 24, pp. 1–185.

[15] Tarnow, Eugen (2005). *The Short Term Memory Structure In State-Of-The Art Recall/Recognition Experiments of Rubin, Hinton and Wentzel*. ([3] (http://cogprints.org/4670/))

[16] Polya G., (1988), *How To Solve It: A New Aspect Of Mathematical Method*, Princeton University press, NJ.

[17] Ericsson, K. A., Kintsch, W. (1995). "Long-term working memory". Psychological Review, 102, 211–245.

[18] Egan, D. E., Schwartz, B. J. (1979). "Chunking in recall of symbolic drawings". Memory and Cognition, 7, 149–158.

[19] Sweller, J., Cooper, G. A. (1985). "The use of worked examples as a substitute for problem solving in learning algebra". Cognition and Instruction, 2, 59–89.

[20] Kirschner, P. A., Sweller, J., & Clark, R. (2006). "Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential and inquiry-based teaching". Educational Psychologist, 41, 75–86.

[21] Belski,I., (2007). TRIZ Course Enhances Thinking and Problem Solving Skills of Engineering Students, *Proceedings of the TRIZ-future conference*, Frankfurt, Germany, 6-8 Nov., pp 9-14.

[22] Belski,I.,(2002). Seven Steps to Systems Thinking, *Proceedings of the 13th Annual Conference and Convention Australian Association of Engineering Educators*, Canberra, Australia, September, pp 33-39.

[23] Belski I., "I Wish The Work To Be Completed By Itself, Without My Involvement: The Method Of The Ideal Result In Engineering Problem Solving", *Proceedings of World of Innovation and Strategy Conference, Sydney*, 1998, pp194-199.

[24] Belski I., *A Course On TRIZ* (Su-Field Analysis, Situation Analysis, Method of the Ideal Result and the Contradiction Table), TRIZ4U, Melbourne, 2000-2005.

[25] Belski I., "Improve Your Thinking: Substance-Field Analysis", TRIZ4U, Melbourne, 2007, ISBN 978-0-9803293-0-8.

The integration of TRIZ and Risk management to increase the ratio of success of innovation Projects

G. Bersano, T. Eltzer, R. Uhl
Active Innovation Management

Abstract.

This paper explores the interaction of project risk management and TRIZ in innovation projects. We started with this paradox: when we generate brand new solutions to existing problems, almost no information is available; however, such information is necessary to evaluate the innovation project success probability. The potential and the cost of a conceptual idea are much more difficult to evaluate than for detailed solutions. This difficulty can let solutions “in a drawer”. In this article we tackle the difficulty to reliably evaluate probability of success of innovation projects, using an adapted risk management strategy.

Keywords:

TRIZ, innovation portfolio management, Relevent™ diagram, risk management.

1. INTRODUCTION

This paper is linked to the paper presented at TRIZ Future Conference 2007 by G. Bersano & V. Bregonzio [1] and consists in a deeper exploration of the interaction of project management key element as the risk management and TRIZ in the development of new products and systems. Normally in companies when brand new solutions are generated to existing problems, few information relating to the innovative solution is available; however, such information is necessary to evaluate the innovation project success probability (in term of feasibility, capacity to solve the problem, risks etc). Furthermore, the potential and the cost of a conceptual idea are much more difficult to evaluate than the ones of more detailed solutions. In this paper we suggest the adoption of an adapted risk management strategy to be integrated from the beginning of an R&D activity.

2. CRITICAL INNOVATION

2.1 Recent surveys on innovation and its goals

Let us first define what innovation is. We adopt the following definition, proposed by the European Commission: “the renewal and enlargement of the range of products and services and the associated markets; the establishment of new methods of production, supply and distribution; the introduction of changes in management, work organization, and the working conditions and skills of the workforce”, [2]. A recent survey in France, done by the French Ministry of Industry and Economy organization (SESSI) has checked on 24000 enterprises the perception of innovation on products, process, organization, etc, [4]. The results show a positive impact for 86% of the companies:

- for 74,4% of the companies, innovating had a positive impact on the products;
- for 50,3% innovating had a positive impact on processes;
- 34,2% of the companies observed other positive impacts.

The same study shows the main reasons that induced companies to launch innovation projects: improve product quality, conquer new markets and widen the product portfolio are the first three reasons. These innovation objectives will later give us the keys to precisely evaluate the success probability of an innovation project. However, although more than 80% of companies acknowledge the positive impact of innovation, the same statistical review shows that companies do not always turn ideas into success: 23,4% of the companies stopped their innovation project (among which 18,7 percent stopped the project during design, and 14% after the project launch) and more than 30% of the companies suffered serious delays in their innovation project. Hence, although innovation is needed to improve product quality, conquer new markets or widen the product portfolio, almost one fourth of the innovation project is simply stopped. What about the other 75% of projects that continued? The research work of Pr. C. M. Christiansen [5] established that no more than 10% of products launched on the market are real successes. What are the reasons why a forth of innovation projects are stopped and only one tenth of the others are really successful?

2.2 Situation analysis

In this paragraph, we present what we will name Innovation Project Failure Source (IPFS): an event (inside or outside the company) that can prevent the innovation project to be successful. An innovation project can be stopped because there are too many potential IPFS (strong competition, limited market share, etc.). We identified IPFS based on a basic literature review. Table 1 summarizes five sources, [6], [7], [8], [9] and [4]. It is very interesting to see that the uncertainty about technology is the less often mentioned issue, this highlights the somehow lack of focus of decision makers about technology and its complexity. Is technology a commodity? According to these responses the answer is generally yes… In order to complement these results, we investigated other information sources. As a summary of Table 1, we propose 6 generic IFPS: **#1 No innovation friendly culture.** It integrates the climate issue (risks are avoided, uncertainty is not tolerated, no openness, rigid domain, conservative industry, difficulty to tolerate mistakes, no creativity opportunity, no possibility to explore uncommon ideas, etc). It also takes into account the capability of the company to introduce the needed change within its own structure and way of working. **#2 Poor management of projects.** This relates to project management techniques first: no clear responsibilities in project team, poor project manager, no fully dedicated project manager, too much loop back in the project. It also takes into account the way each project phase is executed. Absence of team work, which could more efficiently lead to inventive solutions, is part of this IPFS. This IPFS also integrates the fact that the project does not have all the necessary resources (fund, human resources, etc). **#3 Poor competitiveness.** The product is not better than the competition, or it does not have better properties (better functions, cheaper, more reliable, etc.). Or maybe the competition will launch a brand new product. This IPFS also integrates the fact that the market is dominated by very stable and powerful companies. Maybe no customer needs the product we have built. The need does not exist yet (market pull), or cannot be created (technology push). **#4 Low hierarchy commitment.** Stakeholders and management are not enough committed (not involved early, no common understanding). There is no constant interaction with management and stakeholders. **#5 Lack of knowledge about the market & the technology**: very often the company is not capable to perform a proper market analysis and forecasting, therefore hesitates before launching new products; moreover, ideas are often found outside company core competencies or strategy. **#6 Lack of funding and partners:** all activities related to innovation needs resources (both human and financial) and this is often critical for small companies.

In Figure 1, we use the RelEvent diagram of the General Theory of Innovation [6] to show which step of the innovation process can be blocked by the IPFS we identified. This analysis showed us that many uncontrollable events can occur all along the innovation project and prevent it to be completely successful. In the same way we can identify that some characteristics of the company influence greatly the probability of success of an innovation initiative, and these have to be considered more as controllable choices. Such a list can be used as a checklist in order to increase the chance of success: each IPFS if present should be controlled by necessary corrective or preventive actions. This can dramatically increase the innovation project success probability. Starting from this graphical analysis, we can try to block the flow of negative events, introducing these specific counteractions:

- Application of market intelligence;
- Portfolio management;
- Application of state of the art project management;
- Application of innovation management techniques and systematic innovation;
- Partnership and collaborations.

In the following paragraphs, we will focus on portfolio management, and present some considerations and techniques that can be used by a manager to select innovation projects.

3 TECHNIQUES TO MANAGE INNOVATION PORTFOLIO

3.1 Focus on technical aspects using Laws of Technical System Evolution

In TRIZ body of knowledge, the Laws of technical system evolutions are frequently used as a tool to generate ideas [11]. Other authors identified other trends to be added in order to be used to select ideas, see for example the work of Darrell Mann [12]. In fact, TRIZ offers a new point of view to the manager willing to decide whether or not the project should be maintained. TRIZ states that the new product version should only be launched if its modifications from the preceding versions are consistent with the laws of technical system evolution. For example, there is no need to think about transiting to the super system if the system still has poor energy conductivity.

3.2 Focus on market/product strategies according to M. Porter

M. Porter [13], analyzed the possible strategies for a company in a competitive scenario. The three possible alternative strategies are the following: domination (1) by costs (2) by differentiation or (3) by concentration on a limited market segment. According to J.M. Higgins [3] the first two strategies can be deployed by innovation. Figure shows the bi-dimensional result of their analysis for the first of the two strategies. The horizontal axis is the relative cost of the product, compared to the competition, and the vertical axis is the relative differentiation. The author claims that the worst situation is when the relative cost of a product is high and the relative differentiation is low. He also claims that the best situation is when the relative cost is very law and the relative differentiation is high. However, such selection criterion can be pretty difficult to assess in early project phases.

3.3 Focus on Christiansen theory about innovation patterns

A few years ago, Pr. Clayton M. Christiansen from Harvard University, developed a theory of companies evolution and survival based on some innovation pattern. Christiansen links the nature of the innovation project and the company's structure (see Figure 2). According to this diagram, if we are looking for sustaining and standard products, i.e. we are in zone B, functional organization and main commercial structure are adequate; but if we want to provide new products or services that are misaligned with company standard processes and values, then the company organization could be no more adapted and strategies as creation of start-up or dedicated divisions become mandatory in order to succeed.

3.4 Focus on system aspects of the new product using Coefficient of Freedom (GTI)

Greg Yezersky, in his General Theory of Innovation, enhanced the TRIZ Ideality concept and named it Coefficient of Freedom. This coefficient is in the line of the concept of interdependency with the environment, as described by economists J. Pfeffer & G.R. Salancik in the Resource Dependence Theory (RDT), [6]. The Coefficient of Freedom is defined as the ratio between functionalities of the system and system connections with its environment. Yezersky states that technical systems follow the trend of increasing their Coefficient of Freedom. Therefore, this technique can be used to select innovation project: if the Coefficient of Freedom of the new product is not higher than the ones of the preceding version, it is not worth investing time and money in this project. This criterion can also be used to compare company's product with the competition ones. GTI states that the product of higher Coefficient of Freedom will win the highest market share.

3.5 Conclusion

Although we were not trying to present an exhaustive list of portfolio management techniques, it already appears that these techniques focus only on a subset of the identified IFPS. Rather than developing new techniques to assess if the possible IPFS will or won't lead to project failure, we simply introduce in the following paragraph the

Risk Management technique, as proposed by the Project Management Institute (PMI®).

4 ADAPTING RISK MANAGEMENT TECHNIQUE TO ASSESS INNOVATION PROJECT SUCCESS PROBABILITY

4.1 PMI risk management

The Project Management Institute (PMI®) is an international organization of project managers. One of the objectives of this institution is to collect and disseminate knowledge and best practices of project management, [15]. Amongst the nine knowledge areas that constitute the PM body of knowledge, we will focus on project risk management.

The objectives of a risk management technique are (1) to evaluate whether or not the project can reach a scope (time, cost and quality of output) and (2) to plan necessary actions in order to reach the scope. Generally speaking, risk management aims at increasing the probability and impact of positive event and decrease the probability and impact of negative impacts. As proposed by PMI, the risk management has six major steps. **Risk management planning.** Here, the objective is to decide how to approach, plan and execute the risk management activities. The kinds of decision that must be taken at that stage are: who will manage the risks, who are the members of the team, how much time can be dedicated to this, which precision level should be adopted, what risk threshold is the most suitable, etc. **Risk identification.** This activity aims at determining what event might affect the project and documenting their characteristics. The events can be searched in the four following categories: technical (requirements, technology, reliability, etc.); external (subcontractors, regulatory, market, etc.); organizational (project dependencies, resources, funding, etc.) and project management (planning, controlling, etc.). **Qualitative analysis.** This third activity is to prioritize the risks for subsequent further analysis or action by assessing and combining their probability of occurrence and impact on project objectives. The occurrence probability for each event is qualitatively evaluated as well as the impact of the event (for example with a 5 levels scale). The risk can then be estimated by simply multiplying the probability and the impact. If the risk is more than a threshold value, then corrective actions are planned. **Quantitative analysis.** This consists of a numerical analysis of the consequences on overall project objectives of the most critical events identified in the qualitative analysis. One calculates the possible outcomes for the project and their probabilities. For this quantitative analysis, two techniques are classically used: probabilistic (decision) tree and statistic analysis. The second technique enhances the analysis by considering statistical aspects. Rather than assigning a fixed value to the impact, one use continuous distributions curves (Beta distribution, triangular distribution, Gauss law, etc.). This principle is also applied for the occurrence probability. Therefore, the project success distribution is calculated by mathematical operations on impact and probability distribution. **Risk response planning.** This phase of risk management consists of developing options and actions to both enhance opportunities and reduce threats to project objectives. Four strategies deal with the negative events: (1) Avoid. This means to change the project so that the event does not exist anymore; (2) Transfer. Transfer the risk on someone else. Insurances are a typical ways of transferring the risk; (3) Mitigate. Mitigate the probability and/or impact to an acceptable threshold; (4) Accept-it. **Risk monitoring and control.** This final stage is planned to track identified risks, monitor residual risks, identify new risks, execute risk response plans and evaluate their effectiveness throughout the project life cycle.

4.2 Example

We show in Table 2 a typical result of a qualitative risk analysis. The first column of the table lists the name of the IPFS. The second shows the IPFS occurrence probability. This number is 0 if it is very unlikely that the event will happen and 1 if one can be sure that the event will occur. The third column provides a qualitative evaluation of the impact on the project. One put 0 if the event would have no consequence and 1 if it would directly lead the project to complete failure. The fourth column is the risk assessment: the occurrence multiplied by the impact. Therefore, if the risk is 0, the event is not risky and if is 1, it means the event is dramatic. Column 5 shows the risk response planning.

In order to enhance the risk quantification, we assess each criterion with a basic Gauss law, with standard deviations and expected values mentioned in Table 3. A high standard deviation represents a large range of possible values. Mathematical calculations on these four curves allow us the identification of the project success distribution shown Figure 3. The most probable project success is about 0,25. One can also see that the probability the project meets more than 20% of its objective is about 0,75.

4.3 Applying risk management to Innovation Project Evaluation

In the last paragraph, we have presented the Risk Management, as proposed by the Project Management Institute. Let us know investigate how this technique could be used in order to help the manager in deciding whether or not an innovation project should be pursued (what is the most probable result, and the most probable required investment). Based on both the literature review and Risk management technique, we built Table 4 which is a template for qualitative risk management in Innovation project.

Another use of risk management techniques in the scope of innovation project is the application of the decision tree (quantitative analysis of risk techniques). In Figure **4**, we show a possible implementation of the decision tree to innovation projects. Using simple calculation it is possible to give a quick feedback of different scenarios, in order to support company decision makers.

Concerning the use of statistical law for probability and impact in the quantitative phase, we must notice that in any innovation context some risks can be very difficult to assess. Standard deviations for occurrence probability and impact are high; therefore, the project success ranges over a wide windows, which makes the risk management technique completely useless. How can we decide whether or not the project can be successful or not? This is also applicable for evaluating the resources needed for the project: when the standard deviations of influencing events are too high, the evaluation of needed resources is not precise enough. Finally, the key problem of innovation project evaluation is the difficulty to provide a precise yet reliable assessment for events influencing the project (success, needed resources, etc.). In the next paragraph, we apply TRIZ solving tools to imagine new Risk Management techniques, more suitable for innovation projects.

4.4 How to improve the quantitative risk analysis with TRIZ

The aim of Risk Management is to provide an evaluation of a project needed resources and possible outcome, taking into account an extended list of influencing factors (some of them depend on the company itself and some others cannot be controlled). Based on this evaluation, corrective actions can be performed, in order to increase the probable project success ratio (or success probability) or reduce the needed resources. One can say that the risk Management technique should reduce the gap between “assessed project ideality” and “achieved project ideality”. Within a standard design scope, the Risk Management technique proposed by PMI can achieve this function. However, within an innovative scope, this gap cannot really be reduced. Let us try to formulate the contradictions to be solved.

The first contradiction formulation we propose is the following: it is impossible to precisely evaluate an innovation project (as it is impossible to precisely assess impacts and probabilities of each project ideality influencing events) however, evaluating an innovation project is crucial (because decision must be the good one: do not continue with a project dedicated to failure and do not stop a probably very successful other one). We could also propose this other contradiction: if the values of probabilities and impact of influencing events are simply guessed, then the evaluation technique is very simple and rapid, but the evaluation is not enough precise (the gap between what was expected and what really happened can be huge); on the other side if we spend time and money for a precise assessment, then the evaluation might be very close to reality, but such an evaluation can be very complex and time and money consuming. Ideally, we need a technique to evaluate an innovation project which is both reliable (ie: the prior evaluation is close to what will really happen) and use few resources (time, money, complexity, interactions, etc.).

We used TRIZ databases to imagine some solutions to these contradictions. We only provide here the five ideas we think the most interesting:

- **Separation in system level**: install as much routine as possible within the innovation project (for example: predictable cost, unpredictable technical domain). Here are possible implementations: always work with external technical expert for the development phase; rather than performing the innovation project, the company could only be the coordinator of external subcontracting companies
- **Excessive action**: the project can have many possible positive results. For example: everything could be organized so that even if the project is a failure, its by-products will be very useful for the company (knowledge about innovation strategy, technical expertise, knowledge about competitor behavior, maybe the useless machineries can be rented rather than sold, etc.).
- **Before cushioning**: the company should be accustomed to uncertainties about project needed resources and potential result. One could for example imagine computer based simulations tools; another possibility could be to use little yet highly uncertain projects as laboratories to test some uncertainty management techniques or as “pedagogical exercices”. Another interpretation of this inventive principle can be in the form of joint venture with competitors of specific collaboration contracts, etc.
- **Other way around**: rather than evaluating a project proposal, propose project on the basis of target ideality (the target budget is one of the input of project building).
- **Local quality**: rather than to have a precise risk assessment, the company could focus its attention on corrective actions and being extremely reactive to its changing environment.

These proposals should be further defined in term of project procedures, and then tested.

5 CONCLUSIONS

We started this study with the feeling that innovation difficulties have roots far away from technical problems, and this has been confirmed by the analysis reported in section 2. We used TRIZ based problem solving tools to identify that some project management aspects (and more particularly risk management) are still weak in an innovation context. We formulated the contradictions relevant to Risk management and applied TRIZ solving tool (mainly inventive principles) to improve risk management techniques. Only if we will be capable to solve customers’ main problems, that are mainly non technical, we will succeed in improving the general rate of success of innovation projects.

REFERENCES

[1] G. Bersano, V. Bregonzio: “TRIZ as a catalyst for Project Management (PM) excellence (and PM as catalyst for systematic innovation, i.e. the other way around)”, TRIZ Future Conference 2007.

[2] « European Innovation Scoreboard – Comparative analysis of innovation performance », Commission of the European Communities, 2004.

[3] James H. Higgins, Innovate or Evaporate: Test & Improve Your Organization's IQ: Its Innovation Quotient, ed paperback.

[4] SESSI, Service des études et des statistiques industrielles, “L’innovation entre 2002 et 2004”, http://www.industrie.gouv.fr/sessi/enquetes/innov/cis4/cis4.htm.

[5] Clayton M. Christensen, S.D. Anthony, E.A. Roth “Seeing what’s next”, Harvard Business School Press, ISBN 1-59139-185-7.

[6] Thunderbolt Thinking, Inc. http://www.thunderboltthinking.com.

[7] Determinants for Failure and Success of Innovation Projects, Paul A. Kirschner, Bas Cordewener, Fred Paas, Iwan Wopereis, Maaike Hendriks; White paper, Open Universiteit Nederland, Educational Technology Expertise Center.

[8] Cooper, R.G., “The invisible success factors in product innovation,” Journal of Product Innovation Management, 16, 2, April 1999, 115-133.

[9] http://www.rdmag.com.

[10] General Theory of innovation, Greg Yezersky, presented in “An Executive Overview of the General Theory of Innovation (GTI)”, www.ipinetwork.com.

[11] G. S. Altshuller “Creativity as an exact science: The Theory of the Solution of Inventive Problems”, Gordon and Breach, ISBN 0-677-21230-5.

[12] D. Mann: Hands on Systematic Innovation, Ed. Creax.

[13] M. Porter, (1985) Competitive Advantage, Free Press, New York, 1985.

[14] J. Pfeffer, G.R. Salancik, « The External Control of Organizations, a Resource Dependence Perspective », New York, Harper and Row, 1978.

[15] "Project Management Body Of Knowledge", 3rd edition, ISBN 1-930699-45-X, 2004.

CONTACT

G. Bersano, T. Eltzer, R. Uhl

Active Innovation Management,
42, rue des Sources, 92160
ANTONY, France
{first surname letter}.{name}@aim-innovation.com

TABLES AND FIGURES

#	**[6]**	**[7]**	**[8]**	**[9] (top ten, out of 16)**	**[4]**
1	Culture does not embrace innovation and risk taking;	No clearly visible added value	Ignorance about what an innovation project should be	No funding for innovation	Lack of financial resources within the company, the group or the network
2	Innovation is not aligned with company's mission and goals;	The product is not better	Lacks of skills for some key tasks	Staff not enough competent	The innovation is too costly
3	There is no customer for the product;	Weak project management	Wrong use of existing innovation procedures	No collaborative environment	Lack of need
4	No mistake are tolerated in the company	No success celebration and rewarding	Too confident: we already know the answers, so why do all this extra work?	No key individual / leader champion	Lack of qualified human resources
5	No possibility to make exploratory thinking and idea generation.	No management commitment	Lack of discipline and leadership	Infrastructure does not support innovation	Market dominated by stabilised company
6	No teamwork	Project leader not fully dedicated	Big hurry, and no time to do things right	No multidisciplinary approach	Uncertainty about demand
7	No cross-functional collaboration and communication	No ambition	Too many projects and not enough resources	Difficulty to change technological landscape	Preceding innovations
8		No experts in the field		Lack of strategic planning	Lack of financial resources outise the company, the group or the network
9		All stakeholders are not involved		No competitive requirement	Difficulty to find partners
10		Closed minded culture		Industrial sector not innovation friendly	Lack of information about markets
11					Lack of information about technology

Table 1: Summary of IPFS proposed in literature

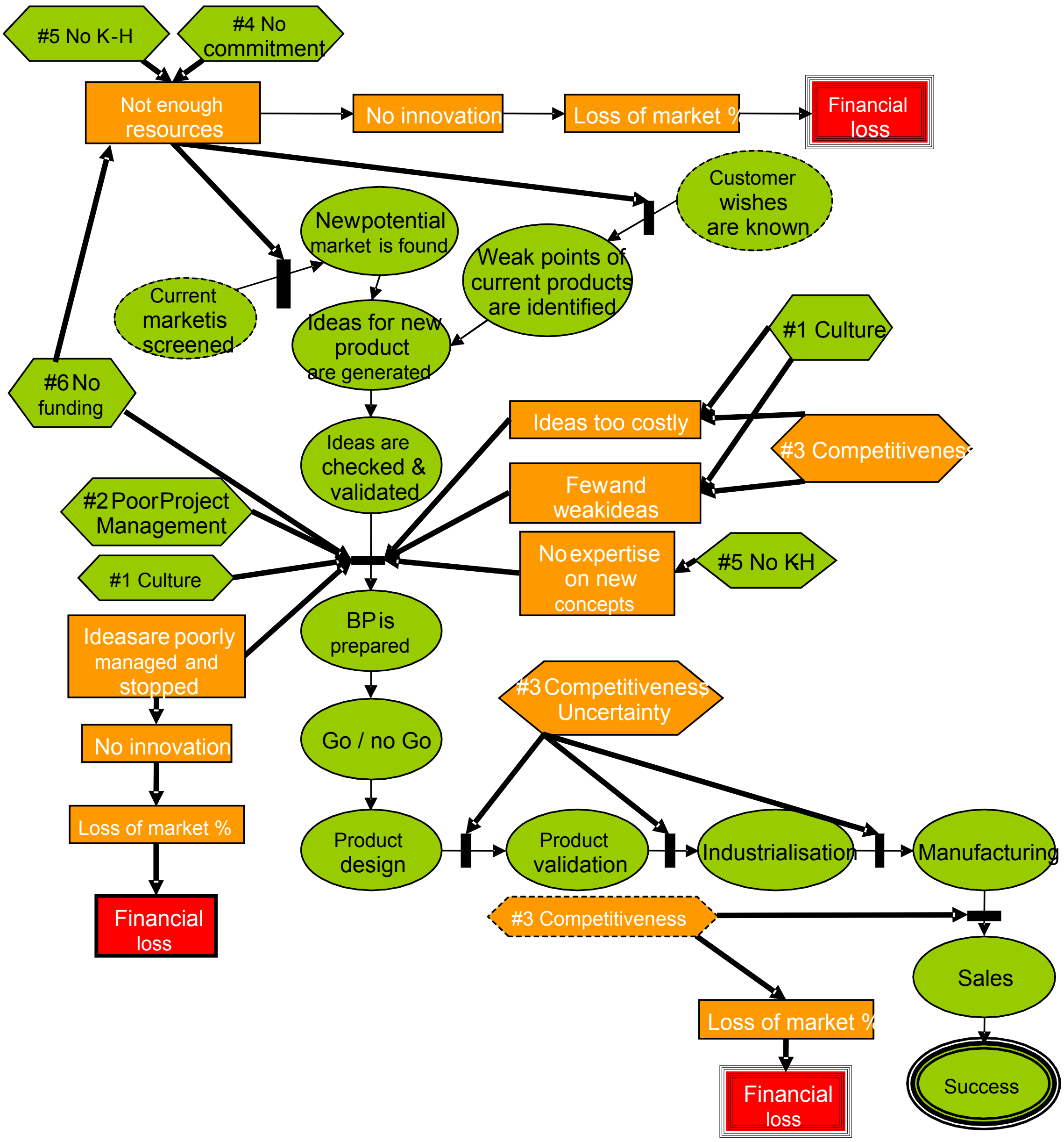


Figure 1: RelEvent diagram for an innovation project

Figure 1 should be read the following way: Dashed lines describe input event; green components are useful event, linked to the function of the system; orange components are negative events. They prevent the system to correctly perform its function; ellipses are intermediate positive events and rectangles are intermediate negative events.

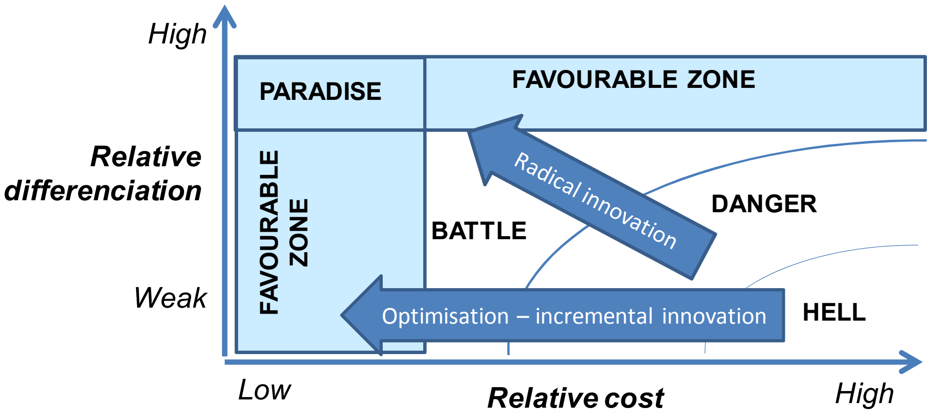


Figure **2:** Two axis for product selection

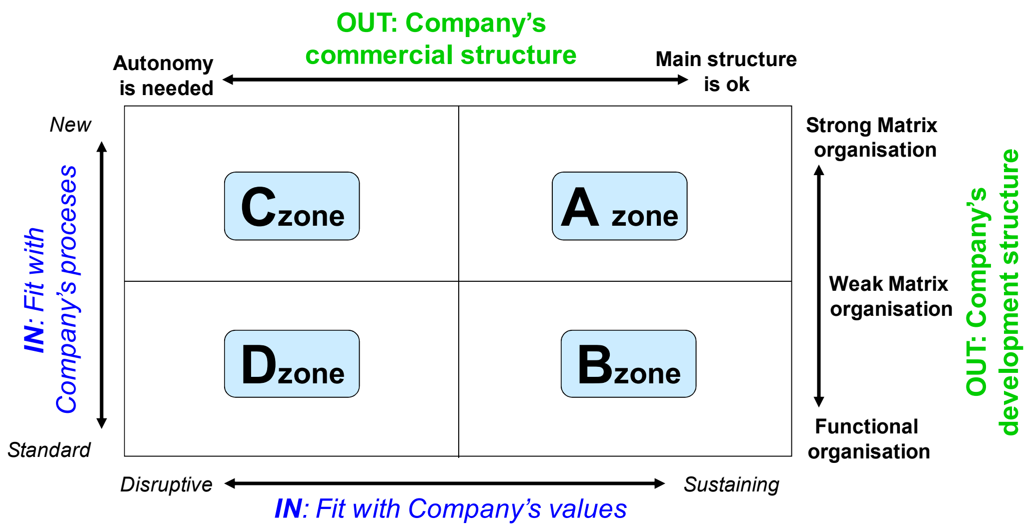


Figure 3: Christiansen company's fit with innovation patterns

Event	**Occurrence probability**	**Impact**	**Risk (Threshold: 0,3)**	**Corrective actions**
Poor competitiveness	0,6	0,6	0,6x0,6 = **0,36**	(1) Market intelligence (2) Joint ventures (3) Intensive marketing and advertising
Lack of K-H	0,8	0,5	0,8x0,5 = **0,4**	(1) Hire expert of the technical field (2) Special training

Table 2: Qualitative analysis of two IPFS

	Lack of know how		**Poor competitiveness**	
	Occurrence probability	**Impact**	**Occurrence probability**	**Impact**
Standard deviation	0,8	0,5	0,6	0,6
Expected value	0,7	1	0,5	1

Table 3: Standard deviation and expected value

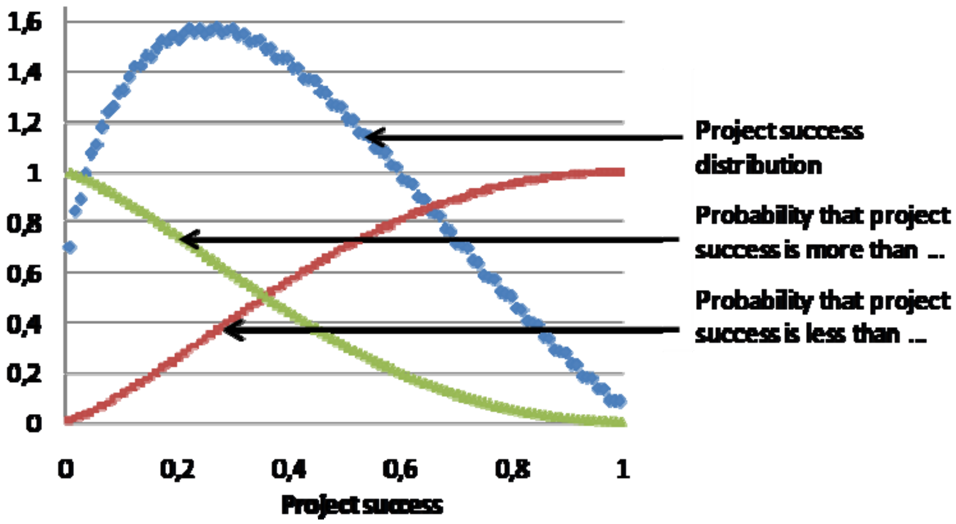


Figure 4: Distribution of project success values

Domain	#	Event Name	Probability	Impact	Risk	Corrective actions
Organization						
	I1	Culture does not embrace innovation				
	I2	No teamwork				
	I3	No commitment from management				
	I4	Not enough funding				
Product	…	…				
	P1	Product function #1				
	P2	Product function #2				
Project						
Design	PJ1	No expert				
	…	…				
Manufacturing	PJ2	No known manufacturing technique				
	PJ3	Unpredicted manufacturing defect				
Sales	PJ4	No clear added value				

Table 4: Generic qualitative IPFS assessment

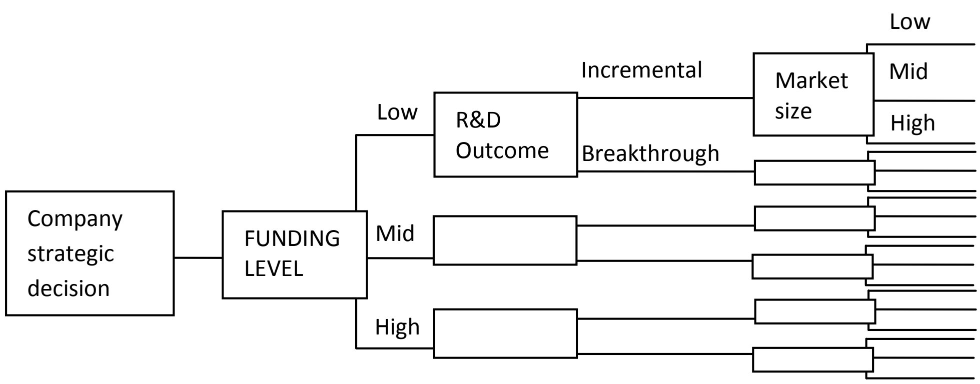


Figure 5: Decision tree for innovation project

Applications of innovative methodologies and IT tool to support European SMEs in Product Innovation Processes

Karsten Böhm[1], Hans-Peter Steinbacher[1] and Paolo Salvatore[2]
[1]University of Applied Sciences KufsteinTirol, Department Business Informatics, Austria
[2]Ciaotech S.r.l. (PNO Group B.V.), Rome, Italy

Abstract

The systematic support of the innovations process in small and medium-sized enterprises (SMEs) is still a challenge because innovation is only done sporadically and often with external consultancy in order to gain sustainable competitive advantages. This paper describes a methodology to cover the conceptual development of new products. This methodology is typically structured into a number of specific steps and introduces an IT-tool that provides the transition from isolated support tools towards an information management along all the phases of the conceptual development in an innovation process. The application of the method in a use case is explained as well.

Keywords

New Product Development, Conceptual Design, Information Management, Innovation Methodology

1 INTRODUCTION

This contribution is presenting work from the collaborative research project KNOW-IT that is addressing one of the main challenges of European SMEs: how to develop a systematic process of product innovation to keep competitiveness in the international market. The primary goal of the project is the support of the conceptual development of the innovation process in companies.

It is widely recognized that one of the key factor for European SMEs to maintain competitiveness in the market is to focus on product and/or process innovation. In spite of this recognised need, SMEs lack a systematic approach that supports them in the overall innovation process. The so called "Innovation Management Techniques" are considered by policy makers (e.g. the European Commission) as an useful driver to improve competitiveness. These techniques (which include knowledge management, market intelligence, creativity development, innovation project management, business creation, etc.) are still underutilized by SMEs. This is especially the case for the Creativity Development Techniques.

The current Innovation Process within SMEs is realised through several steps, each providing one or more challenges that a Systematic Innovation Methodology should be able to solve. These steps are briefly outlined below:

<u>Step 1) Idea Generation</u>: the stimulus to innovate within SMEs come up from a set of possible sources:

- Specific engineering needs (ex: increase reliability within a manufacturing process)
- Specific market needs: a) competitors offering better products; b) customers requests for advanced functionalities; c) the market is mature and the profits are decreasing.
- A "concept idea" born in brainstorming sessions, or through internal discussions among engineers and/or through specific "intuition" of some bright professional in the company

<u>Step 2) Innovation concept definition</u>: depending on where the innovation request has been generated, different needs emerge, that could be faced by the responsible person of production, and/or R&D, and/or of marketing:

- Solving the engineering needs: the engineering problem needs to be defined, then internal sessions are held among engineers to search for a solution. Usually, no knowledge outside of the company is used in such case, and if no solution is found, then somebody takes the responsibility to start searching for solutions using knowledge available outside
- Market needs: the requests coming for the market are very demanding for SMEs. In this case, the marketing responsible of the company is asked to search for "what the customers wants", or for the "hidden needs of customers". The SME market responsible (if any) needs to start searching for customer explicit and hidden needs: a market analysis should be performed, which should bring to a set of functionalities and/or performance that the improved product should deliver. If the analysis delivers a set of functionalities/performance required by customers, technical feasibility of such improved functionalities should be evaluated by engineers, leading to possible Engineering Problem (process and challenges of previous point)
- Technology push: the idea coming from engineers could be the one that brings to face hidden customers' needs (difficult to be identified through market researches). Nevertheless most of the time technology-push innovations are or incremental or fail to result in successful products.

<u>3) Technology Plan</u>: the different concepts should be merged at a certain point to support the SMEs manager in defining the innovation strategy. The innovation strategy will provide the correct elements to make a conscious decision on which technology development the company should focus on.

A comprehensive approach aiming at supporting SMEs in their innovation process, should be able to provide a methodology (guidelines and tools) accompanying the SMEs from the analysis of its internal technology and market need to the definition of its technology plan.

2 THE PROPOSED APPROACH

The presented approach is aiming at facing the evident SMEs need in the overall innovation process. The usage of an IT tool should help to support consultants (or SMEs professionals) in doing their daily business. Gathering the huge amount of data needed and the possibility to store this information along a well structured workflow is the outcome of the developed methodology. It combines the different process steps needed to innovate. These steps are typically divided into requirement analysis, the development of the innovation path, evaluation of the options and finally the conceptual innovation as a result that again will initiate product development.

Therefore the conceptual development of the innovation process in a company starts with the analysis of the current technical system (TS) that is being inspected. This current state of the TS will be projected on the curve of technological trends which then provides a description of the current situation. From there possible developments of the current TS in a possible future TS according to technological trends and market requirement will be derived and the appropriate development process is selected. The Systematic Innovation approach (TRIZ) will be used as a core methodology. Furthermore, the aspect of combining technological as well as market driven factors is essential for the business success.

The main objective from an information technology oriented point of view is the support of weak signals [1] that can be derived from a domain specific information base and the abstracted indicators of the TRIZ/QFD-methodology to stimulate the innovation process. Weak signals are new emerging features in the present that can be used for fore-sighting the future and that often appear as far-fetched and irrational from the current perspective (e.g. new disruptive or alternative technologies). At very early stages they cannot easily be detected but will have a big impact on product development and innovations once they are identified. Ansoff [1] proposes the information flow from the perceived environment to a specific action that is illustrated below. In the case of KNOW IT the environment will be the available options for new innovations inside and outside of the company (technology or market driven) and the action will be the innovation process or a new product development.

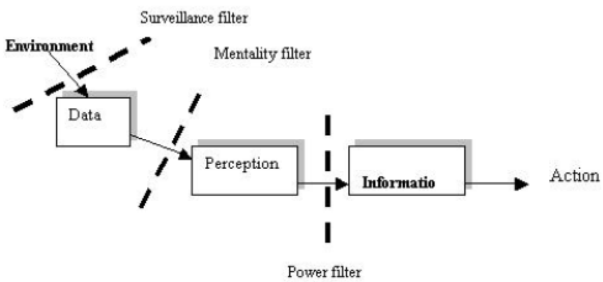


Figure 1: Ansoff [1] filter from Environment to Action

The technology part of the KNOW IT project will help to unlock the available data within the company and in public sources for potential new attributes for product innovations that evolve into new product features (“delighters” or “satisfiers” according to the model of Kano [2]). The interesting aspect of KNOW IT is that it combines an information mining approach with a methodology (TRIZ and QFD) to implement the appropriate filtering in the model of Ansoff. The surveillance filter will be implemented by the crawler engine of the KNOW IT. The crawler engine regularly scans relevant information sources and extracts information from it. The used technology is widely accepted and well implemented in search engines and knowledge management solutions. The mentality filter is implemented by the help of TRIZ and Kano methodologies to focus on the aspects that are the most relevant ones to consider for a new product management. The power filter at last transfers the information along a process oriented perspective that supports the innovation process itself. As the goal of this process becomes clearer, the information will be processed in a more structured way, such that the initial creative phase can be transferred into the already established product development cycle.

An important aspect of our approach is the integrated tool supporting all these activities along the early phases of new product development (NPD) that can take day or even weeks. A consistent support of the information management along this process ensures that all relevant information is captured and taken into account and creates also a source for future NPD-processes that can use the recorded information as a knowledge base. Finally, the whole process will be executed in a more systematic way and automatically documented during its execution.

3 THE KNOW-IT METHODOLOGY

In the KNOW-IT project an integrative methodology has been developed which includes technology and market aspects and fits the SME requirements. Dealing with the complexity in the early steps of innovative new product development process as well as the usability of the method are major aspects of the approach. The high level framework for the conceptual development of the innovation process will be centred on the following steps:

1. Outline the current TS-function in a systematic way with respect to technology and market situation and foreseen development.
2. Positioning of the TS on the technological trends chart. This positioning is supported by analysis methods that operate on relevant information sources.
3. Identify possible developments of the TS using the Systematic Innovation approach with respect to identified relevant technology trends.
4. Evaluate the possible development directions and choose the most appropriate ones in a cost-time-benefit scenario.

This high level framework should be supported by an IT-tool that provides information and analyses tools for every step, as illustrated in the following figure.

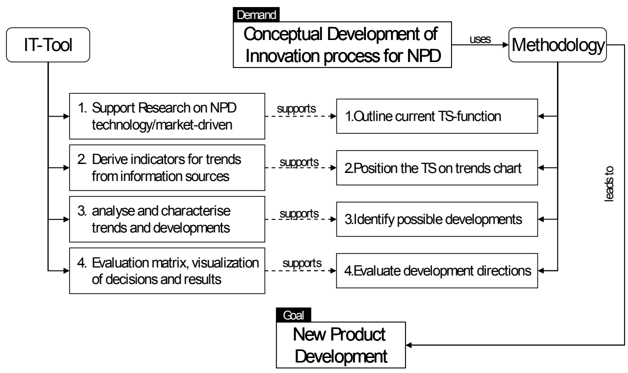


Figure 2: Methodology and tool support

The IT-system is supporting the usage of the methodology to increase the efficiency of information research and knowledge organization. Thus, the retrieval and the organization of information are based on formal and flexible information structures.

4 THE METHODOLOGY

The KNOW-IT methodology consists of a reference process that should capture all relevant aspect of a conceptual NPD process. It has a main process (depicted in the figure 3) and consists of several sub-processes for the Trend-Analysis of the Technical System, the Selection of the High Potentials of the Technical System, the Market Analysis, the Conceptual Development and the Conceptual Evaluation.

The process starts with a company environment analysis that basically has two objectives. One aspect is to determine the departments or areas of the company that are relevant for the conceptual development of the intended new products. This step reveals important factors in the company environment that will be used as the initial parameters for the following market analysis, which will be carried out through the help of an IT-tool that was developed in the former project AMI-SME (see [3] for a detailed description).

The second aspect is related to the product that should be innovated. Again, the aspects and characteristics of the product that are important factors for the innovation process should be derived from the environment. Both aspects should be a result of the first interview with the SME representative personnel. The intention of this analysis is to define the framework in which the NPD will be carried out; it does not necessarily mean that the needed level of detail is already fixed. This will be obtained during the subsequent activities.

The next steps in the main process are the trend analysis of the technical system and the evaluation of the high potential candidates that emerge from this trend analysis. First, a hierarchical product model (product structure) is constructed on which the trend analysis is carried out. This produces a list of relevant functions and functional objects at which the NPD is carried out.

The selection of the high potential solutions from the objects in the product structure defines the technology areas that need to be explored in the NPD and it should identify some initial development direction that can be followed in the next steps. This phase could also make use of structured research methodologies for patent databases, like the one of Cascini & Neri [4] and Nani & Regazzoni [5]. Both results will become a part of the integrative model that is described below.

A parallel activity to the process described above (that is not reflecting the technology perspective but the shaping pressure of the market for the NPD) is the market analysis. The market analysis is fuelled by the company profile that was obtained during the first contact with the customer.

The Results of the previous activities will be fed into the integrative model that is acting as the central repository for the subsequent iterative activities. It unifies the technology aspects and the market demand into a unified model that is building the base for the selective development in the next steps. These are the conceptual development and the concept evaluation, which are repeated until the innovation potentials of the product structure are exploited. The conceptual development is subsuming the TRIZ-based innovation activities for the identified components of the product that have the highest innovation potential. Classical TRIZ methodologies will be applied here. More specifically, we are aligning our methodology at the TechNav-process of Fey & Rivin [6] and the ARIZ-algorithm of Petrov [7]. The new product structure with the applied innovation will be evaluated for its potential performance and this will generate a modified product structure for the next iteration cycle. The evaluation is done based on the forecasted performance of the solution candidates and a multidimensional evaluation of a single domain expert or several domain experts.

The final phase of the process consists of a ranked list of the development options that were derived from the product model and an estimation how this development options can be reached (e.g. by technology-transfer or by research and development). As a by-product this additional information will be added to the final result of the process that is necessary for the NPD. This can be information about the possible suppliers that can contribute to the NPD or companies that can be used as cooperation partners.

The important aspects of this reference process are the two different viewpoints of technology push and market-pull that steer the conceptual development, thus covering both mayor influential steps in NPD (also described in [8]) and the integrated model. The latter is used as central scaffolding on which all the research findings or discovered solutions are aligned. Due to its iterative nature that loops between building the model, executing a conceptual development of one part and finally evaluating the resulting integrative model, it helps to improve the innovation aspects gradually and in a structured way. The use of such an integrated model was inspired by the IPDP-methodology of Yamashina [9]. A basic benefit of this approach is the connection between all the components that are connected in a mechanism tree and an associated function tree. KNOW-IT is extending this model by aligning the information object to the relevant functions and mechanisms, which is thus extending the scope from an integrated calculation model towards an integrated information model.

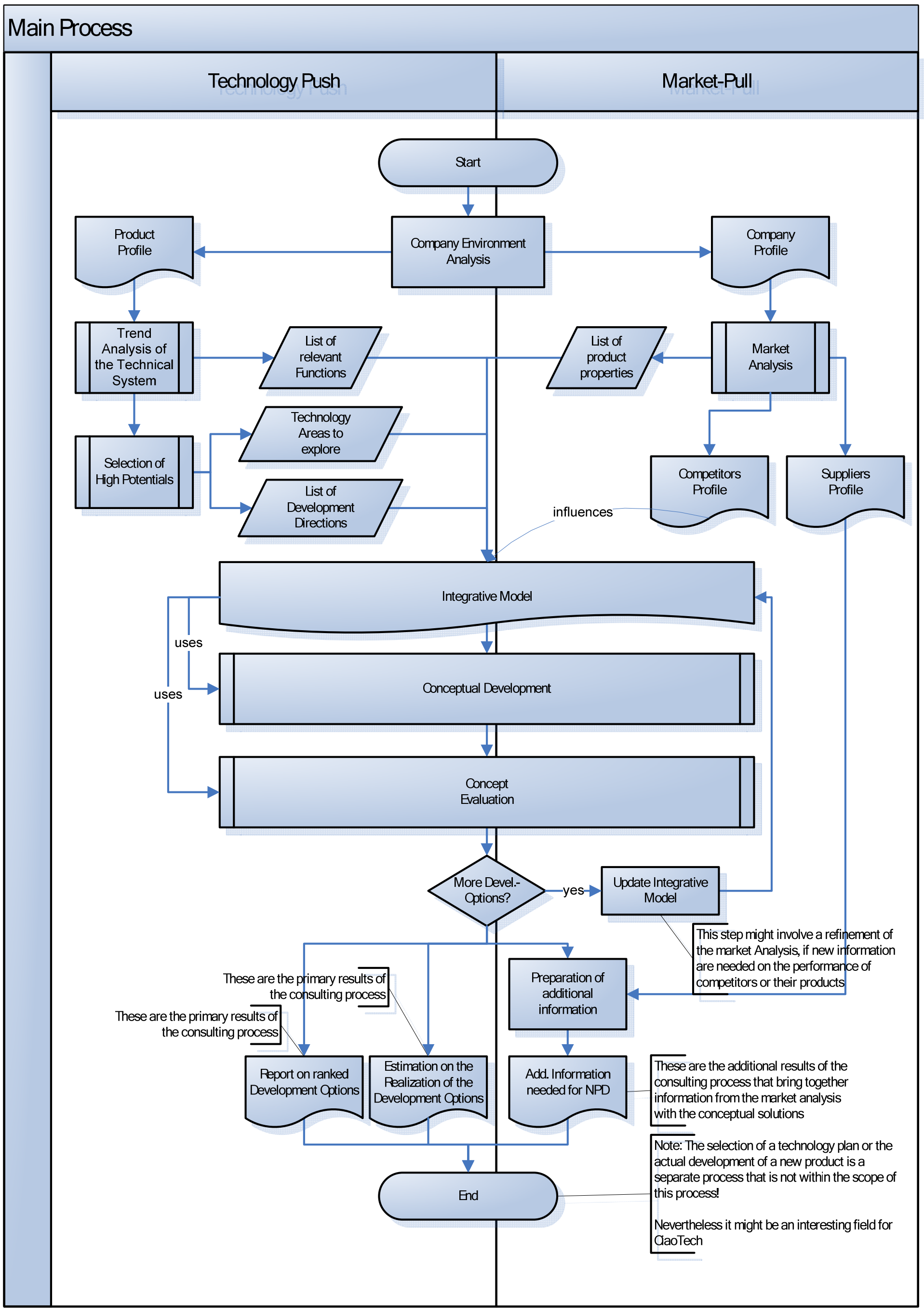


Figure 3: The KNOW-IT Methodology

5 THE IT-TOOL SUPPORT

The following section highlights various aspects of the technical design and implementation of the KNOW-IT system and of the QFD/TRIZ methodologies integration approach.

It is clearly recognized that a full automation of the entire KNOW-IT workflow is now neither advisable nor possible. The implemented software tool aims at supporting and assisting the user rather than replacing him. For this reason, single application components have been defined as modules that consume input data, produce output data, fulfil a task and are bound to a set of requirements.

Java was chosen as development platform for the KNOW-IT software system for to the following reasons:

- *Portability* (platform independence) – the JVM (Java Virtual Machine) is available for all popular operation systems.
- *Availability* of open source libraries – there are many available open source libraries written in Java that can be used for enriching functionality of the system and accelerating the development process.
- *Reuse of further project results*: the software should be integrated with an existing system that was written in Java, so this choice allowed for integration at source code level.

5.1 Architecture Overview

The KNOW-IT platform was designed as a framework for supporting the KNOW-IT process. The user builds the process by means of individual, customizable steps.

A step is built by means of actions performed in the step, and data required for performing the defined action.

For the architectural design several assumptions have to be made. These include the ability to modify and to extend the information structure in the software which is closely related to the requirement of a modular architecture. Finally, platform independence was a major issue.

Easiness of modification

While the KNOW-IT process has been defined at this point of the project, it can be assumed that there will be further requirements in the future which will result in new steps and supporting functionalities. Thus, the easiness of modification and the easiness of adding new functionality is one of the most important postulates that should be taken into consideration in the architecture of the platform.

Modularity

The KNOW-IT platform is designed as a system consisting of separate modules. The separation paradigm is applied not only for large modules as subsystems, but also at programming component level. It means the large modules can also consist of different elements. With modularity another assumption is related, namely each component should be fully functional on an individual level. Therefore the expected functionality has to be provided without intervention from other components. For example, if a given component implements text mining algorithms, it should also provide the graphical interface for setting parameters of the algorithm. This resembles a service-oriented approach on the level of the application framework that can be further extended to integrate distributed components.

Platform independence

The hardware and software platform independence is an important property of the resulting KNOW-IT software. Therefore it was decided that the implementation should be based on Java and should rely on libraries and technologies that are cross-platform.

5.2 KNOW-IT Platform description

The KNOW-IT software tool represents a typical client/server system. The client side is provided by a rich client, which is the main part of the system including the business logic, while the server side is basically limited to the database system, providing persistence of data and some data validation. The client side of the system provides all the functionalities directly involved in assisting the user throughout the KNOW-IT workflow.

Figure 4 shows the KNOW-IT architecture in terms of its main subsystems and their high-level interaction. The platform consists of five subsystems: the process manager which supports performing the KNOW-IT process, a searching subsystem, a local repository searcher, a data storing subsystem, and a patent analysis subsystem.

The architecture forces that interaction between components in the platform is carried out at the data level; there are no protocols for communication between components. The interaction at the data level means that one component produces data required by another component and that such data is read from a database (data component). Thus the architecture is following the Model-View-Controller pattern (MVC), where the view is presented in the process subsystem, the controller encapsulated in the active components and the data is stored in the model.

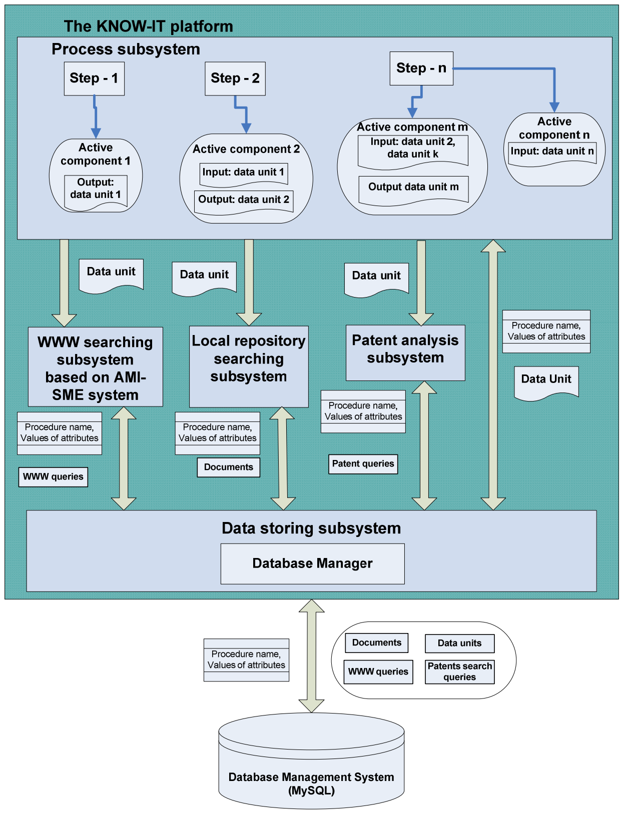


Figure 4: Architecture overview of the KNOW-IT platform

5.3 KNOW-IT Subsystems

The main types of objects that build the Process subsystem are the following:

- *Process manager:* The process manager object is responsible for managing the entire KNOW-IT process. It has the collection of objects (Step) which represent the phase of the KNOW-IT process. The process manager object offers also methods for creating new steps as well as new active component objects.
- *Step***:** A step object represents a single phase of the KNOW-IT process in the KNOW-IT platform. It consists of a collection of the active component objects. The step object has assigned the sequence number.
- *Active component:* An active component object represents a single tool from the KNOW-IT process. The Process subsystem includes several different active component objects. The active component object operates on data unit objects. It can also produce a new data unit object.
- *Data unit:* A data unit object represents a well defined unit of information which is used in the KNOW-IT process. The data unit object consists of a collection of attributes and it is responsible for retrieving data from and saving data into a database by using the Database Manager object. A data unit object can be associated with additional pieces of information e.g. documents or Web-queries.

The Web-searching subsystem is dedicated to searching in Internet and it is a separate part of the KNOW-IT platform. It is loosely connected with the process subsystem and it is based on the results of formal projects. The subsystem provides also functionality for downloading resources from Internet.

The Local repository searching subsystem is dedicated to searching for documents stored in a database and provides functionality for extracting text data from several types of documents and enables saving documents into a database.

The patent analysis subsystem is responsible for supporting the analysis of patent databases. The subsystem consists of elements for searching patent databases and for presenting results obtained from the searches. In the current implementation the esp@cenet patent database is used.

And last but not least the data storing subsystem consists of the objects which are directly responsible for retrieving data from and saving data into a database system. Such action is done by invoking an appropriate, indicated by name, stored procedures.

6 A CASE STUDY

In order to verify the applicability of the developed methodology different case studies were executed, following the methodology of McNamara [10]. To pursue this objective, the reference process has been converted from the methodology into an executable workflow, which was then tested for its usability in a consultancy process. To validate the process the type of evaluation has been fixed to value usability and operability of the established workflow. Therefore a simple Bad-Middle-Good evaluation was used.

To grant a practically case study the pilot study was reviewed by different team members with different expertise knowledge. So failures were eliminated before the next case starts. This was done based on discussions and subsequent on the fly adapting of the pilot case study. Later on, the case study was revised in an iterative way in each new step. To ensure the reliability of the whole process, several case studies should be performed with the same set of validation parameters. As an illustration one case study will be discussed in more detail below.

The case of Solarsystems

The case study focuses on a producer of Solar systems from central Europe. The area of expertise of this company is the development of solar systems which includes collectors and storage in a combined system, without the usage of electrical energy. The company has more than 20 years of experiences in production, however, there has been nearly no improvement of the technology within the last few years. Also restrictions given by current laws influence the sales and the usability of their solar systems. A few points of improvement possibilities are already mentioned. The main issues are:

- The design of the storage system should be changed because of the problems with regional laws
- The effectiveness of the solar panels should be improved

The major benefit of the system is its ability to operate without any electrical energy. So there is nearly no maintenance needed after installing and using the system. With a very low price compared to other more complex system, the Solar system (SS) will have paid for itself within the first 3 years of usage. The storage system has about 10 years of warranty.

The goal of the innovation process is to obtain a leading market position in the national region. There are currently no plans for internationalization, which still might be an option in the future. After doing the developed workflow based on the methodology the following results are obtained:

Results

Analysing the interviews and product descriptions 17 quality characteristics (QC) and 10 customer requirements (CR) have been discovered. This number of parameters (which are used in the ongoing steps e.g. for building the house of quality) has been identified as to much; the matrix will become unclear and confusing. If the number is too high one might fall in to two types of problems:

1. If the quality characteristics are too detailed, it is difficult to determine value for relation between QC and CR.
2. Some quality characteristics are related with each other and this might increase the number of calculation without a really useful effect for the analysis. (e.g. the panel dimension length and width is related to global surface)

For the reliability of the activity it is better if the selection is reduced to 6 or 7 quality characteristics and 5 or 6 customer requirements.

The market analysis used federated search functionality on the web resources to capture the relevant information. Different search strings for the accumulated content (QC, UR, and product description) were used during the search. It turned out that the level of linking to the information was not detailed enough and needed manual intervention to capture the link to the correct resource. A revised implementation will take that into account.

The next step – calculation of HoQ – delivered the value of innovation potential for components out of each technical system level. So in the first level the highest innovation potential was the primary circuit (0,91) of the solar system followed by the tank (0,88) and the panel (0,80). Moving forward to the next level the mechanism with the highest innovation potential was the heating exchange (0,61) followed by the tank isolation (0,42) and the panel (0,33). Selecting the heating exchange and his subcomponents leads in the last level of mechanism that the chamber for heating exchange (0,56) is the most interesting mechanism for innovation on the lowest mechanism level. But performing the house of quality calculation and the mechanism high potential selection, a column reporting the mechanism weight without considering the innovation potential value would be necessary. The user should have the possibility to choose the mechanism also based only on the level of relation with QC and CR because of the maybe misleading innovation potential evaluation.

For the ARIZ approach the final Work Flow (WF) has been used. The final WF combines the Petrov approach [7] with the Fey-Rivin [6] technique. It foresees to apply all the TRIZ knowledge base in parallel to identify possible solutions. At the same system conflict all the techniques Ideality tactics, separation principles, contradiction matrix, standards, su-field analysis are applicable. The focus on the chamber of heating exchanges takes to problems to solve: the optimized thermal energy transfer as well as the visual impact of the system. To find a solution for the energy transfer problem we run through seven main steps with a few sub steps of the ARIZ approach. Starting with the formulation of the technical conflicts and describing the harmful effect (losing too much thermal energy) the technical conflict has been selected, which was expressed by the intensified conflict: The chamber is transferring a high level of energy inside but loosing also a high level of energy to the outside environment. The performed sufield analysis, the ideal final result definition leads to the physical conflict and the corresponding physical solution. The standard solution of breaking harmful effect brought up the solution to replace the chamber from outside to inside, so the chamber itself looses no energy to the outside environment.

The Laws of Evolution have been applied in order to study the position of the technological system compared with the TRIZ trends. The lines of evolution defined for each single law are used for both, position analysis and innovative solutions identification. Again the focus was set on the chamber for heating exchange. The Laws of 'completeness' got the highest value (6) followed by the laws 'increasing dynamism' and 'transition to micro level' (4). The lowest value had the law 'harmonisation of rhythms' (0) and 'transition to higher level system' (1). So the last two mentioned laws let discern the most potential of improvement while the law of 'completeness' and 'transition to microlevel' are already well developed.

It appeared that the effectiveness of the Laws of Evolution is higher if they are applied on a node that is not situated at the deepest level of TS tree. Therefore, it might be useful to apply the laws also to the overall product at level 0 to identify possible radical solutions.

7 RELATED WORK

This section describes architectures and IT-Tools that are currently available on the market to provide a baseline for the conceptual development of new products according with the TRIZ methodology. This section evaluates the most important from the KNOW-IT perspective highlighting those functionalities that are most relevant to support the intended KNOW-IT methodology.

There are a few tools that seem to be established in the market of TRIZ-tools and that are widely used. Furthermore, some new tools have been developed recently, that contain interesting features such as the support of Ontologies (Pro/Innovator).

However, most of the tools focus on the innovative problem solving part only. KNOW-IT is trying to capture the whole process of conceptual NPD and therefore provides a wider range of information management capabilities, than the specialized tools listed below.

Software Name	Short Description
Creax Innovation Tool	Tools to systematize creativity; to help user to manage the complexity of problems; to analyze user current products in short time; solve user problems using the strategies of the best inventors worldwide
Goldfire Innovator	Structured process to inventive problem-solving, easy-to-use problem-identification, problem-solving and solution-generating capabilities.
Innovation Workbench	System that provides engineers with expert I-TRIZ assistance in solving challenging technological problems, helping users to develop implementable solutions that at times represent true technological breakthroughs
Pro/Innovator	Pro/Innovator is a knowledge-based innovation tool that guides strategic thinking by integrating TRIZ, ontology, modern design methodologies and natural language technique to assist engineers breaking psychological inertia during the conceptual design stages of product development. It helps the professionals and corporations to identify engineering problem correctly, develop engineering concepts inventively, evaluate alternatives comprehensively, generate patent application draft, and accumulate knowledge systematically. This tool is used across many different fields of science and engineering. Source: www.iwint.com

Table 1: Overview of IT-Tools for Conceptual Innovation

8 SUMMARY AND OUTLOOK

To summarize the steps before, a well established workflow has been generated from the designed methodology considering the market and technology aspect of products in their lifecycle. Along the structured innovation process, according to the IT Tool support, consultants have the possibility to increase the business value of products that have to be innovated due to different reasons. Complexity becomes more usable in the separated modules which are implemented in the software tool. Due the usage of a structured process also the reproducibility of results is well supported.

However, it is also necessary to mention some shortcomings which were identified during the project. The exact reproducibility can only be granted by limiting the freedom of the consultancy process, which is typically not advisable as the consultant has to react in an agile, flexible and dynamic manner to changing conditions in the NPD-process. This leads e.g. to dictionaries that have to be used to build the System Tree or formalize the product based on the object-action-tool description (OAT). Also the negative correlation in the House of qualities, if quality characteristics affect each others in a negative way, has to be well understood by the user of the workflow. Ignoring this will lead to shifted innovation importance and so to the wrong focus of innovation.

Nevertheless – the developed methodology and the established workflow are a good base for ongoing applied research projects. One of the next steps should be a full implementation of different sets of innovation tools like TRIZ, Advanced Systematic Inventive Thinking (ASIT), and so on. Also the adaption of developed methodology and tool to the possibility to innovate services is an interesting and worth aspect to focus on.

Currently the final implementation steps are carried out as well as a more detailed evaluation of the toolset in more case- studies.

To conclude, the KNOW-IT platform provides an IT-tool supported methodology that does not only help to find innovative solutions, but embedded the whole process of conceptual NPD with regards to an integrated information management.

REFERENCES

[1] Ansoff, I (1984), “Implanting Strategic Management”, Prentice Hall International, New Jersey.

[2] Burns, A., Evans, S., 2001. Beyond Satisfaction: An Investigation of the Delighted Customer and Implications for the Design of Desirable Products, Proceedings of 2001 International Conference on Engineering Design.

[3] Böhm, Karsten; Salvatore Paolo: “Supporting Knowledge Intensive Researches and Systematic Knowledge Organisation in Weakly Structured Business Processes”. In Fähnrich, Härtwig, Kiehne, Weißbecker: “Technologien und Werkzeuge für ein rollen- und aufgabenbasiertes Wissensmanagement”, University of Leipzig, 2007

[4] Cascini G., Neri F., “Natural Language Processing for patents analysis and classification”, Proceedings of the TRIZ Future 4th World Conference, Florence, 3-5 November 2004, published by Firenze University Press, ISBN 88-8453-221-3.

[5] Nani, Roberto; Regazzoni, Daniele: “Practise-based Methodology for effectively Modelling and Documenting Search, Protection and Innovation”, Proc. of the TRIZ Future Conference 2006, Kortijk, Belguim, 2006.

[6] Fey, Victor; Rivin, Eugene; Demand on Innovation, 2005, Cambridge University Press, Cambridge

[7] Petrov, Vladimir; Logic of ARIZ, 2004; TRIZ Future Conference 2004,pp. 315-331

[8] Lucchetta G., TRIZ in the House of Quality: Combining Market Requirements and Technology Trends into Innovative Products, 6th AITEM International Conference, Gaeta, September 8-10, 2003

[9] Yamashina H.; Ito, T.; Kawada, H.: “Innovative product development process by integrating QFD and TRIZ” in International Journal of Production Research, 2002, vol. 40, no. 5, 1031-1050

[10] McNamara, C.: Basics of Developing Case Studies, Link: http://tinyurl.com/5grdn2, date: 070827

TRIZ Value Innovation Roadmap for Projects Innovation Roadmaps

Isak Bukhman
TRIZ Solutions LLC, USA

Abstract

In this paper we will show our experience and best practices of many innovation teams around the world in TRIZ applications for different kind of projects and problems. We will focus your attention on how to use all modules of TRIZ as a complete and harmonic system in combination with others proven methods. We call this composition as a TRIZValue Innovation Roadmap. We use TRIZ Value Innovation Roadmap as a base for each unique project/problem innovation roadmap creation. TRIZ is a "center of gravity" in most of such roadmaps.

Keywords

TRIZ Innovation Roadmap, Project Innovation Roadmap, TRIZ body

1 INTRODUCTION

One of the main practical TRIZ applications is an engineering area. It could be different kinds of projects and problems. To use TRIZ for these projects and problems we recommend:

- First, to be clear about right content (body) of TRIZ;
- Second, to have a common TRIZ Innovation Roadmap for Projects and Problems;
- Third, to create individual Project Innovation Roadmap for the each project or problem, including appropriate modules from VM, SixSigma, DFSS, QFD, RCA, FMEA, and others proven methods if it is necessary.

2 THE PRINCIPAL TRIZ TOOLS – TRIZ BODY

2.1 Laws of System Evolution

Laws of System Evolution is a set of certain and constant rules of being, operation, or change of systems that describes recurring facts or events in the process of systems development.

Laws of System Evolution are the base for all TRIZ modules development. It becomes available to formulate fundamental understanding of the ideal system and to create an ideal image of any product and process, or ideal image of the next generation of them.

Some examples of Laws:

- **Law of Increasing Ideality of the System.** Perfect/Ideal System is a system that requires no energy to operate, costs nothing to produce, and occupies no space

  Example: Transition from the keyboard of button design to optical projected keyboard;
- **Law of Transitioning to a Super-System.** This law states that systems, throughout its lifetime, evolve in the general direction from mono-systems to bi- and poly-systems and the combinations of the different systems.

  Example: Sweden-Denmark bridge – combination of two types of transportation systems: regular bridge idea and tunnel idea;
- **Law of Increasing Controllability/Flexibility of the System.** Evolution of the technical systems is directed towards: increasing controllability, from "rigid" to flexible structures, and from "rigid" to flexible parameters.

  Example: Flexible gates in Shanghai.

2.2 Algorithm of the Inventive Problem Solving (ARIZ-85C)

ARIZ-85C is a set of sequential, logical procedures for problem solving in the perfect manner.

ARIZ-85C is a main module of TRIZ.

First, **ARIZ-85C** performs functions of the TRIZ manager, showing when you are ready to use appropriate modules of TRIZ.

Second, **ARIZ-85C** is a set of specific steps for analyzing the initial problem situation. Here we show first three parts of ARIZ-85C – it is quite enough for the first steps in TRIZ.

The first version of ARIZ was developed in 1956. The name ARIZ was introduced at the first time in the autumn in 1965. The modifications of ARIZ were named ARIZ-68, ARIZ-71, ARIZ-77, ARIZ-82... The last modification of ARIZ is **ARIZ-85C.**

2.3 Inventive and Separation Principles – Technical and Physical Contradictions

Over the following years, Altshuller screened over 200,000 patents looking for inventive problems and how they were solved. Of these only 40,000 had somewhat inventive solutions; the rest were straight forward improvements. Altshuller defined an inventive problem as one in which the one parameter changes is in conflict with another parameter (or parameters) of the process or product. Altshuller called this conflict a technical contradiction.

Altshuller extracted 39 most frequently used technical parameters that causes technical contradiction and conflicts in thousands of problems, products, and processes. He found that often the same problems had been solved over and over again using one of about forty fundamental inventive principles. If only later inventors had knowledge of the work of earlier ones, solutions could have been discovered more quickly and efficiently.

To find which inventive principles to use, Altshuller created the Matrix of Contradictions.

2.4 System of Standard Solutions

Altshuller discovered that most of the problems from different areas could be represented by a limited number of models (model of problem). Each of these models could be transformed into models of available solutions.

Altshuller identified and documented such seventy-six transformations - Standard Solutions and organized them into 5 classes:

- **Class 1.** Creation, Transformation and Destruction of elementary (simple) Substance - Field Models; includes two groups – 13 standards;
- **Class 2.** Substance - Fields Models development; includes four groups – 23 standards;
- **Class 3.** Transition to Super-system and to Micro-level: includes two groups – 6 standards;
- **Class 4**. Standards of Measurement and Detecting of Systems (and in systems): includes five groups – 17 standards;
- **Class 5.** Standards for Using of Standards: includes five groups – 17 standards

Standard Solutions are recommendations of how to transform the system in order to eliminate the problem and could be used to find solutions for most of problems.

Standard Solutions are not related to specific areas of technology and help transfer effective solutions from one branch of technology to another.

2.5 TRIZ Scientific Effects library

It is perfectly clear for any scientist or engineer – evolution and development of the technical system is available only by using the multiple fields of science and combining their strengths.

The TRIZ team was forced to solve a very complicated problem – how to select the right scientific effects for particular problem solving. In the TRIZ Scientific effects library you will find an excellent navigation system which will allow you to easily select appropriate scientific effects for almost any problem.

TRIZ Effects Library, currently the largest scientific effects library, contains about 2,500 descriptions of unique scientific effects and phenomenon.

Mc-Graw Hill Encyclopaedia of Sciences & Technologies contains only 897 scientific effects and phenomenon descriptions.

2.6 Patent Collections

Now it is available to process about 16 millions world wide patents.

3 TRIZ INNOVATION ROADMAP FOR PROJECTS AND PROBLEMS

We included in TRIZ Innovation road map, together with TRIZ principal modules, Project Scenario, Root-Cause Analysis (RCA), Device/Process Function Analysis (VM/VA/VE), Failure Mode & Effects Analysis **(**FMEA), Hybrid System Design, and Trimming in order to create a complete (almost complete) set of tools for Conceptual stage of Product/Process design. We also recommend using it as a basic source for individual Project Innovation Roadmap creation.

3.1 Project Scenario

Project Scenario is a first stage for any kind of projects. We strongly recommend having a complete Project Scenario at the end of the first Project session with consultant. Project Scenario usually contains following stages:

- Project team report about Project initial situation, including requested information;
- Right project topic creation;
- Right initial problems definition;
- Preparation of clear and "understandable" pictures/sketches of subject(s) of project;
- Creation of list of expectations;
- Preparation of list of time-space-substance-field resources and theirs parameters;
- Selection of most effective ways for concepts creation;
- Project innovation roadmap creation;
- "Home work" issue for project team;
- Project team and consultant friendly picture.

3.2 Root-Cause Analysis (RCA)

RCA is one of the main parts for many methods, including: lean manufacturing; failure analysis; FMEA; risk management; accident analysis; DFSS; 6Sigma and so on. RCA answers your problem.

RCA is a step-by-step method that leads to the discovery of a fault's first or root cause. It is a definite progression of actions and consequences that lead to a failure or to a simpler problem.

An RCA investigation traces the cause and effect trail from the end failure back to the root cause. It is much like a deductive reasoning of Sherlock Holmes.

3.3 Failure Mode and Effects Analysis (FMEA)

FMEA is a procedure for analysis of potential failure modes within a system for the classification by severity or determination of the failure's effect upon the system.

It is widely used in the manufacturing industries in various phases of the product life cycle. Failure causes are any errors or defects in process, design, or item especially ones that affect the customer, and can be potential or actual.

3.4 Hybrid System Design

Hybrid System Design allows you to compare several systems that perform a similar function and to combine the best features of these systems into one hybrid system.

3.5 Trimming: Design Simplification Strategy - Radical product/process changes

Trimming improves product/process by eliminating low value (problematic) components and redistribute their useful functions between other components.

Trimming Method simplifies and reduces the cost of user product/process, while preserving the essential functionality.

The design variants that result from Trimming will generate different problem statements, if solved, can lead to highly innovative solutions.

4 EXAMPLES OF PROJECT INNOVATION ROADMAPS FOR DIFFERENT PROJECTS AND PROBLEMS

4.1 Quality/reliability

As an example of such kind of projects we selected a project related with transistor quality improvement. Projects team defined two major requirements: to reduce presence of moisture inside transistor on Al surface; to reduce current leakage on Al surface between two contacts.

We selected following modules for Project Innovation Roadmap:

Device/Process Analysis and Problem Statement:

- **Project Scenario.** Project Scenario module we use for any project as a starting module;
- **Root-Cause Analysis (RCA).** Team have used RCA to define root-causes for two initially selected

problems: “current leakage” and “corrosion of aluminium”;

- **Product/Process Functional Analysis.** Functional analysis of transistor design was done in order to identify problems and to find directions of transistor design development;
- Trimming;
- Problems selection for further solving.

Selected Problem Solving:

- ARIZ-85C first three parts;
- Inventive & Separation Principles;
- Scientific Effects;
- Patent Collections;
- Concepts Selection & Evaluation.

4.2 Manufacturing cost reduction

Innovation Roadmap for such kind of projects usually contains following modules:

Device/Process Analysis and Problem Statement:

- Project Scenario;
- Root-Cause Analysis (RCA);
- Product/Process Functional Analysis;
- Trimming;
- Hybrid System Design;
- Problems selection for further solving.

Selected Problem Solving:

- ARIZ-85C first three parts;
- Inventive & Separation Principles;
- Scientific Effects;
- System of Standards;
- Patent Collections;
- Concepts Selection & Evaluation.

4.3 Information preparation for R&D projects, building patent map

Innovation Roadmap for such kind of projects usually contains following modules:

- Project Scenario;
- Product/Process Functional Analysis;
- Problems selection for further solving;
- Scientific Effects;
- Patent Collections;
- Company Profile;
- Technology Analysis;
- Competitive Analysis of Intellectual Activity;
- Patent Citation;
- Concepts Selection & Evaluation.

SUMMARY

- The most effective way of using TRIZ together with others proven methods like VM, SixSigma, DFSS, QFD, RCA, FMEA, and so on is to use **Project Innovation Roadmaps.**
- We showed you only examples of **Project Innovation Roadmaps** for different projects from our practice. Ours are not templates for yours projects;
- **Project Innovation Roadmap** should be created individually for each Project and should contain sets of modules of different methods which are necessary for the given project;
- TRIZ is “a center of gravity” of **Project Innovation Roadmaps**, but it is not enough to use only TRIZ modules to be successful in projects.

CONTACT

Isak Bukhman

TRIZ Solutions LLC,

93B Spring Street, Watertown, MA, 02472, USA

E-mail: Isak-Bukhman@comcast.net

Phone: +1 (617) 926-7145

Skype ID: Bukhman

TETRIS: Teaching TRIZ at School
Meeting the educational requirements of heterogeneous curricula

G. Cascini[1], J. Jantschgi[2], I. Kaikov[3], N. Khomenko[1], I. Murashkovska[4], A. Sokol[4], F. Tomasi[5]

[1]University of Florence, Dept. of Mechanics and Industrial Technologies, Italy
[2] Carinthian University of Applied Sciences, Austria
[3] European Institute for Energy Research, Germany
[4] Jelgava Regional Adult Education Centre, Latvia
[5] AREA Science Park, Trieste, Italy

Abstract

Enhanced creativity, problem setting and problem solving skills are missing topics in most of secondary schools of the European countries. Besides, actual TRIZ courses, seminars and educational materials are mostly tailored for industry or technical universities while they fail to meet the requirements of many different potential readers and learners from general upper-secondary school students and teachers to people interested in human science disciplines.

The TETRIS project, funded by the European Community within the Lifelong Learning Programme, aims at producing and testing TRIZ educational material suitable for learners from 14 years old onwards following any kind of curriculum. The paper presents the goal and the structure of the project, dedicating a proper attention to the description of the identified educational requirements and to the approach followed to build the Body of Knowledge of the educational material.

Keywords

TRIZ education, educational model, educational requirements, European project

INTRODUCTION

Innovation is the main pillar of Europe's future and it is the main objective of EU policies. To be effective, innovation requires trained researchers and designers with enhanced creativity, problem setting and problem solving skills. Nowadays, these skills are mainly taught in very short professional courses ranging from 2 to 5 days. These courses are too short to overcome psychological inertia and typical trial & error practices. Besides, even such courses are virtually absent in upper-secondary school curricula.

TRIZ, as the theory for solving inventive problems, and its instruments can play a relevant role in pursuing innovation-related EU policies, however its presence in academic curricula is quite limited at the tertiary level and virtually non-existent at lower levels.

Moreover, most of TRIZ books and training materials are tailored to a narrow set of "technicians" (mostly people from industry with a proper attitude to learning methods supporting product development), but fail to address the needs of many other potential readers and learners (e.g., secondary school students or representatives of human and social sciences).

This is the context that led to the appearance of a European project TETRIS, TEaching TRIZ at School (www.tetris-project.org) supported by the European Commission in the framework of the Life Long Learning Programme.

The goals of the TETRIS project are as follows:

- identify the educational requirements of upper-secondary schools, universities and industries from different European countries interested in the introduction of TRIZ in their curricula/training programmes;
- attract secondary school students to the study of methods and tools enhancing their creativity and supporting their problem solving skills with systematic means;
- define an educational model suitable for addressing the heterogeneous demands of TRIZ education;
- produce educational materials adaptable to heterogeneous specific situation;
- validate the proposed educational model and materials by means of five prototype "train the trainer" pilot courses and pilot implementations of courses in three technical high schools (Austria, Italy and Latvia), two vocational training centres (Italy and Latvia), four industrial organizations (Austria and Germany).

TETRIS GENERAL INFORMATION

The consortium of the TETRIS project is coordinated by the Science and Technology Research AREA of Trieste (Italy) and involves the following partners:

- University of Florence (Italy), Carinthia University of Applied Sciences (Austria), Jelgava Regional Adult Education Centre (Latvia), European Institute for Energy Research (Germany), Harry Flosser Studios (Germany) for the definition of the educational model and the development of the training materials;
- Technical Institute for Industry "Arturo Malignani", (Italy) Higher technical College of Wolfsberg (Austria) and Jelgava 1. Gymnasium (Latvia) for the implementation of the pilot courses with teachers and students at school;
- Siemens Automation and Drive Technology (Germany), STENUM Environmental Consultancy and Research (Austria), ACC Appliances – Components – Companies (Austria) for the implementation of the pilot courses in industry.

The project started in January 2008 and was funded for two years with support from the Lifelong Learning Programme of the European Commission.

Although there seems to be a common understanding that teaching creativity and problem solving methods should start as early as possible (since kindergarten) the TETRIS project assumes that readers and participants are at least 14 years old.

IDENTIFICATION OF EDUCATIONAL REQUIREMENTS

In order to find out which are the most relevant key factors for a step-by-step, constructive TRIZ training, all project partners of TETRIS were asked to fill in a prepared questionnaire and pass on their experiences with previous TRIZ trainings (either as participants or as teachers).

Since the project partners of TETRIS are both educational institutions (universities, schools, educational authorities) and companies (industry and SMEs) a special attention was paid to the identification of the differences between the procedures in schools and companies. A further question for investigation was the differences in expectations of partner schools, as well as various requirements to the new materials caused by the peculiarities of the situation in various countries.

A brief summary of the main outcomes of this activity is reported in Table 1.

While no relevant differences were highlighted from the schools due to national regulations, the hardest requirement to fulfil is the limited amount of time schools (as well as small companies) can dedicate to the introduction of TRIZ. Besides, a realistic approach to combine consensus and feasibility is a TRIZ introduction course, where the tools are explained and practised with prepared exercises, followed by the application of TRIZ tools within real project works (typically implemented at least in any technical or experimental school).

Moreover it was recommended to produce a comprehensive map of the TRIZ Body of Knowledge in order to give a clear overview of what TRIZ can offer and what could be studied at the end of the introductory course.

Topics / Questions	**Schools**	**Companies**
What is the goal of the "customer" (school / company) when running TRIZ lectures	Different thinking approach & creativity method	Problem solving competence
How to increase the interest & motivation of participants (in an introductory session)	Simple examples to demonstrate the application of the theory Using multimedia & playing elements	Showing results and outcomes
What should be the content of an introductory TRIZ course	The main concepts of TRIZ Some easy-to-use tools TRIZ tools that can also be applied in other lectures Overview about the TRIZ thinking process (ARIZ)	The mainconcepts of TRIZ Some easy-to-use tools TRIZ tools that can be quickly applied for idea generation Overview of potential applications of TRIZ Overview of the TRIZ thinking process (ARIZ)
What is a good / feasible duration for a TRIZ course	App. 30 to 60 hours	Approx. 2 to 3 days
Important educational elements	Hands-on examples Exercises & Homework Fun (teamwork)	Hands-on examples Templates for easy implementation Benefit of cross-company teams
Specific restrictions / particular requirements to take into account when organising a TRIZ training	No (international) standard handbook for TRIZ trainings is available at the moment! Creativity is not "declared" school topic	No (international) standard handbook for TRIZ trainings is available at the moment! No internationally accepted certification system

Table 1: Main outcomes of the questionnaires and experience reports from schools and companies.

DEVELOPMENT OF THE EDUCATIONAL MODEL

In order to address the complex task of introducing totally new subjects into the student curriculum also taking into account the heterogeneous and strict demands described in the previous section, a specific educational model has to be developed.

1.1 The role of TRIZ in the Knowledge Society

In the 60-ies of the previous century the concept of ‘knowledge society’ appeared in Europe as a response to the inability of traditional educational systems to meet the needs and the demands of the society.

The modern understanding of ‘knowledge society’ was presented by T. Koke as the system of people’s social relationships ensuring high level of innovations in which every personality is able to achieve a high degree of participation getting, using and developing new knowledge independently.

Longworth [1] defines the basic skills necessary in the knowledge society: the ability to manage oneself, the ability to work with information and interpret it, the application of new knowledge to practice, studying skills, the ability to communicate sensibly and critically, management and communication skills, thinking abilities and creativity, the ability to adapt, the ability to work in team and life long learning.

Since the existing system of education, with the actual programmes and curricula, does not fully fulfil the task of preparing the students to the life in the knowledge society, it is necessary to modify these programmes of education according to the skills mentioned above.

TRIZ experts will recognize many skills highlighted by Longworth as those enhanced by the TRIZ way of thinking and supported by the TRIZ instruments. A more detailed definition of the skills developed by people practicing TRIZ on a regular basis is published in [2].

Therefore the introduction of TRIZ to the curriculum can be this possible change of the educational system aimed at fulfilling the new requirements of the knowledge society. The introduction can be achieved in two ways – TRIZ as a separate subject or as content integrated in other subjects.

1.2 TRIZ in school

The traditional way of planning educational content can be described as follows (figure 1):

- A school develops an experimental educational programme and defines the list of necessary list of subject
- The state accepts the subject standards
- Teachers develop subject programmes which include the list of necessary teaching materials. This means that the teacher chooses from the existing sources: course books, literature sources, Internet resources, etc., those which are most suitable to achieve the aim stated in the programme while working with the target audience.

Certainly there are cases when there are no course books and the teacher has to develop the teaching materials for the students independently. He/she does it according to the subject programme on the one hand, and on the basis of subject scientific literature on the other hand.

The schools belonging to the TETRIS consortium, as well as any other similar educational institution planning to teach TRIZ to their students, in the beginning have neither TRIZ skills, nor teaching materials. Therefore the educational materials must be customized to the specific situation. The main difference in comparison with the introduction of more classical subjects is that there are neither programmes nor standards available for TRIZ as a subject.

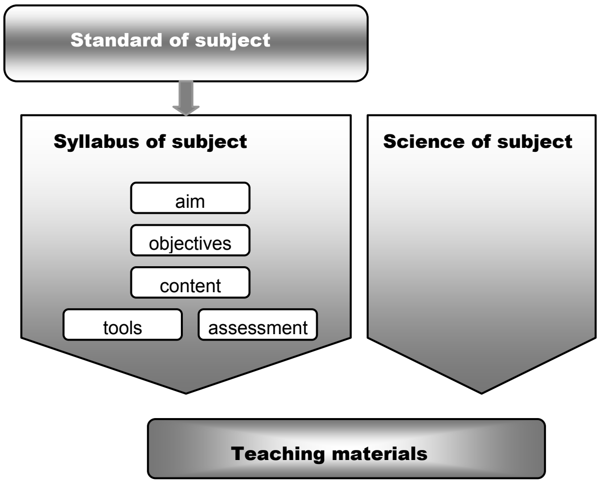


Figure 1: Traditional way of education content planning.

In fact, the programme must be defined in agreement with the system of requirements to be satisfied during the teaching/learning process. Several factors must be taken into consideration while developing the educational programme:

Student factors:

- Human and national values
- Educational needs
- Motivation
- Personal qualities
- Age peculiarities
- Cognitive factors: cognitive skills, creative skills
- Affective factors: sympathy and emotions, their character and strength
- learning style
- Quantity and quality of the knowledge possessed
- Work and problem solving experience
- Ability to learn
- Ability to cooperate

Teacher factors:

- Human and pedagogical values
- Attitude towards professional activities
- Personal qualities
- Personal culture
- Education
- Experience
- Pedagogical believes and preferences
- Professional knowledge
- Attitude towards students and the style of socializing
- Creativity

School factors:

- The aim of activities and the development strategy
- Educational programmes
- Atmosphere and microclimate
- Corporate culture
- Pedagogical traditions
- Teaching environment
- Resources: material, human, time

Country factors:

- National values
- Social, economic and political development
- Education policy
- Education system
- Education standards

The synthesis of all the above-mentioned factors allows to discern which information is understandable/not-understandable, interesting/ uninteresting for the students, if they can learn independently, what tasks are more suitable to their interests and abilities, on the grounds of what pedagogical approaches the learning is going to be more successful, etc. Thus, it becomes possible to develop the materials which will be more suitable for effective application to teaching TRIZ in a specific school or company. It also means that teaching materials for every project participant have to be different and about at least 5-6 sets of teaching materials should be developed just in the framework of the TETRIS project. However, time and budget resources do not allow for such an extensive approach. Only one set of materials can be developed.

The task clearly shows the conflicting requirements: to develop materials that are suitable for different target audiences and in different situations using only the limited resources available in the project. The contradiction – there must be many sets, there must be one set of teaching materials – can be solved by separation between macro and micro level: there is one set of teaching material, but it consists of clearly stated structural elements, which can be tailored to different needs.

This solution also coincides with modern tendencies in education where the importance of context for syllabus design and the active role assigned to both the teacher and the learner are widely emphasized.

There is one more requirement to be met by the project participants. These materials will be used by teachers who have never taught TRIZ before. Thus available resources, i.e. the teacher's knowledge and expertise, must be used to the maximum extent: the train-the-trainers courses delivered to the school teachers before the introduction of TRIZ into the classrooms, should be organized in order to allow the teachers to recognize he examples of TRIZ fundamentals like contradictions, standard solutions, etc.within their own subjects t

As a result, the teachers will feel more comfortable with "new" subjects and a bigger set of examples will be available for the students to understand TRIZ concepts. Eventually, the applicability of TRIZ instruments in different contexts and disciplines will appear more evident.

STRUCTURE OF TETRIS BODY OF KNOWLEGDE

In order to follow the directions of the educational model, i.e. building educational materials as bricks to be combined and adapted according to each specific situation, the authors have defined a common structure for each item of the Body of Knowledge according to the table presented in figure 2. More precisely, Knowledge items are organized in "cells", belonging to a sort of three-dimensional space, classified according to three main reference axes:

- different levels of detail (vertical axis): topics, sub-topics, sub-sub-topics…;
- different types of content (horizontal axis): title, definitions (glossary), theory, instruments (practical directions about how to use the related tools), multimedia, examples, self-assessment resources, references to literature;
- variants of the training contents (3rd dimension of the grey part of the table): mainly examples and self-assessment materials, but sometimes also tools explanations can be presented in different forms in order to leave a wider choice to the teachers.

variants

ID	Title	Definition (Glossary)	Theory (Details)	Tool (How to use)	Multimedia Animation	Example (Problem/Solution)	Self Assessment (Questions, Tasks)	References
0	TRIZ							
…								
2	Fundamentals of TRIZ							
2.1	Laws of Engineering System Evolution							
2.1.1	Law of completeness of system parts							
2.1.2	Law of "energy conductivity" of a system							
2.1.3	…							

Figure 2: Structure of the TETRIS Body of Knowledge and classification of Knowledge items.

Such a cellular structure of the TETRIS Body of Knowledge will allow the construction of customized educational kits for each specific school/training course according to the age and the background of the participants, the duration and the goals of the course, their attitude and experience with TRIZ teaching etc.

It is necessary to note that in order to attract also young students to the acquisition of TRIZ fundamentals, several knowledge items will be illustrated by animations. Moreover, it is expected that a visual representation of TRIZ concepts will improve their acquisition. Some exemplary previews of these animations are shown in figure 3.

Figure 3: Exemplary previews of the animations developed within the TETRIS project with the aim of attract the interest of the students and to speed up the assimilation process by visual elements.

In order to proceed with a harmonized set of contents, the first step has been the definition of an index and a glossary of the contents. Such a set of contents has been shaped in the form of a network, which is the only structure capable to represent the complexity of TRIZ knowledge elements (figure 4). The network still keeps the information related to the content classification of figure 2.

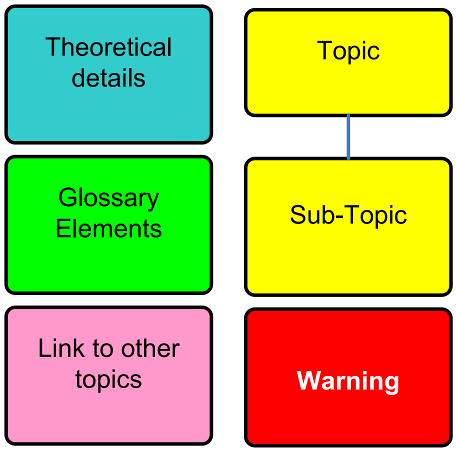


Figure 4: Elements for network representation of the TETRIS Body of Knowledge.

An excerpt of the index of the TETRIS Body of Knowledge related to the system of Standard Solutions is shown in figures 5a, b.

According to the availability of time resources multiple variants of tools explanations, examples, self assessment exercises will be developed in the second year of the project.

As stated above, in order to facilitate the role of teachers at school, their training is organized so that they develop examples of each TRIZ concept within their own subject/field of expertise. The development of these examples will not only help them check their own comprehension but will help the dissemination of TRIZ concepts at school

Among several original educational choices made in the definition of the TETRIS Body of Knowledge, the most relevant certainly is the introduction of ARIZ since the very preliminary lectures/sessions: while ARIZ is usually considered as “too complicated for beginners”, “not necessary because just a small percentage of real problems need to be approached by ARIZ” etc., the authors have focused their attention on the development of a learning process so that ARIZ concepts can be taught also to TRIZ newcomers.

The rationale for this decision is that ARIZ way of thinking underlies all instruments of Classical TRIZ: even basic knowledge of ARIZ helps people use those instruments more efficiently. Moreover, such a choice reflects also Altshuller’s recommendations on preparation of TRIZ teachers [3]. According to Altshuller, the main goal of teaching TRIZ should be the development of the ARIZ way of thinking when facing a problem situation. Although it might be less known by non-Russian speakers, this is also the ultimate goal of ARIZ itself: the underlying but important function of ARIZ is to develop the skills and dispositions for solving inventive problems..

Of course, within this first two-year project, just some steps of the algorithm will be treated in details; similarly, a subset of Standard Solution will be included in the first release of the TETRIS Body of Knowledge.

FUTURE DEVELOPMENT

All the project documentation and training materials will be published on the project web site freely accessible in five languages: English, French, German, Italian, and Latvian.

The usage of the education material will be totally free just by quoting the authors, the TETRIS project and the

Lifelong Learning Programme. Under the same conditions they could be translated to any other languages. This will allow dissemination and exploitation of the project results also in countries different from those originally involved in the project and give the project a wider European if not world wide dimension.

In 2009, the TETRIS educational tool kit will be used and tested by the three schools involved in the project in three different countries (Austria, Italy and Latvia) and by several companies in three countries (Austria, Germany and Italy).

Moreover a further training course for secondary school teachers is already planned in Friuli Venezia Giulia (Italy) on the basis of an agreement with the Regional Office of the Italian Ministry of Education. By the end of the project about 70 teachers will be trained.

In the following years TETRIS partners will continue to train teachers and those already trained will keep teaching TRIZ at school.

It is expected that the training activities that will be organised by TETRIS partners in the coming 5 years following the end of the project will involve about 750 people.

Therefore the ambitious goal of the TETRIS consortium is to disseminate TRIZ fundamentals to about 10.000 students by the end of 2013.

ACKNOWLEDGMENTS

The authors would like to thank colleagues and partners of the TETRIS project for their contribution to the development of the present research.

REFERENCES

[1] Longworth N.: Making Lifelong Learning Work. Routledge; 1st edition, ISBN 978-0749427276, 1999.

[2] Khomenko N.N., Sokol A. New model and Methodology for teaching OTSM-TRIZ.– Proceedings of the annual TRIZ Conference of the Altshuller Institute – TRIZCON 2000.

[3] Altshuller G. S., Vertkin I.: Information on Teaching TRIZ (in Russian), 1988, translation in English available on the ETRIA web site: http://www.etria.net/GSA_For_Students.pdf

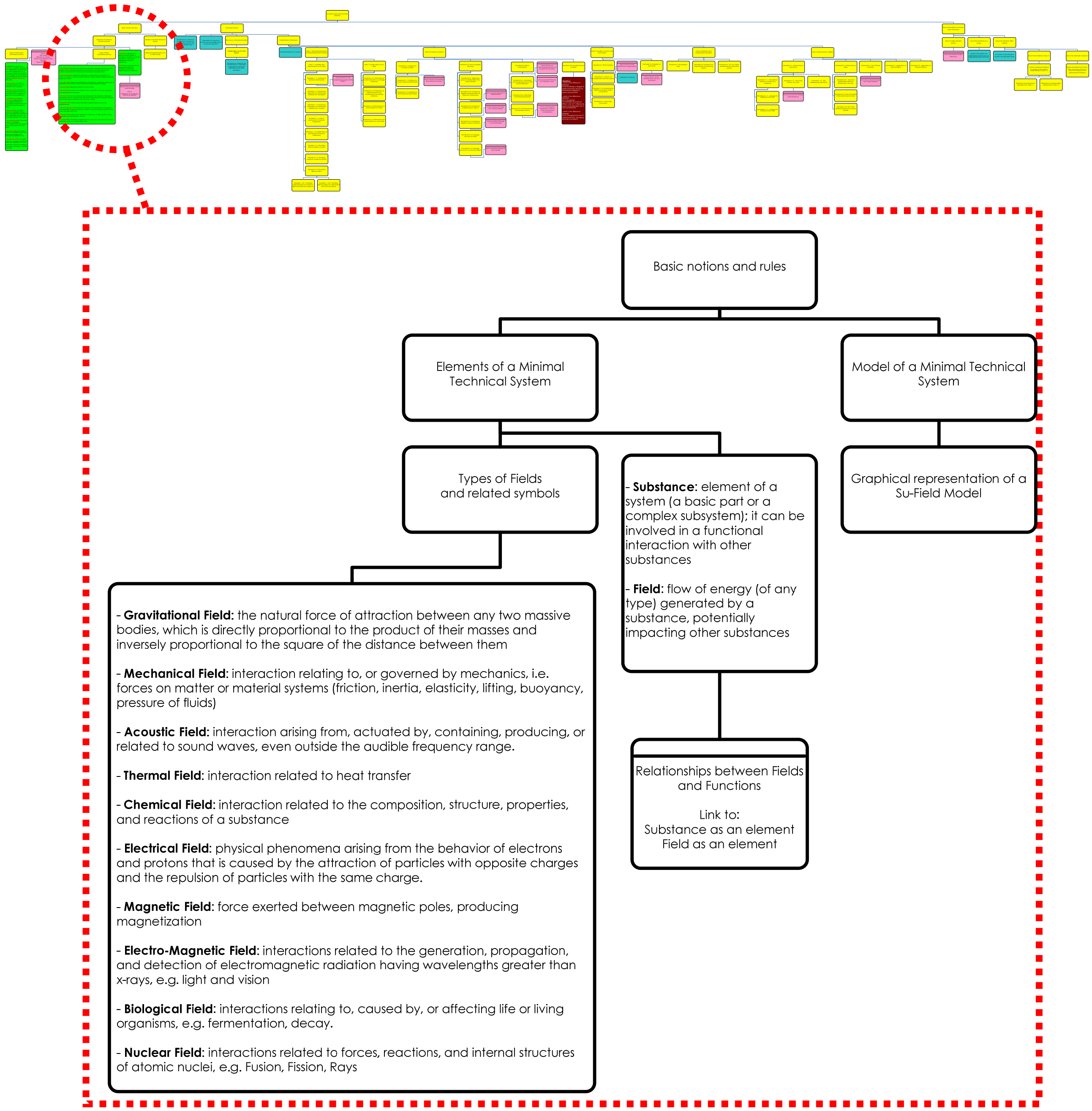


Figure 5a – Network structure of TETRIS Body of Knowledge items (here limited to the System of Standard Solutions) and exemplary detail.

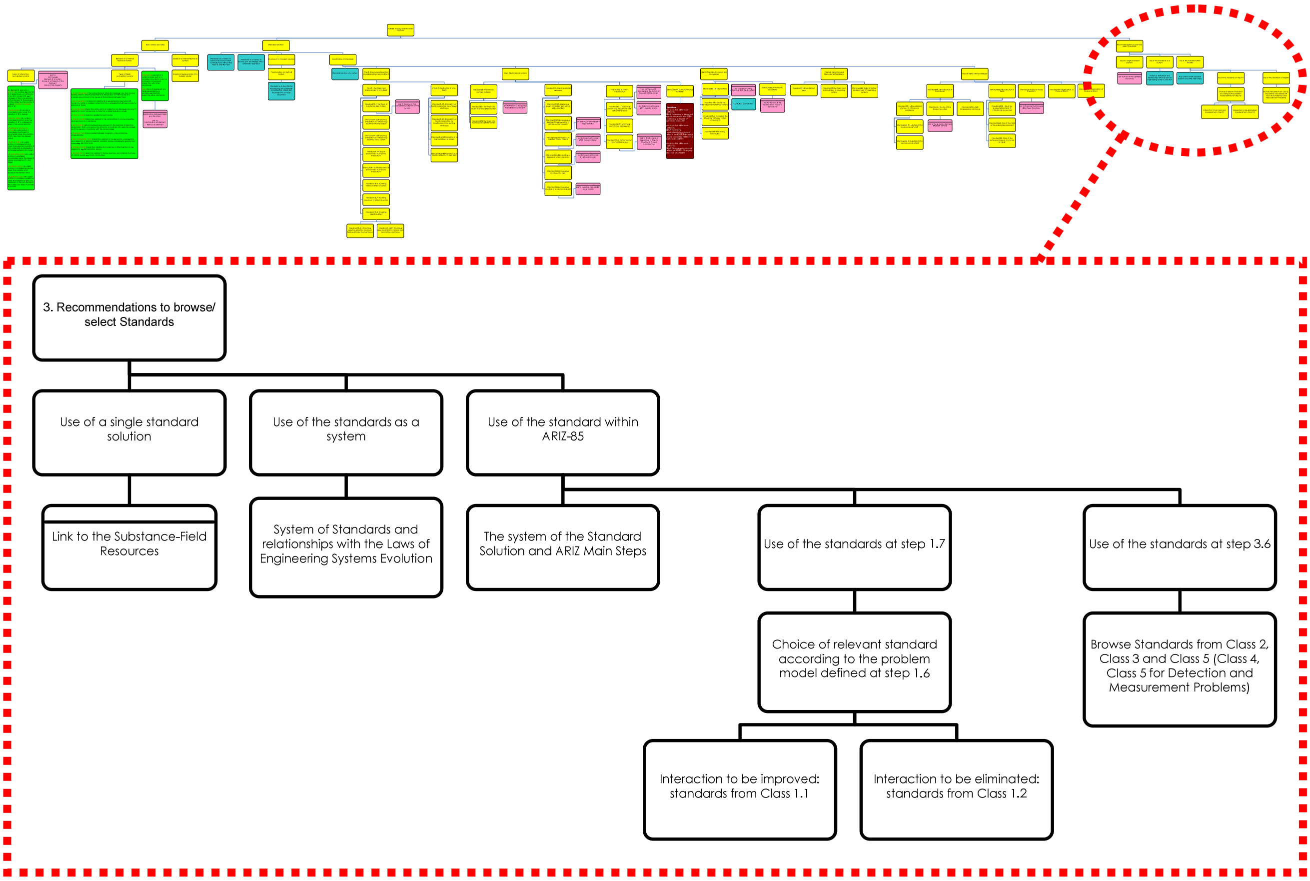


Figure 5b – Network structure of TETRIS Body of Knowledge items (here limited to the System of Standard Solutions) and exemplary detail.

Simplicity in TRIZ related Innovation Methodology -Implementation of 4 Novelties

Simon Dewulf, Vincent Theeten, Bernard Lahousse
CREAX

Abstract

1. Distillation of consumer data out of patents

Patents describe solutions to problems. A large part of the problems are consumer problems (as opposed to production problems). Whatever the quality of solution, the problems are well described. For domains where consumer research is challenging (B2B) patents offer a new source of consumer problem mining. Over time; patents reveal its trend in problems or its evolution.

2. TRIZ states to look outside, where?

One of the foundations of TRIZ is to look across domains for existing solutions. The paper proposes a method to generate a series of domains that are related to the subject at study. Once the 'DNA' of a domain, product or process is identified, an automated algorithm generates a series of 'family' domains.

3. Out of the box in time and space

Generation of the TRIZ 9 windows based on patent data largely automates the charting out of all elements in time and space.

4. What's being changed, what's being gained

Based on the analysis of patent domains generic changes (increase, decrease, stabilize) are detected over time. The research identifies trends in technology variables i.e. properties or functions at study.

Keywords

consumer data, patent analysis, inspiration, TRIZ, computer aided innovation, trend detection

1 DISTILLATION OF CONSUMER DATA OUT OF PATENTS

1.1 Introduction

Patents describe solutions to problems. A large part of the problems described are consumer problems (as opposed to production problems). This part of the paper proposes an approach to effectively extract the problems that have been solved in a specific domain. The algorithm can be used to chart out the evolution of problems over time.

1.2 Extracting problems from text

The algorithm relies on the following logical steps to produce its output;

- In a first step the text is preprocessed in order to optimize the quality of linguistic analysis. This includes normalizing certain patent specific constructs (i.e. "PROBLEM TO BE SOLVED:" or "PROBLEM") into English sentences as well as more generic cleaning steps (i.e. fixing punctuation).
- In a second step the text is run through a tokenizer and an English Part-of-Speech (POS) tagger, a process similar to the process described in [4] [5].
- In the last step the algorithm uses a pattern matching technique to find constructions which indicate a problem. Table 1 shows a list of typical problem patterns to extract.

The **problem to be solved is** peeling of the adhesive layer.
The product may additionally contain xylitol **to prevent viscosity problems**
This **has problems of a long curing time** , poor adhesion when swollen with water , …
…gives real solutions to **the problems posed by** the identification of hydrocarbon production wells.
It is intended to enhance the efficiency of tire production through preventing of inflow of defective green tire moldings…

Table 1: Typical problem patterns

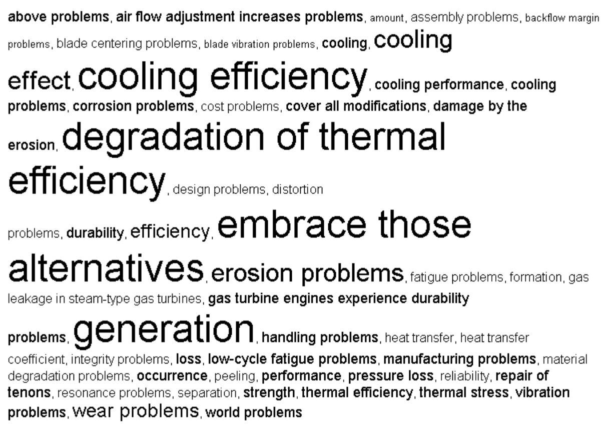


Figure 1: Problems in the domain of Fan Blades

Applying this algorithm to all patents related to a certain domain, and relating the problems found to the issue date of the patent, an easy to interpret graph depicting the evolution of the problems over time can be constructed. Figure 2 shows the results for the domain of fan blades.

Figure 2: Evolution over time of problems in Fan Blades

2 TRIZ STATES TO LOOK OUTSIDE, WHERE?

2.1 Introduction

A first logical step is to define the DNA of the current system. In an earlier paper [2], a method was proposed for automated extraction of the DNA of a system using linguistic analysis on a patent pool.

2.2 Finding related domains via the systems DNA

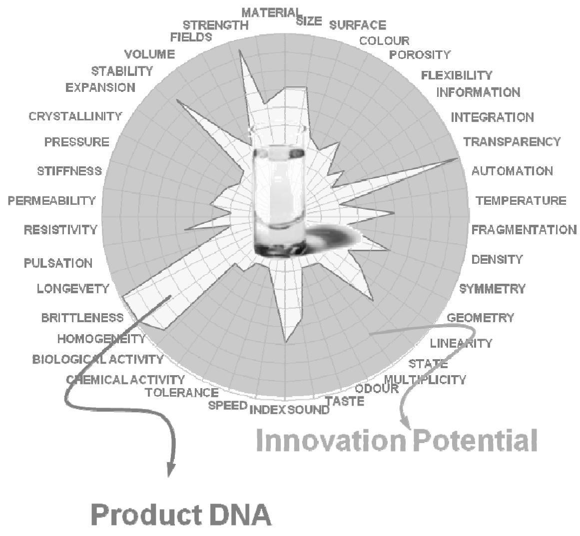
There are multiple ways to find domains that are related to the DNA of the original system. In this approach we limit the family-link to 2 types of relations; (1) on the basis of properties – what the system is and (2) on the basis of functions – what the system does.

For example; finding related domains through properties DNA-link involves iterations over the following steps;

- Define a system A with set properties P, e.g. system Window with properties Brittle, Transparent, Flat, Insulating.
- Make all possible combinations of the specified properties P and order them by percentage DNA match (see table 2) There are 2^N-1 possible combinations of the properties (N=number of properties).
- For each set of properties, use patent classification codes to calculate the closest system B with less than threshold T overlap with system A.

Brittle – Transparent – Flat – Insulating	100%
Brittle – Transparent – Flat – ~~Insulating~~	75%
Brittle – Transparent – ~~Flat~~ – Insulating	75%
Brittle – ~~Transparent~~ – Flat – Insulating	75%
~~Brittle~~ – Transparent – Flat – Insulating	75%
Brittle – Transparent – ~~Flat~~ – ~~Insulating~~	50%
Brittle – ~~Transparent~~ – ~~Flat~~ – Insulating	50%
~~Brittle~~ – ~~Transparent~~ – Flat – Insulating	50%
Brittle – ~~Transparent~~ – Flat – ~~Insulating~~	50%
Brittle – ~~Transparent~~ – ~~Flat~~ – Insulating	50%
~~Brittle~~ – Transparent – Flat – ~~Insulating~~	50%
~~Brittle~~ – Transparent – ~~Flat~~ – Insulating	50%
~~Brittle~~ – ~~Transparent~~ – Flat – Insulating	50%
~~Brittle~~ – ~~Transparent~~ – ~~Flat~~ – Insulating	25%
~~Brittle~~ – ~~Transparent~~ – Flat – ~~Insulating~~	25%
~~Brittle~~ – Transparent – ~~Flat~~ – ~~Insulating~~	25%
Brittle – ~~Transparent~~ – ~~Flat~~ – ~~Insulating~~	25%

Table 2: Example of property permutations



The algorithm allows the identification of similar systems, and discovery of the properties associating or differentiating these systems, which in turn enables detecting possible directed knowledge transfers between these systems.

3 OUT OF THE BOX IN TIME AND SPACE

3.1 Introduction

The TRIZ System Operator or more commonly, the 9 Windows tool, guides users to think in time and space.

3.2 Building the 9 Windows visualization

The algorithm for automated building of a 9-windows visualization consists of a combination of 2 distinct information retrieval steps. The first being the identification of "part→part-of" relations amongst selected phrases. The second step being the extraction of the time-aspect for each of the phrases. All output is presented using a combination of noun phrases and/or adjectives depending on available space for the visualization.

- Part→Part-of relations

Several ways of detecting "part→part-of" relations exist. A first generic way is by using thesauri (for example Princeton WordNet) to retrieve terms based on holonymy or meronymy. Other research by Cascini [1] presents algorithms to analyze patent texts revealing the invention's components, architecture, and positional and functional interrelations, and which can be used as an aid in identifying the TRIZ contradictions solved.

- Time relation

In a similar fashion to research by He and Loh [3], which describes the use of descriptive text information for extraction of TRIZ principles, this research proposes a way of discovering time-relation by using prefixes (or suffixes) usually derived from Greek or Latin. These prefixes are very common in English and are typically expressed as "bound morphemes" that must be attached to another word, generally a verb.

Before	After
Pre-compression Prepackaged Pretreatment Anti-corrosion Antidiffusion	Post-processing Post-extraction Decompress Restore

Table 3: Examples of time-related prefixes

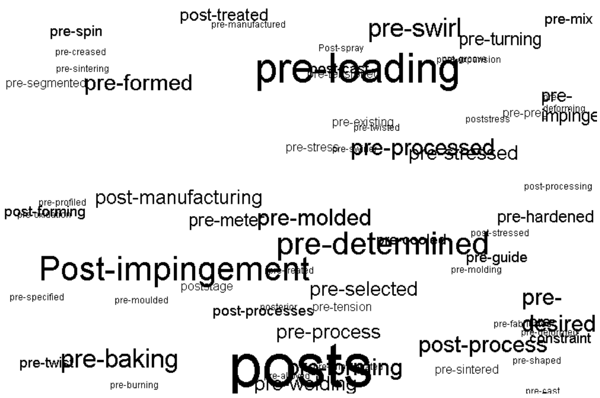


Figure 3: Time-related phrases

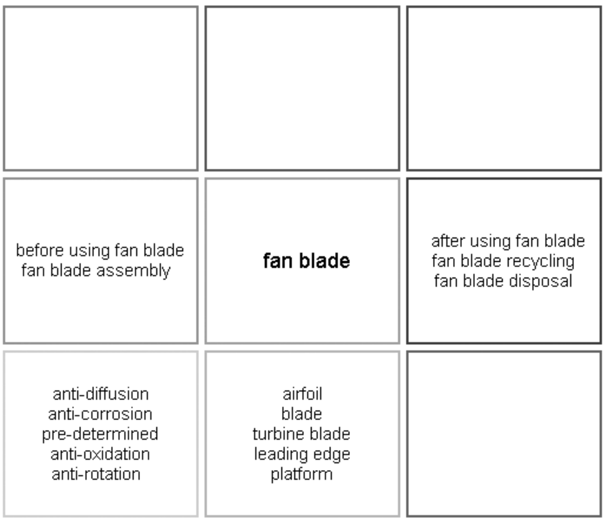


Figure 4: Example 9 Windows visualization
Fan Blades

4 WHAT'S BEING CHANGED, WHAT'S BEING GAINED

4.1 Introduction

An effective way to gain insights into the evolutions in a certain domain is to track its changes. We propose a way of tracking changes using linguistic analysis with modifiers. English modifiers include: increase, improve, enhance, etc.

We have divided the most common English modifiers in 3 distinct groups; (1) increasing, (2) decreasing and (3) changing or stabilizing.

A further level of syntactic classification that can be added is to divide the modifiers by type, either qualitatively or quantitatively.

For the detection of the subject of the modifier, what is being changed, we apply a combination of Part Of Speech tagging and pattern matching. In this method we specifically parse text to match either of these constructs:

Present – active	*The controlled heat **increases the flow of air**…*
Present – passive	*…a primer layer may be used to **increase adhesion** of the outer layer.*
Past participle	*...high vinyl acetate content may result in **increased interaction** with ...*
Post modifier format	*There are a number of suitable **viscosity increasing agents** available…*

Table 4: Linguistic constructs for matching modifiers

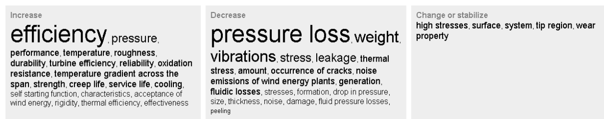


Table 5: What is being changed in the domain of Fan Blades

5 SUMMARY

Patents form an important source of consumer data. The problem descriptions in patents are unrelated to the quality of solutions. The data contains consumer problems, production problems and a variation in time.

TRIZ promotes to look outside one's domain, but where? By creating a Product DNA, i.e. the defining set of properties and functions, family (other domains with similar properties or functions) can be identified in order of % similarities. The domains are thereby source of inspiration, having faced similar challenges in the past.

9-windows stays a most powerful tool out of the TRIZ toolbox. It is a structured way to think outside of the box in time and space. People are biased; computers are neutral and access much more data. Artificially filling the content of the boxes is a useful sample of computer aided creativity.

Finally, properties are variables, their value can be decreased, increased or stabilized. By filtering a domain's variables, their importance and direction, a visualization is made of what the domain is doing, what is changed, and what is gained.

6 REFERENCES

[1] WO03077154 Cascini G. "System and method for performing functional analyses making use of a plurality of inputs"; 2003.

[2] Dewulf S., "Directed Variation of Properties for New or Improved Function – ProductDNA, a Base For Connect and Develop" TRIZ Future 2006 Proceedings

[3] He, C., & Loh, H. T., 2005, Similarity between TRIZ Principles. The TRIZ Journal, September Issue.

[4] Verhaegen, P.A., D'hondt, J., Vertommen, J., Dewulf, S., Duflou, J. R., 2008, Searching for Similar through Patent Analysis, ETRIA TRIZ Future Conference 2008, Twente.

[5] Tseng, Y.-H., Lin, C.-J., Lin Y.-I., 2007, Text mining techniques for patent analysis, Information Processing and Management: an International Journal, 43/5: 1216-1247.

Strengthening the 40 Inventive Principles

Ives De Saeger[1], Eddy Claeys[1]
[1]P41 Partners In Process Innovation, Belgium

Abstract

This article consists of 2 parts. The first part investigates the formulation of the 40 Inventive Principles, one of the classic TRIZ tools. We compare the 40 Inventive Principles from different TRIZ sources in English as described in books or software and point out the differences such as incompleteness of some principles, different words used in the translation to English etc. The second part consists of suggestions to read the 40 Inventive Principles in a different way. First an investigation is made of different approaches to get a more forward use trying to make the principles as less abstract as some of them are without fundamentally changing the 40 IP. We aim to simplify the application and strength of the 40 Inventive Principles by splitting them up into a resources part and recommendation part. Since language triggers thoughts, different meanings can create different interpretations. In order to get a more uniform language we suggest revised 40 Inventive Principles where the used terms are in accordance to a systemic view. Finally the split up is applied to an example.

Keywords

40 principles, resources, recommendation, operator

1 INTRODUCTION

The contradiction matrix is probably the most widely known tool in TRIZ. This link http://www.triz40.com/ contains the translated 'Altshullerian' matrix as a link that automatically gives you the different Inventive Principles.

Although Altshuller stated to have wasted a lot of time [1] on the contradiction matrix and some remarks were made to the 40 Inventive Principles [2] concerning overlap and the level of abstractness, the 40 principles still inspire many new starting TRIZ students.

Off course more modern tools were developed such as the Inventive Standards and ARIZ as an algorithm of inventive problem solving.

Some work on rearranging the principles has been done by Darrell Mann. The 40 Inventive Principles were rearranged to get the new overview [3], the matrix was fully reworked in 2003 [4] where several new combined Principles where added as also the number of parameters changed from 39 to 47. An interesting feature added in the new Matrix 2003 is a linear link between parameters and advised Inventive Principles.

2 COMPARING THE 40 INVENTIVE PRINCIPLES

On the consistency of the 40 Inventive Principles Todd & Domb [5] describe possible symmetries. When looking for text similarity between an IP and patents some obscure Inventive Principles were defined in [6]. The Inventive Principles were also grouped into a 5x3 matrix by space-time-interface entities in [3].

This article compares the Inventive Principles in different English TRIZ sources. Most of the Inventive Principles have subdivisions usually noted with a capital letter.

We will use the abbreviation "IPS" for Inventive Principle Subdivision.

The sources are:

A. H. Altshuller Forty Principles, Translated by Lev Shulyak. Technical Innovation Centre, Worcester MA., 1998 [12]
B. Invention Machine Co. Techoptimiser 3.0
C. Ideation Innovation Workbench, version 2.8.0
D. Darrell Mann, Hands on Innovation 2002 [3].
E. Ellen Domb (version 1997, 40 principles with examples) [14]

where A was logically chosen as a reference. Source A has 98 IPS

Although other sources could have been compared, we only wanted a limited number of sources and the list was chosen at random including of course Lev Shulyak version. Different comparisons on information, used words and meaning, technology and defined starting conditions, have been made within the different sources.

2.1 Regarding the information sources

7 IPS have been added to the reference (6,5 %)

43 IPS have additional information (40,2 %)

3 IPS are not mentioned by the others, id. completely left out (2,8 %)

3 other IPS are not mentioned by all the other sources (2,8 %)

An example is found in comparing principle 39. (see table 1). In total there are 107 IPS

IP	A	B	C	D	E
39	A. Replace the normal environ ment with an inert one	A Replace a normal environ ment with an inert one,	A. Replace the normal environ ment with an inert one	A. Replace a normal environ ment with an inert one.	A. Replace a normal environ ment with an inert one.
	B. Introduc e a neutral substanc e or additives into an object	B• add neutral parts, or inert additives to an object.		B. Add neutral parts, or inert elements to an object or system.	B. Add neutral parts, or inert additives to an object.
	C. Carry out a process in a vacuum		B. Carry out the process in a vacuum		

Table 1: Differences in information.

2.2 Regarding word & meaning

39 IPS within the same Principle use different words eg. Object ≈system≈ structure ≈environment; stationary ≈fixed, …(36,4 %)

28 IPS within the same Principle use different meanings eg separate≈ single out, consolidate≈combine≈make (26,2 %)

An example is given in IP nr 1 (see table 2). Off course it should be stated that due to translations and probably the use of different dictionaries will explain the different meanings found. We could not trace which dictionaries the different sources used to translate.

IP	A	B	C	D	E
1	A. Divide an object into independ ent parts	A divide an object into independ ent parts	A. Divide an object into independ ent parts	A. Divide a system into separate parts or sections.	A. Divide an object into independ ent parts.
	B. Make an object sectional (for easy assembl y and disasse mbly)	B make an object easy to disasse mble	B. Make an object sectional	B. Make a system easy to disasse mble and reassem ble.	B. Make an object easy to disasse mble.
	C. Increase the degree of an object's segment ation	C increase the degree of fragment ation (or segment ation) of an object	C. Increase the degree of an object's segment ation	C. Increase the amount of segment ation.	C. Increase the degree of fragment ation or segment ation

Table 2: Differences in meaning.

2.3 Regarding technology - undefined solution

We use “Technology” when a technical solution is proposed in the IPS. With “Undefined solution” we mean that no technical solution or the means to perform the solution has been proposed. For instance, if you have to divide a system into independent subsystems the only question that remains will be how to perform the division. What specific method will you use to divide the system? A principle is called “Undefined solution” if it is not clear which technology is used to divide the system. Some principles however suggest what to do and what technology to use. For instance nr 14B “Use rollers, balls, spirals, domes” and nr 18 “Use piezoelectric vibrators instead of mechanical ones. Yet we found most of the principles to stay on the abstract level on how to do it. 19 IPS can be considered as having a clear technology described (17,8 %), 88 IPS are abstract (82,3 %). Here we come to the conclusion that some degree of abstract thinking is required to use the Inventive Principles. It is left to the user to try to apply the abstract Principle to a given problem.

2.4 Regarding description starting condition –or only end condition

Some Inventive Principles describe the starting condition. For instance Principle 39a. “Replace the normal environment with an inert one” or 29 “Replace solid parts of an object with a gas or liquid. These parts can now use air or water for inflation, or use pneumatic or hydrostatic cushions.” These examples indicate that the starting condition is defined. In the first case it is called a ‘normal’ environment. The second solids are the starting condition. 66 IPS have only a formulated ‘end condition’ (61,7 %), 31 IPS contain an initial condition (38,3 %). We conclude that the 5 sources can be considered as “3” versions: A and C are very similar such as B and E and D is different from the 2 former.

3 SOME LIMITS OF THE INVENTIVE PRINCIPLES

As soon as the technique is applied the user is ‘trapped’ to see only 2 conflicting parameters limiting the user to use both at its maximum (technical contradiction). Or one conflicting parameter where extremes are needed (physical contradiction). The general idea of an Inventive Principle should be that the user recognises a new direction to solve a conflict. The Inventive Principles should act as a ‘click’ enhancer stimulating the different possibilities in which to overcome the at-the-moment only unsolvable problem. A common way is to make the Inventive Principles less abstract is clarifying it with pictures, movies & examples. Many papers have appeared with examples clarifying what is meant with the Inventive Principle applied in a certain domain. An extended list can be found in the TRIZ Journal (www-triz-journal.com). The lack of knowledge in a specific scientific area however can hinder you to find a solution so we expect that many of the possible solutions are missed. The same is the case with differences in the understanding of the meaning of the words and the ability to think with abstract explanations. As soon as a possible new direction has been found the road towards the implementation can be a ‘problem’ too. It is what Goldratt [15] calls the Transition Tree, which is going from the Current to the Future Reality Tree. The solution can be clear but the changes needed to implement this solution can form another obstacle. The Inventive Principles lack implementation solutions on this part.

4 STRENGTHENING THE INVENTIVE PRINCIPLES

One other way we found useful is to view the 40 IP as resources for a certain problem. Most of the inventive principles could be seen to include a hint of what you should look for and how you should solve it. The part of the Inventive Principle that contains the way to solve it is the recommendation. A practical example will be given in the next paragraph. In this sense we split the 40 IP up into a resources part and a recommendation part.
From our point of view we also wanted to use uniform language. To split the 40 IP up into a recommendation and a resource part could be seen separate from trying to make a more uniform language in the 40 IP. For this reason the following example will not explicitly use the uniform language. For this reason we changed different words in our view to a more uniform word usage for many inventive principles. Some notion of care should be pointed out to the fact that this will include another interpretation of the IP. The fact that these changes give better results only come from the fact that we tested this out in a classroom setting, further experiments and comparison between the traditional matrix and the revised one could lead to proof that the revised matrix is easier and more direct to use.
We replaced 'objects' with "systems". A system is a broader term; it can be one object or several objects. Every problem needs a clear definition of what 'the system' is and where and when the problem is situated (operational zone and time). Of course this should be done by the user in advance.
We replaced the word 'Parts' with "subsystems". A subsystem is a part of the system. The words "Environment" and "surrounding" are changed with "Super Systems". A super system is everything that is not part of the system, but that could affect the system and thus has an interaction with the system.
The words "actions" and "operations" we changed with "processes". A process changes the state in which a systems is to another state e.g. it changes the attributes/properties of a object.
The words "Parameters" and "Characteristic" are changed into "properties".
A "factor" is a "function" or "property".
We also renamed the principles into a verb with or without an adjective. This gives a more active meaning, a forward use to the principles. The complete list can be found at www.p41.be.

5 EXAMPLE

Sometimes it is hard to define a contradiction. This source contains [7] a help to formulate the contractions. Recently V. Souckov [11] defined a sharper way to formulate the contradictions.

As an example of a contradiction we use the one formulated by Rantanen & Domb in Simplified TRIZ [13].

In 1994 the ship Estonia sank resulting in 852 deaths. After an analysis the conclusion was that a locking mechanism had failed. The simplified locking mechanism is shown in figure 1. We will not go into the contradiction formulation itself (which can be read in [13]) but start from the contradiction . The technical contradiction is between the reliability of the lock versus the ease to open en close the lock..

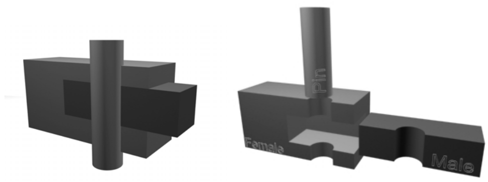
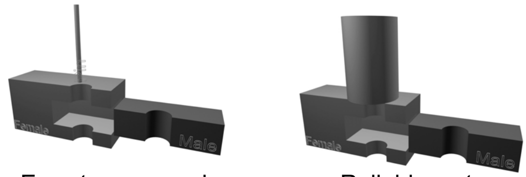


Figure 1: Example of lock open en closed.

Pin is thin	Pin is thick



Easy to open and close yet unreliable	Reliable yet Difficult to open and close

Figure 2: Technical and physical contradiction.

To solve the contradiction TRIZ suggests to use the following Inventive Principles:
17 other dimension
14 Curvature
15 Dynamization
10 Preliminary action

Inventive Principle 17 suggests:
1. If an object moves in a straight line, consider use of dimensions or movement outside the line
2. If an object contains or moves in a plane, consider use of dimensions or movement outside the current plane
3. Use a stacking arrangement of objects instead of a single level arrangement
4. Re-orient the object or system, lay it on its side
5. Use 'another side' of a given object or system

The 5 IPS's from IP17 contain a clue. The clues are formulated through the words plane, moving, dimensions, single level arrangement. Looking at the drawing we can define all the planes, sides, movement.
- There are 56 sides (pin, female male)
- There are 2 linear moves
- There are 28 planes

Beside the clues, IP 17 suggests what to do (operators)
1. If an object moves in a straight line consider use of dimensions or movement outside the line

So one example is to curve the 'line' of the male (Figure 3).

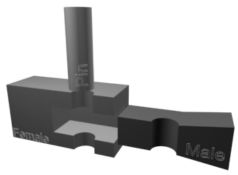


Figure 3: Curved male.

The next step is to adapt the whole design to deliver its function (Figure 4). This means that we need to change the female in opposite form. But this step is clearly a next thing to do after applying the recommendation of the Inventive Principle.

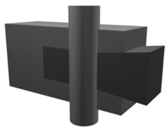


Figure 4: Impact of curved male on total design.

Other possibilities to change the line or movement of the subsystems are (Figure 5; not complete).

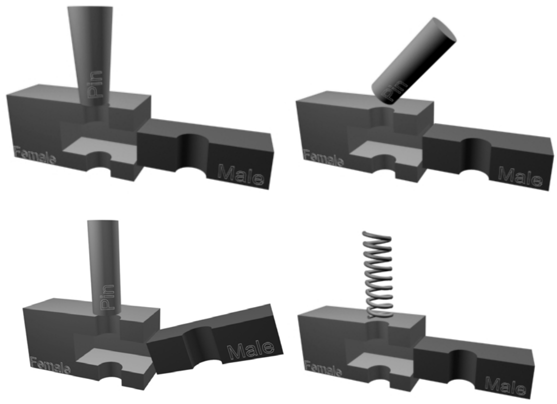


Figure 5: 4 different solutions of movement change and curves.

2. If an object contains or moves in a plane
   - (fe)male moves in a plane

consider use of dimensions or movement outside the current plane (Figure 6)

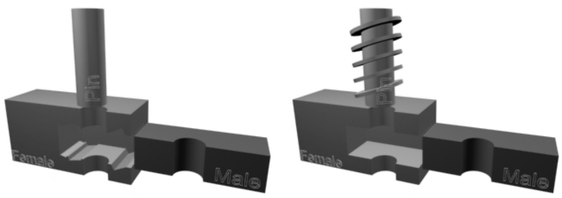


Figure 6: 2 different solutions plane change.

3. Use a stacking arrangement of objects instead a single level arrangement

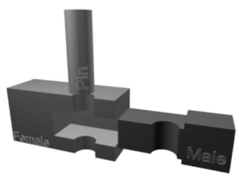


Figure 7: Stacking arrangement.

4. Re-orient the object or system, lay it on its side

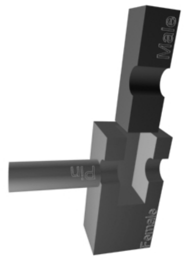


Figure 8: Reoriented lock.

This last solution is a strange one. The final drawing cannot be completed without knowledge of the super system.

5. Use 'another side' of a given object or system

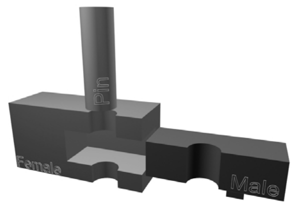
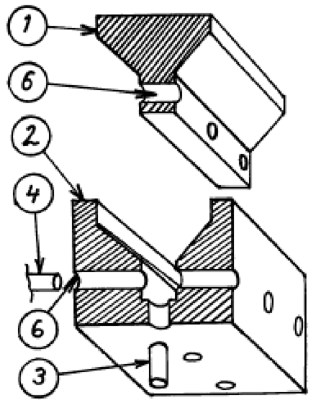


Figure 9: Key concept.

This solution (Figure 9) leads to a key concept



.

Figure 10: Solution from US patent 5.875.658 25/9/1997 Locking mechanism for gates and hatches.

The example shows that splitting the principle up into a resource and recommendation part; the user can come to a step by step approach for finding the solutions.

If we take this further and rename the words as described to a more uniform manner the principle 17 could read something like:.

Principle 17. Use another dimension
Resources: Define all sides, directions of the system. Define distances (x,y,z) and angles (α, β ,γ). Define all planes. Define the arrangement with other systems.
Operate to:

A. Change a system from one to two- or three-dimensional space.
B. Use a multi-story arrangement of systems instead of a single-story arrangement.
C. Tilt or re-orient the position system, lay it on its side.
D. Use 'another side' of the system.

6 SUMMARY.

The comparison of the 40 Inventive Principles from different TRIZ sources in English as described in books or software results in minor differences such as incompleteness of some principles, different words used in the translation to English probably due to the use of different dictionaries etc. Technical solutions are hardly given so the Principles can be considered abstract.

A different approach to get a more forward use has been made trying to make the principles as less abstract as some of them are without fundamentally changing the 40 IP. The change has is on the level of words and organisation splitting it up in a resources part and a recommendation part. Finally the split up is applied to an example.

REFERENCES

[1] Khomenko N., Ashiani M. "Classical TRIZ and OTSM as a scientific theoretical background for non-typical problem solving instruments", TRIZ future 2007, p73-80.

[2] Mann D. ,"Evolving the IP", TRIZ Journal 2002, August.

[3] Mann D."Hands on Innovation", CREAX Press, 2002, 464 pages. ISBN: 4-902716-00-3.

[4] Mann D., Zlotin B., Zusman A., DeWulf S., "Matrix 2003: Updating the Contradiction Matrix", CREAX Press, ISBN 90-77071-04-0.

[5] Todd W. , Domb E., "Reversibility of the 40 Principles of Problem Solving", TRIZ journal 1998, may issues.

[6] Cong H., Tong L.H., "Similarity between TRIZ Principles", TRIZ Journal 2005, September.

[7] Altshuller G. "Forty Principles", Translated by Lev Shulyak. Technical Innovation Centre, Worcester MA., 1998 ISBN-10: 0964074036.

[8] Invention Machine Co. Techoptimiser 3.0.

[9] Ideation Innovation Workbench software, version 2.8.0.

[10] Domb E., "Contradictions", The TRIZ Journal, 1997, July.

[11] Souchkov, Hoeboer, Zutphen, "Application of RCA+ to Solve Business Problems", TRIZ journal 2007, February.

[12] Altshuller G. (Author), Dana W. Clarke (Author), Lev Shulyak (Collaborator), Leonid Lerner (Collaborator), Uri Fedoseev (Illustrator), Steve Rodman (Translator) "40 Principles: TRIZ Keys to Innovation [Extended Edition]", (Paperback), ISBN-10: 0964074052.

[13] Rantanen K., Domb E;, "Simplified TRIZ", CRC, ISBN 1574443232.

[14] Tate K., Domb E., TRIZ Journal 1997, July.

[15] Goldratt E, "Critical Chain", ISBN-10: 0884271536, 1997.

CONTACT

Ives De Saeger

P41 Partners In Process Innovation

Mevrouw Courtmansstraat 4 bus 4,

2600 Berchem, Belgium

E-mail: ids@p41.be

Phone: +32 (03) 2811886

FAX: +32 (03) 2811887

Teaching TRIZ to Beginners

Ellen Domb
PQR Group, Upland CA USA

Abstract
Many people who could benefit from the methods and concepts of TRIZ have rejected it because they were confused by the way TRIZ was taught. Expertise in the method does not necessarily make one a good teacher for beginners. Methods for adult education have been well-researched in the last 50 years, and they can be used to create a robust TRIZ teaching system that is useful in many cultures. Case study examples of application of TRIZ to the development of TRIZ training methods will be demonstrated.

Keywords
TRIZ, Teaching TRIZ, Instructional Design

1 INTRODUCTION

TRIZ has been taught in the West in various modes since the late 1980's. A common finding in both Western and former Soviet republics [1] is that a small fraction of the students become enamoured of TRIZ and pursue further study, a larger fraction become competent users of beginner-level TRIZ, and many ignore it after their initial training. Since the people doing the training are all from the small fraction of enthusiasts, and since there has been no research by outside experts on teaching and learning, progress in understanding this phenomenon has been limited. In general, the teachers of TRIZ have been the practioners of TRIZ.

Simultaneously, there have been many changes in the theory and practice of adult education, and particularly in the methods used to teach working adults new job-related skills. The speed of change is documented in Ruark's recent review [2], and the depth of change is illustrated by Anderson and Krathwohl's survey of the revisions of Bloom's taxonomy [3], which has been a cornerstone of educational theory. Rosenkrantz's interpretation [4] of the stages of the revised Bloom's taxonomy is briefly outlined in Table 1.

Level	Name	Description of student's success
1	Remembering	Retrieving, recognizing, recalling knowledge
2	Understanding	Constructing meaning, interpretation, inference, comparison, explanation
3	Applying	Using a procedure, demonstrating execution of a process, implementation
4	Analyzing	Determining how the parts of a system relate to each other and to the overall system
5	Evaluating	Making judgments based on criteria and standards
6	Creating	Putting elements together into a new pattern or structure

Table 1. Outline of the Revised Bloom's Taxonomy for Learning.

It is clear from the research on education that different methods are needed to teach the different levels of competency outlined in Table 1. A TRIZ example of a fact might be that G.S. Altshuller was the leader of the first stage of TRIZ development. This is fact, and it requires level 1 mastery—the student should know this to be considered "literate" in the field, but is not expected to use that fact to do anything else. In contrast, ARIZ is many-step process, and each process requires level 2, 3 and 4 thinking. Early on, the teacher will provide the level 5 evaluation, and the TRIZ community provides level 6, creating new methods. If the student becomes a competent professional in the field, she or he will do his own evaluation, and will become a contributor to the research and creation of new, ARIZ-based methods.

The goal of this paper is to present modern educational theory in a way that can be easily adapted to the needs of TRIZ teachers, with TRIZ examples, so that research on effective ways of teaching TRIZ can benefit from research on educational methods.

2 RESEARCH

2.1. Observation of teaching paradigms:

Many people who come into teaching as subject matter experts quickly adopt simple teaching paradigms, such as Ken Blanchard's well known 4-step system [5],[6]:

1. Tell them
2. Show them
3. Let them try
4. Give feedback

The problem with this simple system is that it was designed to help managers teach their employees, in a face-to-face, one-on-one context, where the manager/teacher knows the employee/student, and is interactive with the student throughout the process (although the "let them try" stage might take days or weeks, depending on the process being taught.) Extending it to multiple students from a variety of backgrounds in the classroom, or in non-classroom teaching environments, is not justified by the original work [5], [6]. Yet, its simplicity and structure are highly appealing, and we have observed its use in many TRIZ scenarios, such as the tutorial sessions at TRIZCON and ETRIZ TRIZ Futures meetings—sometimes the full 4 steps, and frequently only "tell them, show them" with "let them try" left for the student after class, and no method at all for giving feedback

2.2 Foundations for changing TRIZ teaching

There has been recognition in the TRIZ community that improvement in the training of TRIZ is needed. Many articles have addressed specific methods of teaching specific topics, such as Domb, Miller and Czerepinski [7], [8], and Filmore [9], and Mann [10] and numerous other papers by those authors and their colleagues.

Observation of the effectiveness of these changes is positive—students do learn specific techniques better when their instructors explain them more clearly, use better examples, or structure the lessons in a way that matches the learning style of the particular group of students. But, these are episodic changes, not systematic changes, and, although the methods have been published in widely available venues, these methods are not generally adopted by instructors other than the originators. To overcome these limitations, we are introducing standard methods of instructional design into TRIZ.

2.3 Application Of Instructional Design Discipline To TRIZ

Ruth Colvin Clark is a pioneer of the development of the instructional design methodology that is used throughout much of the industrial training world today. She is a past president of the American Society for Training and Development, and holder of multiple awards for lifetime achievement from multiple professional societies. Her book ***Developing Technical Training*** [11] is comprehensive. It is based on the same logic as the revised Bloom's Taxonomy [3], so it is usable at all levels of learning. Although it was developed for instructional design professionals, we find that TRIZ specialists with no background in instructional design are able to apply her methods. Clark lists the 4 considerations for training design and cautions that many subject matter experts focus exclusively on content, or on content and media, neglecting equal importance of all 4 issues in successful training.

- Content
- Learning Outcomes (These are the Bloom's Taxonomy levels)
- Instructional Methods (This depends in part on the medium. It ranges from simple text or lecture, structured games or simulations in classroom settings, rote practice sessions, on-line simulation, etc.)
- Media (classroom, e-learning, self-paced workbooks, and textbooks.)

These considerations must influence the designer's approach to teaching 5 kinds of information:

- Fact
- Concept
- Process
- Procedure
- Principle

We have developed a sequence of tables to make the translation from the definitions of the kinds of information through the 4 considerations to TRIZ course material relatively straightforward. See Table 2 for the definitions of the 5 kinds of information, and the differences and similarities in methods used for each type.

	Facts	Concepts	Process	Procedure	Principle
Definition	Unique information, specific data	Representation of ideas or objects with common characteristics	How "it" works. A process is composed of many procedures	Routine tasks, clearly defined steps	Strategic tasks, value-based, knowledge-based.
Sub-cate-gories	1 Concrete fact, specific object. Use Diagrams 2 Specific data. Use tables & lists 3 Statement of unique relationship between concepts. Use short labels	1Concrete 2Abstract	1 Business systems-organizational work flow. Situational (could be a procedure) 2 Technical systems 3 Scientific systems (how something works in nature)	1 Linear-same steps and outcome each time 2 Decision- steps & outcome depend on situation	
Training approach	References. Inductive learning (student abstracts from examples)	Identify new or uncommon terminology. Identify features & functions	Process knowledge can improve performance of procedures. Overview, then details.	Move quickly to application, practice, feed-back. Provide job aids, don't memorize steps. How-to	What, why, and how. Teach validated guidelines, workers develop own procedures. .
Presenta-tion	Progressive description.	Formatted information, definition, examples, non-examples, analogies, graphics	Diagrams, flow charts, simulation. Facts & concepts first, then process.	Action tables with illustrations (table version of flow charts)	Situations, stories, best practices, case studies, counter-examples, analogies (with caution)
Class-room Practice	Drill with limited tasks. Use mnem-onics Use facts in job situations. Use the job aids	Teach related concepts together.	Realistic case studies for problem solving.	Demonstrate steps of action table, then short student exercises	Application to a variety of cases.
Evalua-tion	Observation under job-like circumstances	Discrimination: can they pick an example?	Observation of exercises.	Performance test. Judge pro-duct or actions.	Application to a new situation.

Table 2: Summary of Clark's definitions and options for each of 5 types of information.

Table 3 briefly summarizes the learning objectives for each of the 5 types of information. Note the strong relationship between the teaching style and the objective. For example, when teaching the concept of physical contradiction, they student will learn to classify new contradictions successfully. Given a group of contradictions, the student can reproducibly identify the physical contradictions. The teaching method is a formatted definition, possibly with diagrams, so in the case of the physical contradiction, the emphasis would be on the two different values of the same parameter, with examples from physical, social, and business life:

- The coffee must be hot (to enjoy drinking) and cold (to avoid harm when spilled)
- The employee must work continuously (to provide customer service) and the employee must work periodically (to comply with labor laws, for good physical health, for good mental health.)
- The airplane must have wheels hanging down (to manoeuvre on the ground) and the airplane must have wheels not hanging down (to be streamlined, for minimum fuel use, for maximum speed.)
- The training course must be short and must be long.

Training course examples are from Rantanen and Domb, [12].

	Facts	Concepts	Process	Procedure	Principle
Apply	NA	Classify new examples	Solve problems Make inferences	Perform the procedure	Perform the task. Solve problems
Remember	Remember the facts	Remember the definitions	Remember the stages	Remember the steps	Remember the guidelines

Table 3: Learning objectives for each of 5 information types.

In this example, teaching the concept of physical contradiction by means of examples very quickly leads to student capability to identify the physical contradictions in a list of mixed physical contradictions, technical contradictions, and other statements. This is a necessary prerequisite to the next step of process, which is to formulate their own problem as a physical contradiction, then to the procedure of applying the separation principles to the contradiction.

The system can be used for a single situation, such as teaching the concept of physical contradiction, or it can be used for the whole sequence of facts, concepts, process, procedure and principle. Table 4 shows an example of a completed table for teaching elements and teaching methods, for classroom teaching of Ideality, for application in problem definition and problem solving.

	Facts	Concepts	Process	Procedure	Principle
Teaching elements	Actual, situational benefits, cost, harm.	What is “ideality” , the equation and relationship to “value” and cost/ benefit ratios.	How ideality fits into the overall TRIZ system, part of refining the problem definition. Structured problem / opportunity identification	3 procedures: >Equation method >Checklist >“Itself” method	IFR, and evolution to the IFR. Greater ideality = better concept
Teaching method	Show, explain, solicit class examples	Instructor presentation and examples, student examples	Explain, example, student Q&A	Show how equation, “itself” and checklist are the same. Student practice, with feedback	stories
Evalua-tion	Student Questions	Student examples	During projects, do the students use ideality and the IFR at appropriate places	During projects, do the students formulate ideality and the IFR correctly	During projects, do the students use ideality and the IFR correctly, does it enhance their understanding

Table 4: Examples of teaching elements, teaching methods, and evaluation for Ideality, based on the structure of tables 2 and 3.

3. RECOMMENDATIONS

Improvement in the teaching of TRIZ may lead to wider use of TRIZ by more people. If there is no initial barrier of training difficulty to be overcome, more than just the historically small number of TRIZ enthusiasts may get the benefits of TRIZ in their work, and their employers will get much higher return on their training investment.

One basic principle of TRIZ is that breakthroughs come from using methodologies developed outside the field where the problem occurs. [13] Using the disciplined methods of instructional design is a way of recognizing that the field of learning is different from the field of development of TRIZ methods, and that use of the extensive research work in the teaching/learning field can benefit TRIZ.

ACKNOWLEDGMENTS

Thanks to Prof. Phil Rosenkrantz for pointing out the similarities between many of the change management methods, and the fundamental role that teaching plays in change management. Thanks to Dr. Ruth Colvin Clark and her training staff, for their patience with our learning process.

REFERENCES

[1] Panel discussions, TRIZCON 2005 and ETRIA TRIZ Futures 2004. Participants included TRIZ Masters Boris Zlotin, Alla Zusman, Isaak Bukman, Sergei Ikovenko, and TRIZ consultant/instructors Ellen Domb and Larry Smith.

[2] Ruark, Benjamin. "ARDDIE: The year 2013: ARDDIE is In, ADDIE Is Out," T&D Magazine, American Society of Training and Development, July 2008.

[3] Anderson, L.W. and Krathwohl, D.R. (eds.) A taxonomy for learning, teaching, and assessing: A revision of Bloom's Taxonomy of educational objectives. NY: Longman Press. 2001.

[4] Rosenkrantz, P. Professor of Industrial Engineering, California Polytechnic University, Pomona California. Unpublished manuscript, used by permission. 2008. Rosenkrantz@csupomona.edu

[5] Blanchard, K.H., and Johnson, S. The One Minute Manager. NY: William Morrow, 1982.

[6] Blanchard, K.H.; Zigarmi, P.; Zigarmi, D. Leadership and the One Minute Manager: Increasing Effectiveness Through Situational Leadership. NY: William Morrow, 1999.

[7] Domb, E. and Miller, J. "Complete Technical System Generates Problem Definitions," TRIZ Journal, December 2007.

[8] Domb, E.; Miller, J.; "Czerepinski, R. Case Study: Pizza and the System Operator for Teaching." TRIZ Journal, March 2008.

[9] Filmore, P. "Key to Teaching TRIZ: Breaking Mindsets," TRIZ Journal, February 2008

[10] Mann, D. "The Problem With ARIZ And Other Innovation Processes," TRIZ Journal, December 2007.

[11] Clark, R.C. Developing Technical Training, 3d edition. NY:John Wiley & Sons, 2008.

[12] Rantanen, K. and Domb, E. Simplified TRIZ. 2nd edition. Boca Raton: CRC Press. 2007.

[13] Altshuller, G.S. Creativity as an Exact Science. Translated by Anthony Williams. NY. Gordon & Breach Science Publishers, 1988.

CONTACT

To be supplied by Ellen Domb

TRIZ-ARIZ in transformer-type fault current limiter development

László Farkas
Budapest University of Technology and Economics, Department of Electric Power Engineering, Hungary

Abstract

In this paper I present a way to come to possible solutions for present problems in the development of transformer-type fault current limiters with using TRIZ and ARIZ methods. The aim of this study was to examine the use of TRIZ and their tools in a real development process and to suggest future improvement targets to include TRIZ into inventive engineering problem solving. I concluded that TRIZ can help find solution ideas but combination with other methods and tools is required to help other steps in the engineering problem solving process. A system should be handled as numerous and interconnected requirements, parameters, problems and solutions, and step-by-step method, similar to ARIZ, should be developed to go through the conceptual design phases.

Keywords

ARIZ, inventive engineering problem solving, superconducting fault current limiter, TRIZ

1 INTRODUCTION

The aim of inventive engineering problem solving is to give solutions to novel engineering (technical) problems which has no known solution [1,2]. Its main task is to set the system design (or conceptual design) of the engineering system. On the other hand, it can play important roles in the following design stages as well.

Inventive engineering problem solving has the following main characteristic features:

- It has several (min. 15-20) interconnected parameters, aims and considerations.
- Most of the requirements are not technical; however, technical parameters and solutions determine their fulfilment.
- Some of the parameters are not known at the beginning of the development, they arise at later stages of the problem solving procedure so refinement and step-back can be required.
- A lot of inter-connected and affecting problems (and their solutions) exist in the engineering system and a lot of contradictions are between them.
- Taking out the essence and wide comprehension are both important (for example, in case of effects of a proposed solution).
- Problems should be investigated at different system model levels, from functional models to conceptual design. These levels are affected by each other so cyclic development can be required.
- We support it with engineering tools, wherever it is possible (use of measurable values, decision matrices, simulations etc.)

The primary aim of this study was to examine the use of TRIZ and their tools in a real inventive engineering problem solving (development) process and to reckon the consequences on how TRIZ can be used and what future development can be suggested.

The investigation was made on a novel development: a transformer-type superconducting fault current limiter.

During the analysis existing, even well-known and trivial solutions were also included and the originality of the arising ideas was not examined.

2 TRANSFORMER-TYPE FAULT CURRENT LIMITERS

The superconducting Fault Current Limiter (FCL) is a device, which does not break the over-current in an electric power network, but limits it to a safe level. The device does not contain any moving component; the superconductor senses the current itself and operates the current limiter.

The construction of the inductive-type FCL [3,4] is similar to a transformer but in this case the secondary winding of the transformer is a superconductor ring cooled down below its critical temperature – in case of a high-temperature (HTS) ring, below about 80-100 K with the use of liquid nitrogen or other cooling agent.

In normal operation mode the secondary magneto motive force generated by the superconductor ring counteracts to and balances the primary magneto motive force resulting in a low (approximately the leakage) input impedance. In current limiting operation mode the primary current exceeds the activation value – approximately corresponding to the critical current of the HTS ring – thus the HTS ring goes to normal (non-superconducting) state. In this case the impedance of the HTS ring increases highly and the impedance of the FCL is the open circuit (approximately the main field) impedance.

When the current in the superconductor achieves its critical value, it goes to normal state. At this time the limiter becomes definite high impedance in the power network, which will limit the amplitude of the fault current. Because a superconductor is used for sensing and operating, the device is fast (2-3 ms, while the operation time of the conventional circuit-breaker is 80-100 ms). [3]

The ideal limiter has zero impedance in the normal operating mode and the impedance rises up very fast to the right value before the first peak of the fault current appears. After the fault current disappears, the limiter is able to return into normal mode in a short time. So, the FCL is a self-controlled (fully automatic) device with very fast activation time and low losses in normal operation mode.

3 FUNCTIONAL MODEL OF THE SYSTEM AND PROBLEMS INSIDE

The first step of engineering problem solving is to make a functional model of the target system. TRIZ itself does not deal with this step though it uses SF model for problems but does not give guidance to set up a system model. To make this step I used a well-known software connected to TRIZ: TechOptimizer 4.0. [5]

The software uses the following steps to describe the functional model of the system (the model is close to SF modelling):

1. setting the *aims* of the development
2. describing the system as elements and interactions between them
3. interactions are described with parameters and their *difference* from ideal values
4. the *significance* of the interaction is its effect to the aims
5. the *rank* of a problem (interaction) is the sum multiplication of difference and significance
6. trimming can be considered to eliminate “highly problematic” elements from the system

After that, several tools and huge databases are available in the software to look for solutions of the problems.

I followed steps 1-6 to identify important problems in the system model.

3.1 Aims and their importance

TechOptimizer itself does not include any tools to identify the importance of the system-level aims so I used AHP pair wise method to calculate the weights of the aims.

The following high-level aims were included in the process:

- Electrical parameters (should be optimal)
- Starting cost (should be as low as possible)
- Operational cost (should be as low as possible)
- Reliability (should be as high as possible)

The result of AHP to calculate the weights of the above aims were as below:

Item	Value
electrical value	37,50 %
starting cost	12,50 %
operational cost	12,50 %
reliability	37,50 %
consistency level (good, if <0.:	0,00

Figure 1: weights of the system-level aims.

3.2 Functional model

During the next step I made the high-level functional model of the FCL as can be seen below:

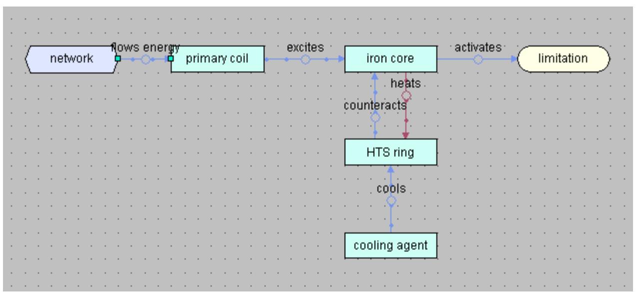


Figure 2: Functional model of the system.

3.3 Parameters of interactions

Parameters of interactions (functions) are the main technical parameters of the system to develop as well. Values of parameters are not easy to calculate as we do not know the exact system at this stage.

Earlier a conceptual design of a 100 kVA FCL was designed as follows:

- Primary current: 5400 A
- Primary voltage: 6450 V
- Primary winding turns: 122
- Induction in the iron core: 2 T
- Main field impedance: 5 Ω
- Inner diameter of HTS ring: 0.39 m
- Cross-section of HTS ring: 0.12 m^2
- Critical current of HTS ring: 2000 A/cm^2
- Heat production (of HTS ring during fault): no data
- Heat capacity of cooling agent/system: no data

The design theory and the design data above were used by the courtesy of Prof. Istvan Vajda, Department of Electric Power Engineering, Budapest University of Technology and Economics.

These parameters and their values form the ideal values of the system to develop. In the next step the actual parameter values should be identified. To do this, a working laboratory FCL model is used and its parameters are modified to get the most similar small-scale system. For this system parameters should be set that it models (electrically) the target system. Model parameters can be calculated with similarity laws [6] coming from the following conditions:

1. Induction in the iron core must be identical because this value influences the behaviour of the HTS ring.
2. Impedances of the system must be the same in order to model the working principles in the electric power network. Voltage and current values grow linear.
3. Geometry can be changed in order to get the correct electric and magnetic similarities.
4. Critical current (j_c) of the HTS ring is assumed to be the same.

From condition 1 and 2 we get the following requirements:

$$B = const. \tag{1}$$

$$\frac{U_1}{I_1} = const. \tag{2}$$

$$X_m = const. \tag{3}$$

$$X_s = const. \tag{4}$$

In a FCL induced voltage is:

$$U_i = 4{,}44 \cdot f \cdot N \cdot B \cdot A \tag{5}$$

where $U_i \approx U_1$, f=50 Hz (constant), $A \sim D^2$, so from (1) and (5) we get:

$$\frac{U_1}{N \cdot D^2} = const. \tag{6}$$

Excitation (mmf) of the HTS ring is:

$$\Theta = N \cdot I \tag{7}$$

and j_c is constant (2000 A/cm^2) so we get:

$$A = \frac{N * I}{j_c} \tag{8}$$

Cooling system has to take away the generated heat. Taking into account identical HTS materials and critical currents (j_c) heat is a function of volume (heat per unit is identical):

$$\frac{Q}{A * D} = const. \tag{9}$$

From the equations above we get the following model parameter values:

parameter	target	model
Primary voltage (U_1) [V]	6450	50*
Nominal current (I_1) [A]	5400	42
Diameter (D) [cm]	39	2.5*
Primary number of turns (N)	122	230
Limiting impedance (X_m)	5	5
Cross-section (A) [cm^2]	330	4.8
Heat (Q) [unit**]	40300	38

* values of the original working model

** only ratio is indicated

Table 1: target and model values of the FCL system

3.4 Significance of interactions

After calculating the parameter values we have to set the significance of the interactions to the aims of the system. In this step I used qualitative values in TechOptimizer as 0-1-3-9 (no influence-small-medium-large influence). For example, primary winding turns influence aims as below:

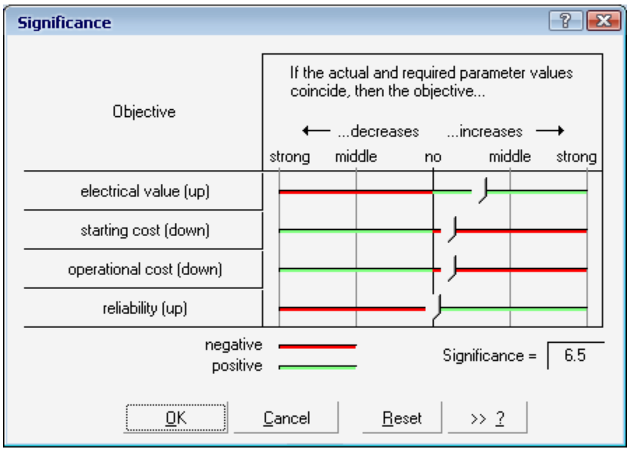


Figure 3: Significance of primary number of turns.

3.5 Ranking problems

Rank is the multiplication of difference and significance of parameters of an interaction. From this, TechOptimizer calculated the following ranks:

32.6 Improvement of "voltage" (network - primary coil)
32.6 Improvement of "turns" (primary coil - iron core)
34.5 Improvement of "HTS cross section" (HTS ring - iron core)
37.9 Improvement of "current" (network - primary coil)
41.2 Improvement of "inner diameter" (HTS ring - iron core)
48.0 Improvement of "cool capacity" (cooling agent - HTS ring)

Figure 4: Problem ranks.

Problem rank does not include the technical difficulty to solve the problem. This is useful as a solution is not considered when ranking the problem. Solving a less difficult problem can have high consequences.

3.6 Trimming the model

Its aim is to eliminate elements associated with a lot of problems. Trimming has three types in general:

- Eliminating element (and its interactions)
- Function of the element is transferred to another element
- Function of the element is transferred to the environment/super-system

TechOptimizer offered cooling system for trimming first, based on the problems associated with it.

Idea: applying the third type of trimming cooling is transferred to an outer system. For example, if we use FCL with HTS cables, these cables already have a cooling system which can be connected to cool the FCL.

My opinion is that trimming can be used rarely at high level functional system analysis. In high level models elements or functions cannot be neglected easily because we take into account only important ones that are essential to fulfil the main function of the system. Trimming can be useful in high-detail functional models. Anyway, simplifying a system before inspecting the problems inside is a logical step.

3.7 Problems selected

Based on the problem ranks (Figure 4) the following problems are selected to investigate further: increasing HTS ring diameter, increasing HTS ring cross-section, improving cooling. Increasing diameter means that the cross-section of the iron ring can be increased; increasing HTS cross-section can increase critical (activation) current, cooling system is important to take away the heat generated from the current flowing inside the HTS ring with definite resistance during activation. Both problems are important.

Increasing primary (activating) current got a high rank as well. However, this value is characterised by the activation current of the HTS ring which is influenced by the three problems described above. This problem is neglected from the next problem solving steps.

The interconnection of the problems cannot be described in TechOptimizer and in TRIZ as well. Interconnections can be handled with different analysis methods, for example RCA or FMEA analysis, or with problem nets. If we solve a problem, the solution can influence (positively or negatively) the solution of other problems. Even more, most of the interconnections of technical solutions can be described with (simplified) equations and in this case optimization of solutions is possible. TRIZ lacks these considerations.

4 FINDING SOLUTIONS WITH USING TRIZ TOOLS

The next section describeswhat solution ideas arise when using standard TRIZ tools [7,8].

4.1 Technical contradictions

Contradiction table can be used when increasing one technical parameter decreases another in the system. When using the contradiction table it is examined how it covers the solution ideas coming from the 40 principles.

Increasing HTS diameter:

Length-stability of composition: principle 39,37,35

Length-stress: 1,14,35

Length-reliability: 15,29,28

Length-object affected: 1,18

Going through the 40 principles I got the following solution ideas:

1. Segmentation – hybrid (partially HTS, partially copper) ring, multiseed HTS growing, welded HTS ring

3. Local quality – growing HTS as a ring instead of brick shape during fabrication

18. Mechanical vibration – vibrating HTS material during melt growth, in this case more homogenous material could be made

From these ideas 2 were present in the contradiction table but 2 were missing.

Increasing cross-section of HTS ring:

Area- stability of composition: 2, 38

Area -stress: 10,15,36,37

Area -reliability: 32,35,40,4

Area -object generated: 22,1,40

Going through the 40 principles I got the following solution ideas:

5. Merging – several rings in one iron core limb, parallel connection of FCLs [4], several iron core limbs

30. Flexible shells and thin films – multilayer HTS thin film

4. Asymmetry – using of asymmetrical cross-section instead of rectangular (during melt growth the quality of HTS material does not propagate symmetrically)

1. Segmentation – several rings

From these ideas 2 were present in the contradiction table but 2 were missing.

Improvement of cooling:

Temperature-stability composition: 1,35,32

Temperature-loss of energy: 21,17,35,38

Temperature-complexity: 2,17,16

Going through the 40 principles I got the following solution ideas:

37. Thermal expansion – heat conducting ring around the HTS ring which tightens during cooling down

11. Beforehand compensation – worsening HTS material at certain points of the ring (in this case the heat generation points can be located)

24. Intermediary – heat conducting layer, heat conducting grease, two-cycle cooling, copper cooling agent

31. Porous materials – perforated HTS ring

16. Partial or excessive actions – cooling down liquid nitrogen more, below 77 K

35. Parameter changes – cooling with solid nitrogen

1. Segmentation – eliminating heat conductor and cooling agents

21. Hurrying – using HTS materials with sharp transition (YBCO instead of BSCCO), because heat is generated mostly during the superconducting-high resistance transition

17. Dimensionality change – cooling in volume (perforation of HTS ring)

From these ideas 5 were present in the contradiction table but 4 were missing.

Examining the three problems it can be concluded that using the whole 40 principles instead of the contradiction table can give more ideas and cover more existing solutions. When using the contradiction table, several solution ideas can be missed.

4.2 Physical contradictions

Physical contradiction is when two requirements coincide for one technical parameter. To solve this contradiction several methods are possible to use:

- Elimination in space
- Elimination in time
- Elimination with using phase states
- Switching to sub-system
- Switching to environment/super-system

Increasing HTS ring diameter:

Diameter should be small (good quality) and large (large iron core).

Switching to sub-system: several small rings can be used with several iron core limbs. The sub-system ring is small (good quality) while the whole system operates as a large ring.

Increasing HTS cross-section:

Cross-section should be small (good quality) and large (high activation current).

Switching to sub-system: several rings with smaller cross-section are placed one above the other.

Cooling:

High capacity is required for high heat but small capacity for cost (and other parameters).

Elimination in space: circulating cooling agent which cools continuously, re-cooling is done at a distance (analogously to oil cooling in transformers)

Elimination in space: pipe system, re-cooling is done outside

Elimination in time: cooling system which can be overloaded for a small time as high heat generation appears only at the beginning of the activation (while HTS goes to normal state)

From examining the three problems it can be concluded that separation methods gave new ideas comparing to the principles used for technical contradictions. Some ideas, however, were the same, especially when using sub-system separation method.

4.3 Other tools

Substance field (SF) analysis was not followed because it gives a lot of possible ways to modify, substitute or develop the system but does not guide their use. Also, effects database does not give guidance to use the physical, chemical etc. effects.

I want to emphasize that databases (patents, solutions, SF, effects etc.) are very important and useful tools when solving a technical problem but these tools are not unique for TRIZ, almost every other problem solving method include them.

5 ARIZ

TRIZ methodology suggests using ARIZ when no possible solution comes from standard TRIZ tools. In this section I selected the problem of cooling to examine with ARIZ. The steps and chain of ideas in ARIZ were followed [8], I did not deal with standard tools usage. These tools were examined in the previous section.

5.1 Problem analysis

Formulate the mini problem

A fault current limiting device consists of a primary winding, iron core, secondary superconducting ring and cooling agent. Superconductor is a fast current-driven switch but low temperature is required for its work. The device is in the electric power system.

Technical contradictions:

TC-1: if I increase cooling capacity, the cost and volume of the system increases.

TC-2: if cooling capacity is low, it is cheaper and smaller, but superconductor heats up during switch and cools down again in a long time.

It is required, with minimum changes to the system, to prevent superconductor from heating up and allow fast re-cooling.

Defining the conflicting elements

Work piece: superconductor

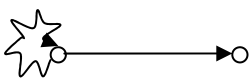
Tool-1: cooling (agent)

Tool-2: iron core which induces high current in the superconductor. High current generates heat which should be taken away by Tool-1.

In the next steps Tool-2 is not inspected as it is required for the main function of the system.

Graphical model

TC-1:



TC-2:

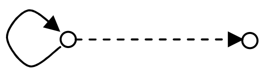


Figure 5: Selecting the graphical model

For ideal operation TC-1 is more suitable as cooling is optimal.

Enforcing conflict

TC: cooling capacity is infinite, but in this case cost (and volume) is also infinite.

Problem model

Given is a cooling agent with infinite cooling capacity and a superconducting ring. Cooling is ideal but the price and volume of the cooling will be infinitely high.

Required is an element X for which cooling capacity is infinite but its price and volume remain under the given limits.

Applying the standard solutions

Not examined here, see section 4.

5.2 Analyzing the problem model

Operational zone

Volume of superconductor and the surrounding (limited) volume, and the surface between them.

Operational time

T1 (conflict time): beginning of fault in the network, when superconductor goes to normal state from superconducting state.

T2: time elapsed between two faults.

Substance and field resources

Existing resources:

- volume around superconductor
- volume of superconductor
- gravity
- volume around the FCL system
- voltage, current, power of electric network

5.3 Formulating the ideal ultimate result

Identify IUR-1

Element X does not complicate the system at all, does not create any harmful effects, and eliminates the big and expensive cooling during fault time (T1) in the volume of the superconductor and surrounding, while maintaining cooling of the superconductor.

Enforce IUR-1

There is no special cooling agent/system, we use existing resources. These resources can be, primarily, air around the superconductor, superconductor itself, gravity, environment, power of network.

Physical contradiction at macro level

A. Heat capacity is infinite (or high) inside and around the superconductor during the start of a fault, and small between two faults.
B. Cooling agent should be there to take away big heat but does not have to be there to be cheap and small.

Time and space separation can be used, see section 4.

Physical contradiction at micro level

There must be cool particles inside and around the superconductor to cool down the superconductor, but they do not have to be there (in large quantity) to be cheap and small.

IUR-2

Space or air should be able to provide high capacity inside and around the superconductor during the starting of the fault. After that small cooling capacity is enough. This means that cooling agent should become high heat capacity immediately at the beginning of the fault and can become normal afterwards.

Standard solutions

Not examined here, see section 4.

5.4 Utilizing SF resources

<u>Ideas</u>:

- Cooling down air around the superconductor
- Perforation of superconductor (see section 4)
- Gravity circulation (see section 4)
- Peltier-cell operated by current of electric network (high current flows at the beginning of the fault, this can be utilized for cooling)

Simulation with Small Little Creatures

Superconductor is surrounded by small creatures. These creatures take away small heat during normal operation. When a fault occurs:

A) some of the creatures take out large bags immediately and catch and take away large heat.

B) creatures with large bags come and take away heat fast.

Stepping back from IUR

Reviewing the procedure no step back was necessary.

Mixture of resources

No new idea. Perforation can be treated as mixed resources.

Using empty space

Vacuum is good heat insulator but very poor heat conductor. No idea arose.

Using derived resources

<u>Idea</u>: Using solid air/nitrogen cooling agent instead of gas or liquid one.

(This idea has already appeared in section 4.)

Using electrical field

<u>Idea</u>: movement of particles taking away heat can be accelerated and directed with the use of electrical field.

Using field sensitive substance

<u>Idea</u>: there is leakage magnetic flux around the superconductor during a fault. This magnetic field can influence the movement of the cooling agent particles.

5.5 Rest or ARIZ steps

These steps (applying knowledge base, changing the problem, analyzing) were not considered as they are not unique for ARIZ, almost every other problem solving method include them [1].

5.6 Evaluation

When going through ARIZ steps systematically I specified, refined and understood several aspects of the problem. For example, I stepped back from 5.1.3 to 5.1.1 as not the system itself but the cooling agent/system will be expensive and large. ARIZ helps understanding the problem in more details.

Systematic processing gave new ideas, especially when taking into account the use of existing or modified resources.

6 SUMMARY

I examined the use of TRIZ and ARIZ in a case of inventive engineering problem solving process. I concluded that:

- TRIZ approaches systems, problems and solutions with engineering tools and methods, especially if we combine it with other tools (e.g. AHP, RCA, modelling etc.).
- TRIZ does not give tools for setting aims and parameters of the system to be developed. A possible way to estimate required and actual parameters is to use similarity laws.
- When using TechOptimizer, ranking of problems were as expected. However, other tools, like QFD, can also be used here.
- Trimming of system model is useful in high-detail models but less useful in high-level functional models.
- Using the 40 principles and separation methods gave more ideas. When using only the contradiction table, several solution ideas can be missed.
- Interconnection of problems and solutions are not handled in TRIZ.
- ARIZ gave new as well as well-known ideas and helped the systematic processing of the given problem.
- TRIZ and its tools cover wide range of possible solution ideas with using a systematic, logical and useful method.
- Professional knowledge is required for effective use of TRIZ and ARIZ. This is not unique; every engineering problem solving method requires this.

7 CONCLUSIONS

- TRIZ/ARIZ method can help find solution ideas to engineering problems systematically, especially when using it with other methods. However, most of the ideas are typical and obvious well-known solutions.
- TRIZ does not handle the problems in a system as numerous and interconnected requirements, parameters, problems and solutions. Interconnections play a major role in design. It is advantageous to use TRIZ with other methods and tools (e.g. risk management and decisions, RCA, QFD, problem nets, design tools etc.). More research is suggested in this field.
- TRIZ methodology stops at the end of idea generation and at the beginning of conceptual design. TRIZ does not help the steps of conceptual design. More efforts are suggested to be taken to make the link between the two fields. Step-by-step methods, similar to ARIZ, can help go through the conceptual design phases (from several stages of functional models to conceptual and detailed design).

REFERENCES

[1] Frye E., Engineering Problem Solving for Mathematics, Science, and Technology Education, Trustees of Dartmouth College, 1997 http://engineering.dartmouth.edu/teps/book.html

[2] Lumsdaine E. and Lumsdaine M., Creative Problem Solving. McGraw-Hill, 1995

[3] Vajda I., Györe A., Porjesz T., Sokolovsky V., Meerovich V., Duration Tests of an Experimental High Temperature Superconducting Fault Current Limiter, International Journal of Applied Electromagnetics and Mechanics, Vol. 14., Numbers 1-4/2001/2002, pp 121-126., 2002

[4] Gyore A., Farkas L., Vajda I., Series and Parallel Connections of Inductive HTS Fault Current Limiters, Superconductor Science and Technology, 18 No 2 S82-S85, 2005

[5] Invention Machine Corporation, TechOptimizer 4.0 User's Guide, 1998.

[6] Meerovich V. et al., Performance of an Inductive Fault Current Limiter Employing BSCCO Superconducting Cylinders, IEEE Transactions on Applied Superconductivity, vol. 9, no. 4, December 1999, pp. 4666-4676.

[7] Altshuller G., The Art of Inventing (And Suddenly the Inventor Appeared). Technical Innovation Center, 1994.

[8] Altshuller G., Zlotin B., Zusman A., Philatov V., Tools of Classical TRIZ, Ideation Intl. Inc., 1999

CONTACT

László Farkas

Associate professor, PhD

Budapest University of Technology and Economics

Department of Electric Power Engineering

H-1111 Budapest, Egry J. Str. 18, Hungary

E-mail: farkas.laszlo@vet.bme.hu

Phone: +36 (1) 463 2743

FAX: +36 (1) 463 3600

FUNCTION APPROACH FOR RESOURCE ANALYSIS

Oleg Feygenson, Maria Urusova
ALGORITHM Technology Research Center, Saint-Petersburg, Russia

Abstract

This paper demonstrates the importance of Resource Analysis in modern TRIZ and provides an overview of existing findings regarding resources. The main goal of the paper is to suggest an approach that can be used for the identification and evaluation of resources. The advantages of the developed approach are as follows:

- Practicality: the suggested approach is focused on the rapid development of workable ideas without significant effort.
- Efficiency: the suggested approach is based on recommendations of proven TRIZ tools, such as ARIZ, Trimming and Function-Oriented Search.
- Simplicity: the suggested approach is quite understandable and can be used by everyone who has a basic knowledge of TRIZ.

Keywords

Resources, Resource Analysis, Function Approach, Trimming, Function-Oriented Search, ARIZ

1 INTRODUCTION

Resource Analysis is a very powerful TRIZ tool that was originally developed as a part of the Algorithm of Inventive Problem Solving (ARIZ). In ARIZ, Resource Analysis looks at where the selected conflict is taking place (Operating Zone), the periods of time when the conflict is happening (Operating Time), and the substances and fields of the Engineering System and its Supersystem. But there are no practical recommendations on how to identify resources. In other words, how to make sure that only workable resources are included in a resource list while excluding the unnecessary ones.

At the present time Resource Analysis is widely used as an independent TRIZ tool or in combination with some other tools (Function Analysis, Function-Oriented Search, etc.) for problem identification and idea generation. There are some articles in TRIZ literature that contain recommendations concerning the procedure of Resource Analysis. Generally, they are about how to identify a great number of available resources but do not contain any practical recommendations regarding the selection of workable resources among all available ones.

The main goal of this paper is to provide a function approach for resource identification. The general idea is to identify resources to be included in the list based on their functionality. This approach has been developed through practical experience and applied in some innovative consulting projects.

2 LITERATURE REVIEW

It would be appropriate to mention that the elegance of a problem-solution depends on how efficiently we apply the resources. By 'efficiently' we mean both the quantity and quality of resources.

A great number of good examples when elegant solutions were developed by using different resources is presented by Vladimir Urazaev [1].

Voluslav Mitrofanov illustrates the situation with resources as follows "When I decided to select resources for solving scientific problems, I obtained a whole list of phenomena, substances and fields - from the center of the Earth to the center of the Sun." [2]

Most publications concerning resources in TRIZ literature focus on understanding the role of resources and the identification and classification of as many resources as possible. As a result of this attention to resources, the term 'Inventive Resources' was developed in TRIZ. Boris Zlotin and Alla Zusman [3] define Inventive Resources as:

- Any substance or anything made of a substance (including waste) that is available in the system or its environment.
- An energy reserve, free time, unoccupied space, information, etc.
- The functional and technological ability to perform additional functions, including properties of substances as well as physical, chemical, geometric and other effects.

Zlotin and Zusman developed a checklist for readily available resources and suggested a way to reveal hidden resources [3].

Alexandr Gasanov gives a classification of resources and suggests an algorithm for revealing resources [4].

Sandra Mueller surveys different approaches for classifying resources inside both the field of TRIZ and in strategic management [5]. All the approaches she surveyed are used for revealing the maximum number of resources to subsequently solve a problem: technical or management solving.

Alexandr Bushuev attempts to quantitatively evaluate and compare technical and physical contradictions by vector analysis of resources [6]. He evaluates the resource-intensiveness of different physical quantities and, based on these values, compares the potency of dual conflict in physical and technical contradictions.

Vladimir Urazaev surveys patents and describes interesting examples of solving problems by using resources [1].

Val Kraev in his lessons describes a resource approach and gives many colorful examples of resource application, specifying features of different types of resources and ways they can be applied [7].

Gennadiy Ivanov describes an improved and more practical procedure for identifying resources in his ARIP (Algorithm of Engineering Problem Solving) [8].

Of course, there are more publications available concerning resources in TRIZ, but those mentioned above are the most complete as they summarize previous experience. Again, all these publications describe how to reveal and classify resources, but not how to select the most suitable ones.

So in this paper, we have tried to develop an approach on how to choose the necessary resources instantly.

3 FUNCTION APPROACH FOR RESOURCE ANALYSIS

3.1 Background

The classic inventive problem statement is formulated as follows: ES has a disadvantage that needs to be eliminated in order to increase system value. Then, this disadvantage has to be analyzed with TRIZ tools and Key Problems should be revealed. And the next step is to address the Key Problems and describe a possible solution. Addressing the Key Problems means finding the right resource that eliminates this problem and therefore eliminates the initial disadvantage of the ES.

In general, everything around us could be used as a resource for problem solving, but is there a way to selecting the 'right' resources? What approach should we use instead of trying each resource one-by-one?

Every ES is a part of a technological process: development process, manufacturing process, shipment process, etc. Even usage of a consumer product could be considered a technological process. At each step of a process, ES interacts with different systems that could be used as substance resources; and these systems generate fields or energy that could be used as field resources; and they perform some functions that could be used as function resources. The main question again is: How to choose the most appropriate resources for solving a particular problem.

3.2 Function-Oriented Search and Trimming as tools for searching and evaluating resources

We believe that some ideas could be taken from such TRIZ tools as Trimming and Function-Oriented Search (FOS).

Trimming.

Trimming gives us very structured recommendations on how to find a component that can potentially perform a required function. This component is definitely a resource - substance or field - and this resource is definitely the most suitable one because it was chosen based on its functional capability. Trimming recommendations are as follows:

To select a Component as a Function Carrier, at least one of the four conditions should be satisfied:

1. The Component already performs an identical or similar function on the Object of Function
2. The Component already performs an identical or similar function on another object
3. The Component performs any function on the Object of Function or, at a minimum, simply interacts with the Object of Function
4. The Component possesses the set of resources necessary to perform the required function

The 4th Trimming condition does not sound practical especially when we are talking about evaluation of resources. This is why we suggest not using this recommendation while doing a resource evaluation. Instead, we recommend applying FOS when it is difficult to find a resource in a considered system or its nearest supersystem.

Function-Oriented Search.

The main idea of FOS is to use an already existing technology from a very remote area of science and engineering as a solution to the problem in the initial area that needs an innovation [9].

FOS shows us how the required functions are performed in different areas and gives us ideas on how we can perform such functions in our ES, where components/resources of our system could be considered a Function Carrier.

This can be seen in the example about Anti-Allergenic Nasal Filter, which has become a classic example. [9] The problem was to prevent allergies caused by contact between small organic particles (5-20 microns) with the mucous membrane in the nostrils. First, a technology was found that can separate tiny particles from air flow, that is, the Industrial Cyclone. And then, it was necessary to significantly reduce its size to insert in the nose.

One adaptation problem had to do with the motor that the Industrial Cyclone is equipped with to move air. This problem could be formulated as: how can we significantly decrease the size of the motor and dramatically reduce cost. Now we have to look for resources in our system and its supersystem. We know that a potential Function Carrier/resource has to perform the function "to move air" and parameters of the function are "flow rate", "operational cost" and so on.

As soon as we described the function requirements, the resource could immediately be found in the supersystem: the human body. Lungs move air through the nose, provide the required flow rate, and they do it all for free!

3.3 Algorithm for searching and evaluating resources

In summary, we have developed a systematic approach for evaluating resources. We call it the Function Approach for Resource Analysis. The suggested algorithm for evaluating resources is as follows:

1. Identify the Key Problem to be solved in order to increase value of ES
2. Formulate Ideal Final Result in the form suggested in ARIZ:
   Without complicating the Engineering System and adding additional harmful effects, the X-element must [perform a function]
3. Formulate function requirements for the potential X-element
4. Apply FOS to identify technology from remote areas and specify function requirements for the potential X-element
5. Search for X-element as a Function Carrier inside the considered ES and its nearest supersystem. At least one of the following conditions should be satisfied:
   - The Component already performs an identical or similar function on the Object of Function
   - The Component already performs an identical or similar function on another object
   - The Component performs any function on the Object of Function or, at a minimum, simply interacts with the Object of Function
6. Describe the idea(s) of solution
7. Identify and address the Adaptation Problems required to implement the idea

Conclusion: we do not need to list and classify all available resources. Instead we ensure that we apply only the suitable ones based on their functionality. This saves a lot of time.

3.4 Examples

Let us consider a couple of examples to demonstrate the applicability of the suggested approach.

The first example has been mentioned in a previous article [10] but we would like to provide it again because of its demonstrativeness.

In fact, this example was taken from an actual consulting project which was aimed at developing a new product for moisturizing human skin, and which would identify some alternative systems for existing body lotion. One of the subdirections here was a new delivery system for the moisturizer: a packaging and/or application procedure.

At that time, the Function Approach for Resource Analysis had not yet been formalized, but essentially we can see its influence at the idea generation stage.

In this project, a human's daily activities were considered as a technological process. Skin moisturizing was included as one of the operations in the process. Existing body lotion was considered to be the ES involved in the operation.

The traditional application of the lotion is to spread the lotion over the skin. The inconvenience related to such application procedure can be defined as the necessity for the consumer to perform additional actions.

So, we have a problem: How to apply lotion all over the body's skin without additional actions by the consumer?

Ideal Final Result would be: Without complicating the Engineering System and adding additional harmful effects, the X-element must deliver lotion all over the skin.

Function requirements for the X-element were stated as follows: "amount of additional actions required from the consumer" and "skin surface area processed per time unit."

All ESs involved in the human daily activity process were considered to be supersystem components and potential X-elements (see Figure 1).

A number of supersystem components were recommended as a potential delivery system for a moisturizing product. For instance, shower gel, water and shower head can be components at the washing stage; a towel can be a component at the wiping stage, bed linens can be a component at the sleeping stage, etc

Product portraits on the basis of new delivery systems were proposed and described in the project.

What is important here is that we did not list and classify all possible resources; instead, we were focused on the resources with the required functionality only.

Thus, the resource analysis of the supersystem is an effective tool for identifying a new delivery system (package, format, etc.) for existing products.

Another example that we would like to consider here is about the evolution of the wristwatch. The wristwatch is a simple, well-known system, which is why we decided to use it for illustrative purposes.

At the present time, it is not necessary to have a watch on the wrist because clocks are around us everywhere: they have been incorporated into cell phones, computers and TV screens, and so on.

Let us illustrate the applicability of the suggested approach to trace the evolutionary line of the watch. Imagine we need to predict a new generation of the watch.

First of all, we need to formulate the main function of a wristwatch: "to inform the consumer". Then the problem statement could be: how to inform the consumer (about time) without a wristwatch. Possible function requirements could be: "visually", "available all the time or most of the time." Now we are ready to look around and find possible candidates. We can immediately find a lot of things: a cell phone, a music player, a pen and so on

We all know how the cell phone increased its functionality by incorporating a clock - the classic TRIZ logic. It follows, then, that if we were in the watch-making industry, we would start with the watch.

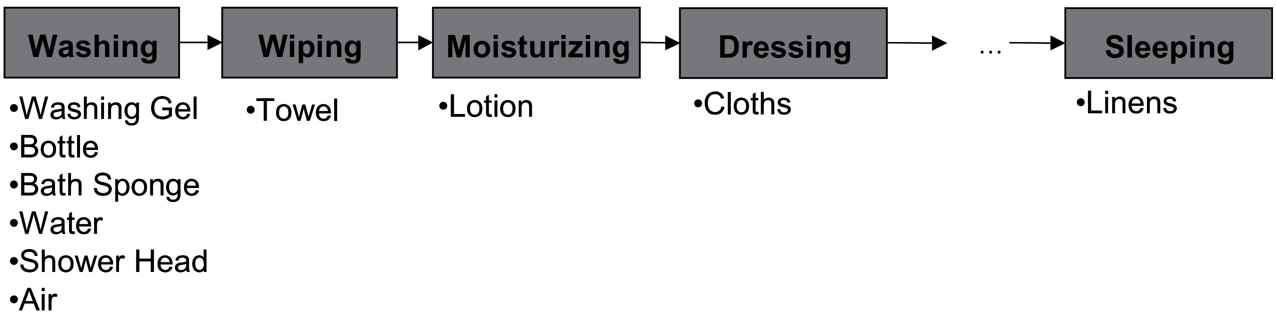


Figure 1: Identifying possible resources for moisturizing human skin

The most suitable candidates for the X-element were evaluated based on the criteria discussed above:

- The Component already performs an identical or similar function on the Object of Function
- The Component already performs an identical or similar function on another object
- The Component performs any function on the Object of Function or at a minimum simply interacts with the Object of Function

But let us assume we are in the cell phone business and apply our Function Approach for Resource Analysis to find possible candidates that could incorporate a cell phone.

In other words, we can identify resources for cell phone development. And one of the possible resources is the wristwatch: a cell phone is a wristwatch (see Figure 2).

Figure 2: Wristwatch with Cell Phone

Finally, we would like to consider one more example that illustrates the applicability of the suggested approach for complicated technical problems. This example is about initial start-up of inductively coupled plasma (ICP) torches at atmospheric pressure. Such plasma torches have been widely used since 1960 for different applications: plasma chemistry, spectroscopy, refractive powder purification and spheroidization, and others.

Principle of operation of ICP plasma torch is as follows: when a time-varying electric current (usually radio frequency (RF) current) is passed through the coil, it creates a time-varying magnetic field around it, which in turn induces azimuthal electric currents in the rarefied gas, leading to break down and formation of plasma. Plasma temperatures can range between 6 000 K and 10 000 K at atmospheric pressure depending on gas composition. Treated materials are injected into the plasma torch by different techniques. See for example [12].

One of the most important issues of using ICP torches at atmospheric pressure is the initial start-up.

A known solution is the decreasing pressure inside the plasma torch at the moment of start-up [13]. Because the free length is high enough at a pressure below 1 Torr, an electron can have the energy to ionize an atom if it collides with the atom. Then a so-called avalanche-like ionization occurs and we have plasma inside the torch. Now pressure can be increased to atmospheric level and even higher. But one can see how expensive this solution is because it requires to use of vacuum equipment.

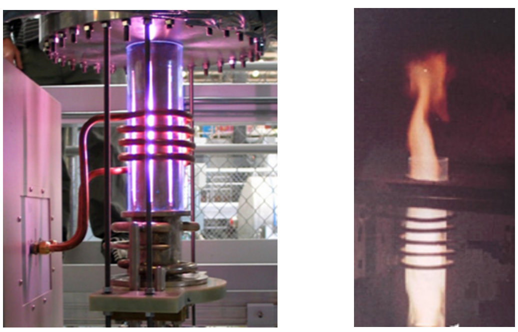


Figure 3: Photos of inductively coupled plasma (ICP) torches operated at atmospheric pressure

Other known solutions concerning an ICP torch ignition are based on the application of additional external sources of ionized gases, for example, laser (see Figure 4) or direct current (DC) arc. These techniques have been tested and they work well, but require additional equipment. Moreover, the installation of different types of additional sources requires space in the torch body and makes it difficult to install injectors for materials to be treated by plasma.

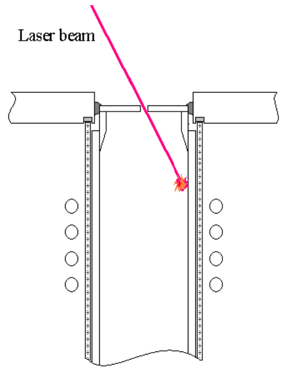


Figure 4: Laser spark for ICP torch ignition

So, let us apply our Function Approach for Recourse Analysis. The problem that we are solving is "How to initiate avalanche-like ionization inside the ICP plasma torch?. According to the suggested approach, we are looking for the X-element that would ionize gas inside the torch without complicating the torch and adding additional harmful effects. The requirements for the X-element are as follows: "utilize no space of the torch body", "repeatability", "work at atmospheric pressure". Then we can identify a list of possible candidates for the X-element. Here, we will describe just one idea that we found out of several. The RF coil is considered the X-element. It performs the same functions: "to accelerate electrons", "to ionize gas", but it works with already ionized gas: plasma which requires relatively low current. The idea was to run high power short pulse through the RF coil for the start-up of the torch. The power of such pulse is high enough to accelerate electrons even at atmospheric pressure when free length is not long. This idea has been tested, the initial mock-up had additional coil for the short pulse which was placed under the main RF coil (see Figure 5)

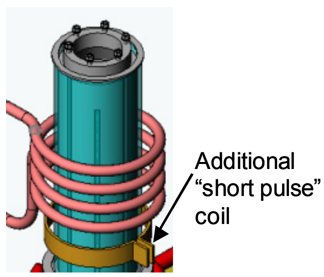


Figure 5: ICP torch with additional ignition coil

4 INVERSE RESOURCE ANALYSIS. SOME RAW IDEAS

Another problem concerning resources is associated with the excessive amount of some resources. There are often times when we have too much of some resource and need to decide how to use it. In general, all waste from our Engineering System could be considered resources for other ESs. Practical recommendations regarding the utilization of excessive amounts of resources have not been identified in modern TRIZ. But this problem definitely exists. Some directions for intensifying utilization of resources have been formulated by Naum Feygenson. [11].

One possible direction for future development of Function Approach for Resource Analysis could be a systematic approach for waste utilization. Such approach could be called Inverse Resource Analysis.

5 SUMMARY

Here we have combined and verbalized an approach that could be used for solving inventive problems by searching and evaluating resources. We believe that in TRIZ, as in any area of science, two general approaches exist: scientific and engineering. The Scientific approach means that for solving a problem it is necessary to build a very precise model of the initial system in order to completely understand the situation. The Engineering approach assumes that a problem can be solved by using some simplified empirical equations, trends or experiments. The suggested Function Approach for Resource Analysis can be considered an engineering approach according to the definitions provided above because it is simple, practical and effective at the same time.

ACKNOWLEDGMENTS

We extend our sincere thanks to all authors and TRIZ developers mentioned in references who have revealed the importance of resources in modern TRIZ and developed some approaches for classifying resources. Special thanks to Deborah Abramova who helped to make this paper sound literate in English.

REFERENCES

[1] Urazaev V. April 2008. Innovations in Engineering: Ideality and Resource Approach. http://www.metodolog.ru/01362/01362.html (Last view July 24, 2008 17:05:00)

[2] Mitrofanov V. March 2008. Resources (in Russian). http://www.metodolog.ru/01342/01342.html (Last view July 24, 2008 17:05:00)

[3] Zlotin B., and Zusman A. December 2004 - March 2005. The Concept of Resources in TRIZ: Past, Present, Future. http://www.ideationtriz.com/new/materials/finalconceptresources.pdf (Last view July 24, 2008 17:05:00)

[4] Gasanov A. TRIZ manual. Part 5. Substance-Field Resources. (in Russian) http://www.metodolog.ru/00034/00034.html (Last view July 24, 2008 17:08:00)

[5] Mueller S. 2005. The TRIZ Resource Analysis Tool for Solving Management Tasks: Previous Classifications and their Modification. Creativity and Innovation Management, Vol.1, pages 43-58.

[6] Bushuev A.B. June 2008. Vector Analysis of Resources. http://www.metodolog.ru/01424/01424.html (Last view July 24, 2008 17:08:00)

[7] Kraev V. January 2007. Kraev's Korner: Resource Analysis - Lesson 4, TRIZ-Journal. http://www.triz-journal.com/archives/2007/01/08/ (Last view July 24, 2008 17:08:00)

[8] Ivanov G.I. July 2008. Algorithm of Engineering Problem Solving - ARIP 2008. http://www.metodolog.ru/01432/01432.html (Last view July 24, 2008 17:08:00)

[9] Litvin S. 2007. Substantiation of Function-Oriented Search Derived Solutions http://www.metodolog.ru/01100/01100.html (Last view July 24, 2008 17:30:00)

[10] Ksenofontova M., and Feygenson O. 2007. Innovative Improvement of Consumer Products. Proceedings of ETRIA TRIZ Future 2007 Conference Nov. 6-8, in Frankfurt am Main, Germany

[11] Feygenson N. 2007. Resources as a Source for Problem Statement. (in Russian) http://www.metodolog.ru/01067/01067.html (Last view July 24, 2008 17:30:00)

[12] Putvinski, S.; Agnew, S. F.; Chamberlain, F.; Freeman, R. L.; Meekins, M.; Feygenson, O.; Evaporation of Molten Salts by Plasma Torch / American Physical Society, 45th Annual Meeting of the Division of Plasma Physics, October 27-31, 2003, Albuquerque, New Mexico, MEETING ID: DPP03, abstract #LP1.113

[13] Dashkevich I.P. High Frequency Discharges - Industrial Applications. Leningrad. Polytechnika. 1991 (in Russian)

CONTACTS

Oleg Feygenson,

Technology Research Center “Algorithm”, St.-Petersburg

16 Ruzovskaya str., Saint-Petersburg, Russia, 190013

E-mail: oleg.feygenson@algo-spb.com; oleg.feygenson@yahoo.com

Phone: +7 (812) 449-8990; +7 (901) 305-1882 (cell)

Maria Urusova

Technology Research Center “Algorithm”, St.-Petersburg

16 Ruzovskaya str., Saint-Petersburg, Russia, 190013

E-mail: maria.urusova@algo-spb.com; popicherep@gmail.com

Phone: +7 (812) 449-8990; +7 (921) 358-1040 (cell)

Early Experiences Employing the Matrix Principles Modified for the Communications and Electronics Domain

Nasir Ayub[1] and Paul Filmore[2]

[1] MSc student, School of Computing Communication and Electronics, University of Plymouth, UK

[2] School of Computing Communication and Electronics, University of Plymouth, UK

Abstract

Different authors have developed examples of the TRIZ Principles in a number of domains ranging from finance to microelectronics. To the authors' knowledge, no one has attempted to develop examples for the 40 Principles in the electronics and communications domain. Also past authors have seemed reluctant to explain how the examples were derived. This paper explains how the examples were obtained systematically by interviewing a number of domain specialists who knew little of TRIZ. In fact experience of trying to explain TRIZ before the knowledge capture phase, proved highly problematic and weakened the task focus. A condensed list of the 40 Principles is included.

Keywords

TRIZ Principles, Communications, Electronics, Knowledge capture.

1 INTRODUCTION

TRIZ is a collection of problem-solving methodologies and tools originally developed by Genrich Altshuller (October 15, 1926 - September 24, 1998) of Russia. He created the Teoriya Resheniya Izobreatatelskikh Zadatch, translated as the Theory of Inventive Problem Solving, or TRIZ. By examining hundreds of patents, Altshuller was able to describe a framework of system conflicts and resolutions. These conflicts and resolutions provide a method for creative problem solving originally based in the technology domain. The body of work surrounding Altshuller has grown to include a number of techniques that provide structured creativity for analysing and solving problems. [6]

For trained engineers, TRIZ offers the best of all worlds; the individual tools are straightforward, the problem-solving process is systematic and repeatable, and with an open mindset, the creative opportunities are excellent. Engineers appreciate TRIZ better than anyone else because there are engineering success case studies, and it is perhaps most highly developed and used in the engineering domain [7]. It is thus surprising that no one has developed Principles with examples in the communication and electronics engineering domain.

2 TRIZ AS PROBLEM SOLVING TOOL

In recent years TRIZ has evolved to be an effective tool for innovative problem solving. A number of people have attempted to develop examples of TRIZ Principles in different fields. Stephen Dourson's "The 40 Inventive Principles of TRIZ Applied to Finance" [1] provides a good method to develop TRIZ Principles for finance. Another paper by Gennady Retseptor "40 Inventive Principles in Microelectronics" [2] presents good examples of TRIZ Principles from microelectronics. This paper discusses the editor's experience as a TRIZ teacher and says that "most people need a mixture of examples from their own field and from others" to trigger their minds and become more creative in their own field. A different paper "Application of 40 Inventive Principles in Construction" by Abram Teplitskiy and Roustem Kourmaev [3] discusses examples from construction and associates them with the 40 Principles. They have followed the general method of using the 40 inventive Principles as described in the original work of G. Altshuller and taken examples from US patents, the Russian Federation patents, and from their inventing, consulting practice, and construction experiences. NB A useful summary of the Principles being adapted for different domains is given in the TRIZ Journal [8].

The motivation and ideas for this research come from Dr Paul Filmore's papers "Teaching TRIZ as a Systematic Problem Solving Method: Breaking Mindsets" [4] and "The Real World: TRIZ in Two Hours for Undergraduate and Masters Level Students!" [5] which discuss the history and evolution of TRIZ as an effective tool for innovative problem solving in light of some practical examples and case studies. The papers also highlight the importance of teaching TRIZ in modern academia and give an experience based guideline for teachers to motivate students to learn TRIZ in practical ways.

3 TRIZ FOR ELECTRONIC COMMUNICATION SYSTEMS

This work to find Inventive Principles in the communication and electronics domain formed the basis of an MSc project for one of the authors(1) as part of their MSc Communications Engineering and Signal Processing course. The students found the project of growing interest as they started to get into greater depth. Making use of simple tools to solve problems and the way TRIZ has already been used in other domains was found to be quite encouraging. Browsing through the TRIZ Journal and other electronic resources gives a good idea of the papers published about the applications of TRIZ in different domains like microelectronics, construction, finance, manufacturing etc [8]. However, the author(1) could not find any work specifically undertaken in the electronic communication domain which is probably the fastest growing industry in modern world. To obtain a well documented list of the 40 Principles (published here as an addendum), the authors discussed the Matrix and the Principles for practical work based problems, with groups of professional electronic/ communications engineers who knew little of TRIZ. The people selected for discussion are highly skilled professionals and engineering postgraduate students who fall into three groups:-

1. Teachers from the School of Computing Communication and Electronics at the University of Plymouth (10 people).

2. Postgraduate students at the University of Plymouth, Manchester University, University of Edinburgh, University of Trento, Italy, Oxford University and the Ghulam Ihsaq Khan Institute of Engineering Sciences and Technology, Pakistan (35 people).
3. Professionals and engineers working in telecom companies like Ericsson, Vodafone, Orange, Microsoft and Alcatel (26 people).

The papers published about TRIZ Principles for other domains were used initially to trigger ideas in translating the 40 Principles for the electronic and communication domain. The authors' method was to interview a number of people from the above categories and take their opinion about the topic. To achieve this, the author(1) started off with emails to different people asking for their time to interview and discuss the topic. The task seemed easy at first but got difficult and the authors had to discuss and come up with a modification in the knowledge acquisition method later.

4 THE 40 PRINCIPLES

The author(1) started off with the list of 40 Principles. The idea was to gather examples for each Principle in the electronics and communication domain. "The 40 innovative Principles of TRIZ applied to finance" [1] provided a fine guideline to gather examples for this purpose. A file folder with a section for each Principle was made. The author(1) had to gather examples and points from different people and note them in the file. By the end of interviews, the author would re-organise the points and place them in their respective categories. Starting with emails to different people (from the above three categories) who are directly or indirectly involved in the electronic communication technology but had little or no idea of TRIZ, the author interviewed them and asked for suggestions and feedback to translate the TRIZ Principles for electronic and communication systems. In fact experience of trying to explain TRIZ before the knowledge capture phase, proved highly problematic and weakened the task focus.

5 PROBLEMS IN GETTING IDEAS FOR TRIZ PRINCIPLES

The aim was to look at how TRIZ is used in other domains especially in engineering and, by keeping a reference sheet for each Principle, generalising each Principle according to the needs of electronics communication systems. A small presentation about the history of TRIZ and some application examples in other fields was sent via emails along with a questionnaire to different people related to communication engineering. Realising that many people do not spend enough time reading presentations sent via email, the author made the presentation very small. Some replies were received with questions about TRIZ because many did not understand the concept and thus could not answer the questionnaire. Making the presentation fully explanatory could have resulted in people not bothering to read it due to size and even then it would not be easy to get the concepts over by just going through the slides. Also the email replies came from very few of those emailed so the author decided to interview them personally. Emails were sent to those who were easily approachable and request made for appointments. This time the outcome was encouraging and the author was successful in getting times for discussion sessions with many of them. The author started with an interview of a staff member in the Faculty of Technology, University of Plymouth. Luckily most of the faculty members know about or at least are familiar with the name TRIZ since Dr. Paul Filmore has already done some work in this area. However some were not familiar with the concept. The interview appointment was for limited time so starting by explaining TRIZ first and getting their suggestions later did not help because the author(1) had to skip a lot of background information to meet the time restrictions. This caused problems in the sense that questions were raised about the origin and development of TRIZ before integrating it with electronic communication systems. To answer these questions the author had to explain the background and history of TRIZ and then the applications in other disciplines which itself was time consuming. Eventually it was found that discussing history of TRIZ before getting the feedback was slowing down the process and the need for an alternative method raised itself. The authors discussed this and concluded that carrying on the interviewing process without mentioning TRIZ can still help in getting the required results. So in the following meetings, the author(1) started the discussion with the 40 Principles and asked those being interviewed to give examples from electronic communication domain for each principle. This gathered a lot of examples but most of them were similar or repeats. The reason was that none of them had had any preparation or any specific homework before the discussion session. They knew that a lot of examples could be found but during the interview time they were having difficulties to surface them. This was natural because it is not easy to stop someone 'cold' and ask for examples even if they are specialists in the field. Some of them promised to send further examples in emails later and with some, the author was able to get a further follow up appointment, which was productive.

6 MIND TRIGGERS

From the interviews and discussion sessions, notes were made of examples of each Principle but most of the examples were repeated and similar in nature. At this stage Dr. Paul Filmore who had ready solutions to many such difficulties, suggested using examples from other domains which can trigger minds and people would come up with similar examples from their own field. This trick proved to be very effective as the author(1) gathered a lot of examples in this part of the research phase. The interviewing process with this tactic continued and the author gathered a lot of examples compared to the previous approach. The author already had a folder with sections for each Principle and their examples. In the following discussion sessions, the author used the examples already gathered as further mind triggers and eventually this speeded up the process even more. In this way a good amount of examples for each Principle were recorded.

7 CLASSIFICATION

The next step was to classify the examples according to each Principle. There were already confusions about some examples like the term **triple play** [11] in broadband as an example of segmentation, combination, composite material or universality. Another term **clustering** raised questions about being an example of segmentation or composite materials, since by definition of composite; it could be a synonym of segmentation. To sort this out, it was needed to distinctly characterise the differences between the Principles, which could be thought of as the same. The papers discussed earlier also contained reasons for characterising Principles which could raise similar questions e.g., in the finance paper[1]; Principle 32 "Colour Change" could have an example of "Currency Colour" or "Colour of Money" (a term used in finance meaning relating to fund allocation). In that case "Colour of Money" is presented as example because the currency colour is more a matter of aesthetics, ergonomics, and error-proofing. In this paper, attempts are made to distinctly characterise Principles to avoid such confusions. For example in the case of segmentation and composite materials, the confusion was that both had the same meaning since in electronic communication, engineers discussed the architecture of a network only with respect to the way the system works, i.e. designing RF Planning and the mathematics and science involved behind its working. But this limited the scope of the project so it was decided to include examples from circuitry involved in electronic communication systems and the equipment used. With this the principle, Composite Materials was strictly confined (characterised) to the equipment used and manufacturing of equipment used in telecommunication. This meant clustering is characterised as an example of segmentation and not composite materials. But **triple play** [11] is easily an example of combination, universality and nesting because it provides multiple services in one package.

8 FURTHER WORK

In the original project specification, a further activity was specified which was to try out these new Principles with two local 'electronics' companies. The result from these trails on practical in-house problems was to further refine the Principle set presented here. As the original knowledge capture stage over ran, this stage nor the follow-on final stage of having the Principles checked by TRIZ practitioners, was completed. This is left to a continuation project next year.

9 SUMMARY

This paper details the knowledge capture undertaken to formulate a set of Principles in the communication and electronics engineering domain. A summary of the Principles is attached in the addendum. Future work will test and further refine this new Principle set by practical usage in engineering companies.

ACKNOWLEDGMENTS

We extend our sincere thanks to all who contributed to preparing the paper material. Special thanks to the faculty and staff at School of Computing, Communication and Electronics, University of Plymouth for their time and support. The authors also extent their gratitude to colleagues and friends at other universities and telecom companies who gave their support, time and knowledge in suggesting and refining this new TRIZ principle domain set.

REFERENCES

[1] Dourson, S. (2004) *The 40 Inventive Principles of TRIZ Applied to Finance,* http://www.triz-journal.com/archives/2004/10/07.pdf

[2] Retseptor, G. (2002) *40 Inventive Principles in Microelectronics*, The TRIZ Journal, August 2002, http://www.triz-journal.com/archives/2002/08/b/index.htm

[3] Teplitskiy, A., Kourmaev. R. (2005) *Application of 40 Inventive Principles in Construction*, http://www.triz-journal.com/archives/2005/05/03.pdf, accessed 1/8/08.

[4] Filmore, P. (2006) *The Real World: TRIZ in Two Hours for Undergraduate and Masters Level Students!* TRIZCON2006, Milwaukee, WI USA, April 2006.

[5] Filmore, P. (2007) *Teaching TRIZ as a Systematic Problem Solving Method: Breaking Mindsets*, TRIZCON2007, Louisville, Kentucky USA, 23-25th April 2007.

[6] Savransky, S. D. (2000) *Engineering of Creativity* CRC Press LLC ISBN 0-8493-2255

[7] Orloff, M.A. (2002) *Inventive Thinking Through TRIZ: A Practical Guide,* Springer Verlag, ISBN 3-540-44018-6

[8] TRIZ Journal (2008) http://www.triz-journal.com/archives/contradiction_matrix/, accessed 1/8/08.

[9] Insight Centre (2008) www.insightcentre.com/triz.html, accessed 1/8/08.

[10] Ayub, N. (2008) *TRIZ for Electronics Communications Engineering*, MSc thesis, University of Plymouth, (in preparation)

[11] Wikipedia (2008) http://en.wikipedia.org/wiki/Triple_play_(telecommunications), accessed 1/8/08.

[12] Mann, D. (2002) *Hands-On Systematic Innovation*, CREAX Press.

CONTACT

Dr Paul Filmore

University of Plymouth,

A320 Portland Square, Plymouth, PL4 8AA, UK

E-mail: pfilmore@plymouth.ac.uk

Phone: +44 (0) 1752 586231

FAX: +44 (0) 1752 586300

ADDENDIUM: THE 40 PRINCIPLES

(Based on the headings by Mann [12].) NB A comprehensive list will be published later [9, 10].

1. Segmentation

A. Divide a system into separate parts or sections.

- Clustering (cellular and/or wifi hotspots)
- For a range of different focal length lenses for a camera (cell phone) use one which is adjustable or use organic electronic lens (which changes focal length by varying voltage)
- Transmission mode (wired or wireless)
- Bandwidth (frequency bands, frequency reuse etc)
- GSM,CDMA, (2G, 3G,4G)
- Communication mode (telephone, fax, email, IM, VoIP)

B. Make a system easy to put together and take apart.

- Modules and functions in programming languages (especially Object Oriented)
- Splitting large computer networks into smaller subnets
- Plug and Play Devices/Operating Systems

C. Increase the amount of segmentation

- Segmenting a Larger Collision Domain in Computer Networks

- Sub dividing clusters for frequency reuse
  - Each cell has a base station. Cells when grouped together form a cluster. MSC (Mobile Switching Centre) is connected to all the base stations in a cluster. MSC itself is connected to MSCs of other clusters and to the PSTN (Public Switched Telephone Network)

2. Taking out

A. Where a system provides several functions of which one or more are not required (and may be harmful) at certain conditions, design the system so that they are or can be taken out.

- *Techniques t*o minimise interference
  - Frequency reuse
  - Using directional antennas
  - Using shielded cables
- Data Backup
- Encryption (use noise to encrypt)
- Test/Debug data for a Computer application's development stages

3. Local Quality

A. Where an object or system is uniform or homogenous, make it non-uniform

- Design equipment according to requirement of space. E.g. rack mount or tower routers and servers (in networks)
- Use drawer mounted keyboards to operated system computers.
- Use KVM switches to operate many computer systems via one keyboard/monitor display

B. Change things around the system (e.g. the environment)) from uniform to non-uniform

- Use of Variable Length Subnet Masking in a subnet
- Different modules/libraries functioning in a computer software
- Office software including word processing, spreadsheets and database programs

4. Asymmetry

A. Where an object or system is symmetrical or contains lines of symmetry, introduce asymmetry.

- Antenna Structure (size or area)
- Network architecture

B. Change the shape of an object or system to suit external asymmetries (e.g. ergonomic features)

- Special connectors with complex shape/pin configurations to ensure correct assembly

C. If an object or system is already asymmetrical, increase the degree of asymmetry

- Antenna design
- Networking structure
- Special connectors with complex shape/pin configurations to ensure correct assembly

5. Combination

A. *Physically join or merge identical or related objects, operations or functions.*

- Home entertainment centre
- Multi SIM handsets
- Share frequency band and antenna by multiple operators (cellular)
- Network Bridge (different subnets in LAN/WAN)

B. Join or merge objects, operations or functions so that they act together in time.

- Satellite TV
- Broadband (Triple Play)
- Internet radio
- VoIP

6. Universality

A. Make an object or system able to perform multiple functions; eliminating the need for other systems.

- Multiband handset
- Automatic Voltage Selector (110/220)
- Email, voice, text, conference calls, video calls in one package
- Personal Computer (used for many types of communication including voice and video)
- Broadband
- IP network
- Home entertainment centre

7. Nesting

A. Put one object or system inside another

- Camera in phone
- Mobile TV
- Use large touch screen instead of keypad
- GPS

B. Put several objects or systems inside others.

- Smartphone (office, mobile, GPS, calendar, calculator, internet)
- Navigators in Smartphone
- Call waiting, voice sms (short audio message), answering machine, text message, mms, speed dial functions within a handset (or service)

C. Allow one object or system to pass through an appropriate hole in another.

- Operational Amplifiers
- Darlington Transistors
- Retractable cables in electronic equipment

8. Counterweight

A. Where the weight of an object or system causes problems, combine it with something that provides lift.

- Multi SIM cell phones (used instead of taking off SIM and replaced by different one with different operator/carrying more than one handsets(useful for people who use different numbers/phones for home and work))
- Use solid-state electronic devices and heavy battery for longer life
- Use mobile signal for charging

B. Where the weight of an object or system causes problems, use aerodynamic, hydrodynamic, buoyancy and other forces to provide lift.

- Using hands free/ Bluetooth listening device with cell phone
- Circuit breakers instead of fuse wires
- Phone charging via Bluetooth
- Retractable car antenna

9. Prior Counteraction

A. Where an action contains both harmful and useful effects, precede the action with opposite or anti-actions to reduce or eliminate the harmful effects.

- Using repeaters/switches in networks
- Using Optical Amplifiers in Internet cable (submarine cable systems)
- Quality of Service (QoS)
- Using directional antennas for increasing range

B. Introduce stresses in an object to oppose known harmful working stresses later on.

- Security software in PC
- Firewall
- System restore/backups
- Uninterrupted Power Supply (UPS) in case of Power failure

10. Prior Action

A. Introduce a useful action into an object or system (either fully or partially before it is needed.

- Clustering to minimize interference
- Using directional antennas for increasing range

B. Pre-arrange objects or systems such that they can come into action at the most convenient time and place.

- Using cordless phone instead of traditional telephone

11. Cushion in Advance

A. introduce emergency backups to compensate for the potentially low reliability of an object ('belt and braces')

- Dual channel communication system
- Using UPS (Uninterrupted Power Supply)
- Data Backup /Zip-Files
- Battery back-up
- Automatic save operations performed by computer programs
- The Motorola MC68000 and initial Intel microprocessors had unused pins which were used in later models
- Installing extra antennas on BTS
    - **Base Transceiver Station** (**BTS**) is the equipment which facilitates the wireless communication between user equipments (mobile phones, wireless modems, WiFi etc) and the network (operator)
- Circuit breakers

12. Equipotentiality

A. If an object or system requires or is exposed to tension or compression forces, redesign the object's environment so the forces are eliminated or are balanced by the surrounding environment

- Frequency remain same throughout a cluster in cellular communication
- Multiple operators share the same band of frequency !
- Common ground (electrically) between connected devices

13. Inversion

A. Use an opposite action(s) used to solve the problem (e.g. instead of cooling an object, heat it).

- Modulation/Demodulation
- Coding Decoding

B. Make movable objects fixed, and fixed objects movable.

- Data Encryption
- Signal distortion for security
- Data Compression
- Voice commands in handsets

14. Spheroidality

A. Turn straight edges or flat surfaces into curves

- Change shape of the antenna (straight edges or flat surfaces into curves and vice versa)
- Error detection and correction

15. Dynamicity

A. Allow a system or object to change to achieve optimal operation under different conditions.

- Equipotentiality
    - Grounding the chassis of large electronic equipment containing different modules operating simultaneously. In that case we can save extra wiring for common grounding these equipments.
    - Ground equipotentiality in electrical wiring to avoid shocks
- Wireless communication

B. Split an object or system into parts capable of moving relative to each other.

- Rotating antennas
- Satellites in outer space

C. If an object or system is rigid or inflexible, make it movable or adaptable.

- Mobile handsets
- Universal handsets

D. Increase the amount of free motion

- External hard drives/flash memories
- External memory chips for mobile phones
- Extra batteries

16. Partial, overdone or excessive action

A. If exactly the right amount of an action is hard to achieve, use 'slightly less' or 'slightly more' of the action, to reduce or eliminate the problem.

- Extra battery in equipment
    - For power surges
    - Can be useful in devices that are on move (for longer journeys e.g. 9 cell laptop battery last longer than a 6 cell battery)
    - An extra battery to retain certain data in memory)
- UPS at Base Stations and towers
- Using excessive power to transmit

17. Moving to a new dimension

A. If an object contains or moves in a straight line, consider use of dimensions or movement outside the line.

- Multipath (LOS + Reflected waves) in wireless communication

B. Use a stacking arrangement of objects instead of a single level arrangement.

- Using touch screen in handsets (bigger screen and can serve keypad)
- Double sided PCBs

C. Re-orient the object or system, lay it on its side.

- Wifi access points instead of switches and hubs
- Cordless telephone sets

D. Use 'another side' of a given object or system.

- Mount computer chip components on both sides of a silicon card

18. Mechanical vibration

- Temperature and mechanical vibration change characteristics of laser in optical fibre communications
- A surface acoustic wave (SAW), which is used as signal delay line, involves the mechanical transmission of a wave that travels on the surface of a material
- Accelerometer in new phones
- Reaction of equipments (antennas, switches, amplifiers, power supplies etc) to shock and other physical disturbance

19. Periodic action

A. Replace continuous actions with periodic or pulsating actions.

- Logging events within a system
- Communication signals with periodicity

B. If an action is already periodic, change the periodic magnitude or frequency to suit external requirements.

- Dots and dashes in Morse Code transmissions
- CDMA techniques
- Packet switching in telephone communications

C. Use gaps between actions to perform different useful actions.

- Temporary Servers operation during backup

20. Continuity of useful action

A. Make all parts of an object or system work at full load or optimum efficiency, all the time.

- Parallel processing (clustering) in computer networks
- Transmission through power lines

B. Eliminate all idle or non-productive actions or work.

- Digital storage media allow ‘instant’ information access (as opposed to tapes which require to be rewound)
- Using DSP in communication

21. Rushing through

A. Conduct an action at very high speed to eliminate harmful side-effects.

- Compression and coding of data
- Packet transmission
- New technology
- Skipping security at unimportant access points (or data source)

22. Convert harm into benefit

A. Transform harmful objects or actions (particularly, the environment or surroundings) so that the deliver a positive effect.

- Multipath strengthens the signal
- Polarization (of wave) covers for absence of direct LOS (Line of Sight) in wireless communication

B. Add a second harmful object or action to neutralize or eliminate the effects of an existing harmful object or action

- Using noise for distortion (encryption) of signal
- Repeaters (switches) in computer network can also function as nodes

C. Increase a harmful factor to such a level that it is no longer causes harm.

- Increase the level of encryption of signal so the leakage risk is minimised.
- Using routers instead of switches in computer networks

23. Feedback

A. Introduce feedback to improve a process or action.

- Acknowledgment signals in communications

B. If feedback is already used, make it adaptable to variations in operating requirements or conditions.

- QoS calculation
- Operational Amplifiers with different feedback can serve as oscillator, amplifier, integrator, adder, differentiator

24. Mediator (Intermediary)

A. Introduce an intermediary between two objects, systems or actions.

- Retractable cord in telephone receiver
- USB peripherals for PC (USB memory, USB WLAN etc)
- UPS

B. Introduce a temporary intermediary which disappears or can be easily removed after it has completed its function.

- Car Antenna
- Retractable antenna in handsets

25. Self-service

A. Enable an object or system to perform functions or organise itself.

- Charging cell phone by Bluetooth or operator’s signal
- Voice commands in phones
- Programmable devices
- Answering machines

B. Make use of waste resources, energy, or substances.

- Use noise for distortion (encryption) of signal
- Solar cells

26. Copying

A. Use simple and inexpensive copies in place of expensive, possibly vulnerable objects or systems.

- Virtual mock-ups/electronic pre-assembly modelling
- Data compression and coding
- Encryption

B. Replace an object, or action with an optical copy.

- Backups
- Transient copying (from public sources like internet)
- Carbon copy (electronic) in email

C. If optical copies are already being used; make use of infrared or ultraviolet wavelengths

- Conference instant messaging (internet)
- Conference calls

27. Inexpensive short life

A. Replace an expensive object or system with a multitude of inexpensive, short-life objects.

- Mobile handset
- Electronic components
- Organic electronics/semiconductors (inexpensive)
- Low quality batteries
- Low quality cables (in office buildings since expensive cables are replaced with new (and non-compatible) technology)
- Ad-hoc networks

28. Replacement of a mechanical system

A. Replace an existing means with a means making use of another sense (optical, acoustic, taste, touch or smell).

- A keypad in cell phone
- Mechanical dial replaced by touch tone keypad in traditional telephone set
- Mechanical switches replaced by transistors

B. Introduce electric, magnetic or electromagnetic fields to interact with an object or system.

- Field-activated switches
- Mechanical timers replaced by electronic timers
- Mechanical shutter replaced by optical sensors (cameras)
- Fingerprint/retina scan instead of a key

C. Change from static to movable, fixed to variable, and/or from unstructured to structured fields.

- Early communications used omni-directional broadcasting. We now use antennas with very detailed structure of the pattern of radiation.

D. Use fields in conjunction with field-activated (e.g. ferromagnetic) objects or systems.

- Traditional antennas (retractable) replaced by solid state antenna

29. Use pneumatic or hydraulic systems

A. Use gases and liquids instead of solid parts or systems

- Liquid Crystal Display (LCD)
- Organic semiconductors, OLEDs
- Rechargeable batteries (e.g. Li-ion batteries)

30. Flexible film or thin membranes

A. Incorporate flexible shells and thin films instead of solid structures

- Flexible electronics (OLED)
- Organic touch sensitive display to make thin and flexible (bendable/foldable) phones

B. Isolate an object or system from a potentially harmful environment using flexible shells and thin films.

- Stored energy in flexible bags – e.g. accumulators in a hydraulic system

31. Use of porous materials

A. Make an object porous or add porous elements

- Drill holes in electronic device's casing to reduce the weight
- Electronic or digital filters (low pass, hi pass, band pass etc)

B. If an object is already porous, add something useful into the pores.

- Digital filters using microprocessors and microcontrollers
- Drill holes in device's casing for air flow and cooling of electrical components

32. Changing the colour

A. Change the colour of an object or its surroundings.

- Coloured wires for different signals
- Different colours for different modules within a system
- GREEN for dial/accept and RED for drop/reject call (in handsets)
- Coloured wires in Networking cables (UTP, STP etc)

B. Change the transparency of an object or its surroundings.

- Different colours for different communication ports in a PC
- CISCO colour cabling for Console and AUX Ports

C. In order to change the visibility of things, use coloured additives or luminescent elements

- UV marker pens used to mark computers in public offices
- Reflecting paint on BTS towers and antennas

D. Change the emissivity properties of an object subject to radiant heating

- Use of parabolic reflectors in solar panels to increase energy capture.
- Paint object with high emissivity paint in order to be able to measure it's temperature with a calibrated thermal imager.

33. Homogeneity

A. Make interacting objects from the same material (or material with matching properties).

- Making a device of metal acting as common ground
- Designing ports in a way to prevent accidental plugging (e.g. RJ45, PC ports, power plugs, power cables etc)
- Special connectors with complex shape/pin configurations to ensure correct assembly

34. Rejecting and regenerating parts

A. Make elements of an object or system that have fulfilled their functions disappear (by dissolving, evaporating, etc.) or appear to disappear.

- Repeaters and Switches
- Electronic/Digital filters
- Amplifiers
- Memory functions in telephones/mobiles for contacts directory, dialled numbers etc
- Wireless channels
- CDMA
- Token Ring topology for computer networks
- TCP/IP

- Dialling through PSTN, mobile telephone networks
- TV channels
- Radio channels

B. Restore consumable or degradable parts of an object or system during operation.

- Encryption
- Coding/Decoding
- Modulation/Demodulation

35. Transforming physical or chemical states

A. Change an object's physical state (e.g. to a gas, liquid, or solid).

- Transformation (using transducers) to transform voice/video/data/text into electrical/optical/electromagnetic signal and vice versa
- Coding and decoding signals

B. Change concentration or consistency.

- Encryption types for different levels of security
- Modulation and demodulation of signals

C. Change the degree of flexibility.

- Heat sink for electronic components act as antenna
- Retractable antennas

D. Change the temperature.

- Antenna characteristics change with temperature
- Design antenna according to environment/region
- Design equipment according to environment/region

E. Change the pressure.

- Equipment function at altitude
- Antenna structure for optimum performance at different altitude

36. Phase transition

A. Make use of phenomena taking place during phase transitions (e.g. volume changes, loss or absorption of heat, etc.).

- Dispersion and polarization of electromagnetic waves (signals)
- Distortion of signal (because of noise and interference etc)
- Transformation of signal from one form to another (e.g. electrical to optical etc)
- Delta-Wye (Δ-Y) and Wye-Delta (Y-Δ) transformation of electricity in high power transmission lines

37. Thermal expansion

A. Use thermal expansion (or contraction) of materials to achieve a useful effect.

- Transmission wires and towers
- Antenna characteristics change with temperature
- Heat sink for electronic components
- Super cooling conductors for superconductivity
- Super heating semiconductors for superconductivity

B. Use multiple materials with different coefficients of thermal expansion to achieve different useful effects.

- Bi-metallic strips used for thermostats, etc
- Two-way shape memory alloys.
- Combine materials with positive and negative thermal expansion coefficients to obtain alloys with zero (or specifically tailored) expansion properties – and use in installing equipment at high temperature zones

38. Use strong oxidisers

- Using phosphorous (oxidiser) for glowing in lamps
- Using phosphorous in camera flash for high intensity light

39. Inert environment

- Necessary in public places like hospitals etc to avoid electromagnetic interference (EMI)

40. Composite materials

A. Change from uniform to composite (multiple) materials where each material is optimised to a particular functional requirement.

- Use to make towers, handsets, networking equipments for extra strength
- Using composite materials in designing equipment can also increase aesthetics.

Further Development of the Trends of Evolution – Trend of Sustainability Increase

Sergei Ikovenko, Dr.-Eng, Ph.D., professor, TRIZ Master
GEN3Partners and Massachusetts Institute of Technology, USA

Abstract

Trends of Engineering System Evolution (TESE) are statistically proven directions of Engineering System (ES) development. They describe the natural transition of Engineering Systems from one state to another. These directions are statistically true for all categories of Engineering Systems. TESE, their mechanisms and tools are in the focus of TRIZ development these days. Major factors that drive the development of products through TESE are requirements of the supersystem.

An important requirement that has emerged lately is a requirement of sustainability. The article describes a new step in TESE development – Trend of Sustainability Increase: in the process of the evolution of ES the degree of its sustainability increases. The sustainability here includes multiple factors – recycling, reuse, etc.

A number of mechanisms (sub-trends) have been also discovered. For example, a sub-trend: non-recyclable→ recyclable material→several recyclable materials→reusable parts modification→using parts with no modification.

Keywords

TRIZ, Trends of Evolution, Sustainable Design, Sustainability, Contradiction.

1. INTRODUCTION

Sustainable Design is the systematic application of environmental considerations to product design at all stages of a product's life cycle. These stages include resource extraction, manufacturing, shipping/transport, useful life, and end of life (from cradle to grave or cradle to cradle). The ultimate goal of Sustainable Product Design is to create systems that enable us to produce and consume goods and services without compromising our future. To achieve it requires a redesign of goods and services so that they are eco-efficient and/or eco-effective.

The essential aim of sustainable design is to produce places, products and services in a way that reduces use of non-renewable resources, minimizes environmental impact, and relates people with the natural environment. Sustainable design is often viewed as a necessary tool for achieving sustainability. It is related to the more heavy-industry-focused fields of industrial ecology and green chemistry, sharing tools such as life cycle assessment and life cycle energy analysis to judge the environmental impact or "greenness" of various design choice.

While the practical application varies among disciplines, some common principles are as follows:

- Low-impact materials: choose non-toxic, sustainably-produced or recycled materials which require little energy to process
- Energy efficiency: use manufacturing processes and produce products which require less energy
- Quality and durability: longer-lasting and better-functioning products will have to be replaced less frequently, reducing the impacts of producing replacements
- Design for reuse and recycling: "Products, processes, and systems should be designed for performance in a commercial 'afterlife'."
- Biomimicry: "redesigning industrial systems on biological lines ... enabling the constant reuse of materials in continuous closed cycles..."
- Service substitution: shifting the mode of consumption from personal ownership of products to provision of services which provide similar functions, e.g. from a private automobile to a carsharing service. Such a system promotes minimal resource use per unit of consumption (e.g., per trip driven).
- Standardization and modularity: standard, modular parts allow products to be repaired rather than replaced and promote interoperability so that systems can be upgraded incrementally rather than wholly scrapped and replaced.

Design engineers have a tough job, balancing safety, energy efficiency, and cost with the consumer's passion for the latest and greatest technology. Unfortunately, it seems that the design engineer rarely even gets to the point of thinking about what will happen to the product at the end of its useful life. At most manufacturing companies, the folks in the environmental department are usually concerned with the product's environmental impact, but they are primarily focused on the manufacturing operations and the operating life of that product. Good intentions aside, it seems that most folks don't give much thought to what happens to a product when it has reached the end of life. We have simply relied on the scrap recycling industry to deal with that problem and, up to now, recyclers have done a good job. However, as time goes by and new materials and technologies are developed, the challenge that recyclers face in safely and economically recycling those products grows ever more difficult. The issue becomes more and more vital and urgent.

To address these challenges, the concept of Design for Recycling was created to help protect the environment and create a sustainable means for conserving our resources. Design for Recycling seeks to achieve two very basic goals: first, to eliminate or reduce the use of hazardous or toxic materials that may present a grave danger to the environment or put a recycler's workforce in jeopardy, and second, to discourage the use of materials that are not recyclable or manufacturing techniques that make a product non-recyclable using current technologies. The best time to address these issues is at the design stage.

Addressing a product's end-of-life is essential at the very beginning. Adopting this premise helps to ensure a thriving recycling chain, which goes well beyond the scrap processor to the mill, smelter, or extruder who will take the recycled materials and make them into new steel, copper, brass, aluminum or plastics. Design for Recycling is a mindset that every design engineer must embrace if they hope to have their products considered environmentally friendly. The days of a manufacturing just concerning itself with the environmental impacts of its manufacturing process and its products during their useful lives are long gone – it is essential to design products having in mind their recycling.

Over the years, industry has faced significant challenges from materials such as cadmium, lead, to name a few. In each instance, engineers worked with the industry that has used these materials to seek alternatives that will still meet their needs and satisfy the customers' desires while still protecting the environment and workers involved.

There's more than environmental compliance at stake here. As new materials are developed, such as graphite composites, they pose a new threat to the recycling of products. As these new materials are introduced into products, displacing materials that have been recyclable for generations, they adversely affect the recyclability both practically and fiscally. Both can have a devastating impact.

Even materials that are recyclable can pose a problem when used in combination. Take for instance a product that uses many different types of plastics. Today's recycling technology is such that it is very difficult to mechanically segregate more than two or three different types of plastic and hand sorting is simply not a cost effective means of accomplishing the job. A product that utilizes six, seven, or more polymers effectively becomes non-recyclable, or at least the plastics fraction of that product will be non-recyclable.

In sustainable design the concepts of Design for Reuse and Design for Disassembly go hand in hand with the Design for Recycling.

Recycling is the reprocessing of materials into new products. Recycling prevents useful material resources being wasted, reduces the consumption of raw materials and reduces energy usage, and hence greenhouse gas emissions, compared to virgin production [1]. Recycling is a key concept of modern waste management and is the third component of the waste hierarchy. Recyclable materials, also called "recyclables" or "recyclates", may originate from a wide range of sources including the home and industry. They include glass, paper, aluminium, iron, textiles and plastics. Biodegradable waste, such as food waste or garden waste, is also recyclable with the assistance of micro-organisms through composting or anaerobic digestion. Recyclates need to be sorted and separated into material types. Contamination of the recyclates with other materials must be prevented to increase the recyclates value and facilitate easier reprocessing for the ultimate recycling facility.

TRIZ can be effectively used for both sustainable design problem identification and for problem solving. The essence of problem identification lies with determining so called eco-contradictions that is contradictions that derive from contradictory requirements of the Design for Reuse, Design for Recycling, Design for Disassembly etc. and the operational specifications for a product.

Typical requirements of the Design for Recycling, Design for Reuse and Design and Design for Disassembly, for example, are:

- remove subassemblies that can be resold as is.
- remove hazardous materials
- separate the remaining materials into single materials with as little effort as possible
- use modules (consolidated parts) that can be removed and reused in other applications
- mark all materials for identification that cannot be sorted easily
- make parts easy to disassemble
- reduce materials and energy invested in the parts
- reduce the number of parts
- reduce the part size
- reduce the time to assemble
- eliminate redundant components
- use recycled materials where possible
- reduce scrap
- evaluate materials chosen for their environmental impact, and recyclability
- minimize waste in production processes
- packaging should be eliminated, or replace with reusable packaging
- when reliability is a problem, make the components easy to maintain and repair.
- avoid finishing operations that might contaminate materials
- use snap fits that can be undone or broken easily
- mark the location of snap fits so that they can be separated quickly
- reduce the fastener count
- avoid threaded and permanent fasteners (for example, glue)
- reduce the number of components to reduce the number of steps in disassembly
- assembly from top in layers so that parts can be picked off
- avoid parts with mixed materials
- etc.

Analyzing the recommendations that were derived from Design for Recycling and Reuse and from Design for Sustainability in general we can clearly see several generic mechanism that focus on the same objective – to increase the level of sustainability of the engineering systems. That brought up a hypothesis that there was a Trend of Sustainability Increase: in the process of its evolution the sustainability of engineering systems increases. It is obvious that such a statement is a sub-trend on the Ideality Increase Trend.

Further analysis of engineering systems in sustainability patents, designs as well as increasingly tough regulations of EPA and other environmental agencies allowed to distill several more granular mechanisms that express the general notion of sustainability increase:

1. Recyclability – Usage Increase

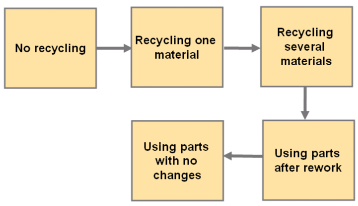


Figure 1: Recycling-Usage Increase

2. Hazardous materials reduction

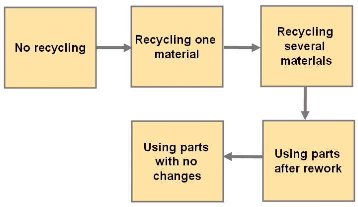


Figure 2: Hazardous material reduction

3. Part modification

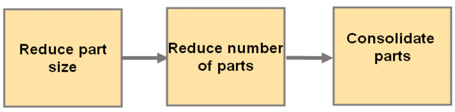


Figure 3: Part modification

4. Fasteners

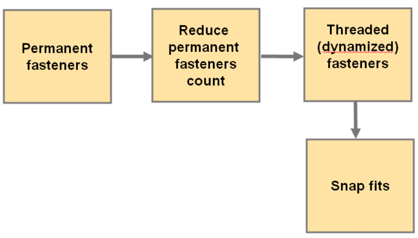


Figure 4: Fasteners

There are several more mechanisms, but they require further confirmation and research. However eco-efficiency becoming an important MPV (Main Parameter of Value) for many systems, Trend of Sustainability Increase gets very interesting for system development and evaluation.

The TRIZ tools in general can be effectively used for problem identification here are Function Analysis, Trimming and Function- Oriented Search.

2. FUNCTION ANALYSIS AND ECO-CONTRADICTIONS PROBLEMS

Function Analysis is a primary tool for identifying eco-contradictions. The algorithm is rather simple:

1. Build a function model of a product/engineering system following the requirements of the operational specifications.
2. Build a function model of a product/engineering system following the requirements if the Design for Recycling, Reuse and Disassembly.
3. Juxtapose these function models.
4. Identify eco-contradictions.

Example: Filter bags for bag-houses for cleaning industrial gases should be durable: the non-woven fibers should be well entangled, the bag should withstand intensive abrasion against the supporting cage of the bags during the regeneration (especially in case of pulse jet cleaning). The fibers of the bags may have complex nomenclature – they may contain biodegradable threads and non-biodegradable or even threads that may be toxic when deposited into a landfill (Figures 5-7).

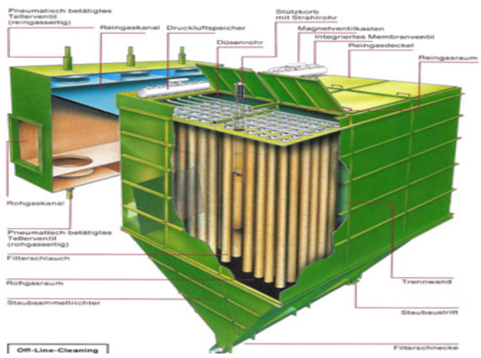


Figure 5: Bag filter with pulse-jet cleaning

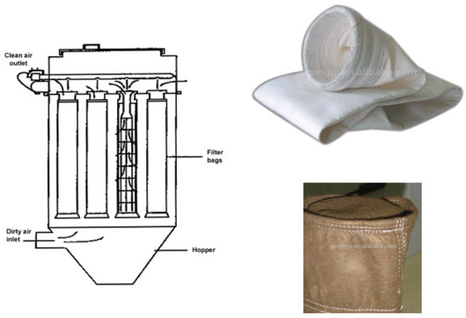


Figure 6: Non-woven filter bags

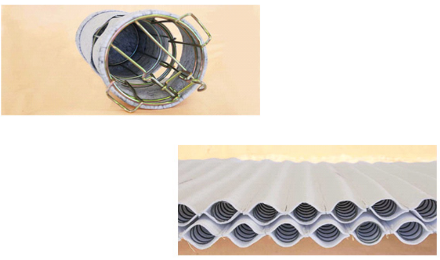


Figure 7: Supporting wire cages of the filter bags

At the same time, the requirements of the Design for Recycling the bags should be:

- easy to disassemble – the fibers should be free from each other
- the toxic threads should be easily extracted and encapsulates (should be loose and free)
- the fibers should be weak and easy to break, etc.

We build two function models that correspond to two different life stages of the filter – during its operation and during its recycling (Figure 8 and 9)

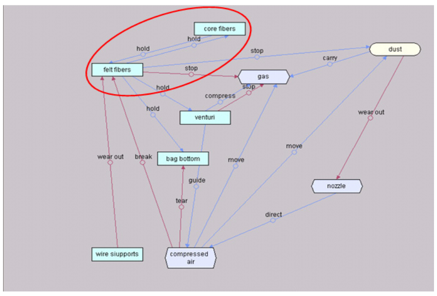


Figure 8: Function model during operation

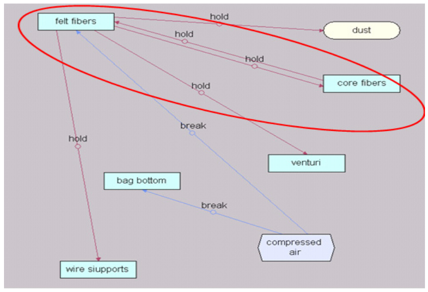


Figure 9: Function model during recycling

Juxtaposing the models allows to formulate a physical contradiction that can be resolved in time: the strength of core fibers should be high to provide durability of the bags and it should be low to guarantee fast bag destruction and biodegradation during the recycling (so called eco-contradiction). It can be addressed using usual TRIZ tools.

3 TRIMMING AND TRIMMING ECO-PROBLEMS

There is a number of requirements of the Design for Recycling, Reuse and Disassembly that appeal to Trimming directly. For example:

- reduce materials and energy invested in the parts
- reduce the fastener count
- reduce the number of components to reduce the number of steps in disassembly
- avoid finishing operations that might contaminate materials eliminate redundant components
- etc.

To identify eco-trimming problems:

1. Build a function model of a product/engineering system following the requirements of the operational specifications.
2. Perform Trimming according to the Design for Recycling, Reuse, Disassembly.
3. Identify Trimming Eco-Problems.

4 FUNCTION-ORIENTED SEARCH AND ECO-SUBSTITUTION PROBLEMS

The environmental benefits of recycling are well known. Many businesses, governments, and households are collecting discards for recycling, and are recovering more materials than ever before. In fact, over one-fifth of the municipal solid waste generated in our country is currently recycled or composted. Despite progress in recycling, however, people are still generating too much waste. Every day, on average, each individual discards about four pounds of material. These discards burden both the environment and our economy.

Even recycling, which adds major economic and environmental benefits, creates economic and environmental costs. The best approach to our solid waste challenge is to cut the creation of waste in the first place. Waste that is not created does not have to be managed later. That's why waste prevention (reducing and reusing) is the ideal solid waste solution.

Waste prevention involves altering the design, manufacture and other life stages of a product towards either reducing the usage of the resources or at least substituting the expensive, toxic or hazardous materials with cheaper, environmentally benign and biodegradable substitutes.

As soon as the substitution gets into the picture Function-Oriented Search (FOS) can be effectively used for this purpose. Knowing what functions the undesirable components/materials perform a less harmful substitute can be found using a usual algorithm for using FOS.

Some comments on eco-problem solving. Because the majority of contradiction can be successfully resolved by separating contradictory requirements in space, time, on conditions or system level as well as by satisfying them, a special role in problem solving belongs to so called smart materials.

Smart materials are materials that have one or more properties that can be significantly altered in a controlled fashion by external stimuli, such as stress, temperature, moisture, pH, electric or magnetic fields, etc. There are a number of types of smart material, some of which are already common. Some examples are as following:

- piezoelectric materials
- thermoresponsive materials, either shape memory alloys or shape memory polymers
- magnetic shape memory alloys are materials that change their shape in response to a significant change in the magnetic field.
- pH-sensitive polymers
- halochromic materials
- chromogenic systems (electrochromic, thermochromic, magnetochromic, etc. materials)
- etc.

CONCLUSIONS

1. Trend of Sustainability Increase that is a sub-trend of the Trends of Ideality Increase was described. There are several mechanisms through which the trend reveals itself. The mechanisms should be expanded, refined and there may be other mechanisms that belong to this trend.
2. TRIZ tools can be effectively used for problem identification in Sustainable Design.

   - Eco-Trimming problems
   - Eco-Substitution problems
   - Eco-Contradictions

   This with consecutive application of tools of classical TRIZ and Function-Oriented Search for problem solving.

REFERENCES

1. Fan Shu-Yang, Bill Freedman, and Raymond Cote (2004). "Principles and practice of ecological design". Environmental Reviews.
2. Ryan, Chris (2006). "Dematerializing Consumption through Service
3. Substitution is a Design Challenge". Journal of Industrial Ecology. 4(1).
4. S.Ikovenko, K.Stevenson. TRIZ as a Tools for Sustainable Design and Environmental Engineering. Abstracts for TRIZCON 2005, April17-19, 2005, Brighton, MI, USA.
5. S.Litvin. New TRIZ-Based Tool – Function-Oriented Search. ETRIA Conference TRIZ Future 2004. November 2-5, 2004, Florence, Italy.
6. S.Litvin. TRIZ Readings – Altshuller's Tradition Continues. ETRIA Conference TRIZ Future 2005. November 16-18, 2005, Graz, Austria.
7. Sergei Ikovenko. Course for Graduate Students, Massachusetts Institute of Technology, Cambridge, MA, USA, 2006-2008.
8. Lenox, M., Ehrenfeld, J., "Organizing for Effective Environmental Design", 1997, Business Strategy and the Environment, vol. 6, pp. 187-196
9. Brezet, J., Van Hemel, C., "Ecodesign: A Promising Approach to Sustainable Production and Consumption", 1997, United Nations Environment Programme (UNEP) publications

CONTACT

Sergei Ikovenko, GEN3Partners
10 Post Office Sq. Boston, MA, 02114, USA
E-mail : sergei.ikovenko@gen3partners.com
Phone: + 1- 617-728-7021
Fax: + 1- 617-728-7500

or

Sergei ikovenko
2 Hawthorme Place, suite 10 D;
MIT Center for Product Develipment
Boston, MA 02114
E-mail: sergeiikovenko@aol.com
Phone: +1-617-720-1811
Phone: +1-617-304-1646

Revising the TRIZ-based Business Idea Database to Find Customers' Potential Needs on Business and Technical Seeds to Resolve Them

Atsuko Ishida[1]
[1]Hitachi Consulting Co., Ltd., Japan

Abstract

The business idea database released in 2003 which used 40 principles of invention and the contradiction matrix suggested solutions of business problems from their essential subjects and contained contradictions. To improve effectiveness, it is revised with two points of view. One is that business contradiction statements for reminding unconscious and potential business problems are introduced. The other is that requirements analysis and definition techniques of software engineering and Enterprise Architecture framework are applied for finding technical seeds from suggested business ideas. The revised business idea database can be effective in finding unknown business needs and hidden technical seeds.

Keywords

TRIZ, Business Idea, Contradiction Statements, Technical Seeds

1 INTRODUCTION

The author proposed the business idea database which used 40 inventive principles and the contradiction matrix in 2003 [1], and a product lifecycle model including it in 2007 [2].

The business idea database gave several business idea statements to support flexible and creative thinking about solutions of contradictions on business. But it's difficult for users to find essential problems on business before use. Moreover it used patterns of technologies to extract feasible ideas from various options, but it might restrict creating variety of ideas.

The author attempted to revise the business idea database for improving creativity.

2 TO REVISE THE BUSINESS IDEA DATABASE

2.1 Objectives of the business idea database

The main object of the business idea database was to suggest solutions of problems on business. For the purpose, strategies of business or products were classified and essential subjects and contradictions on business were defined with them.

The business idea database was based on a hypothesis that new business models were born from contradictions which were generally believed to be irresolvable then.

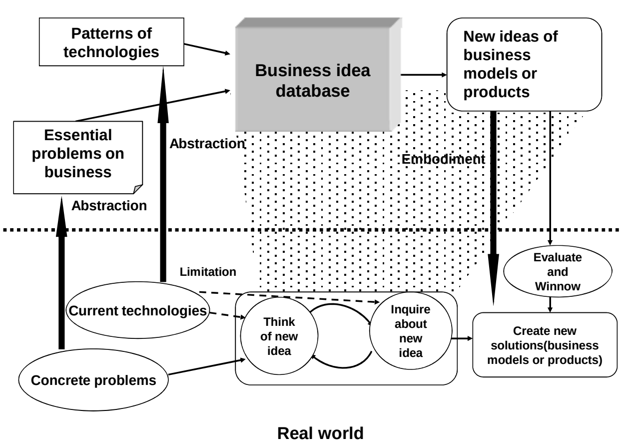


Figure 1: Concept of the business idea database.

Figure 1 shows a concept of the business idea database. Under a broken line, there is a concrete way of thinking and inquiring new idea. They are projected on elements of a way of generating ideas from the business idea database. Using the business idea database, it became easier to find new ideas of solutions. In the business idea database each business idea was linked with some patterns of technologies. Some patterns of technologies were accepted as input which were used for extracting feasible solutions from a variety of options.

2.2 Remaining problems for making creative business ideas

There were two kinds of inputs to the business idea database; essential problems on business and usable patterns of technologies. The author noticed that there remained two problems. One was that it's difficult to find essential problems, unknown needs or lurking risks on business. The other was that usable patterns of technologies conceived from current technical reports might prevent users' flexible imaginations.

To solve them the author attempted to introduce two ideas for revising the business idea database. Firstly, business contradiction statements would be prepared to support reminding unconscious problems. Secondly, extracting feasible ideas would be given up and a way of finding technical seeds from new ideas of business models or products would be introduced.

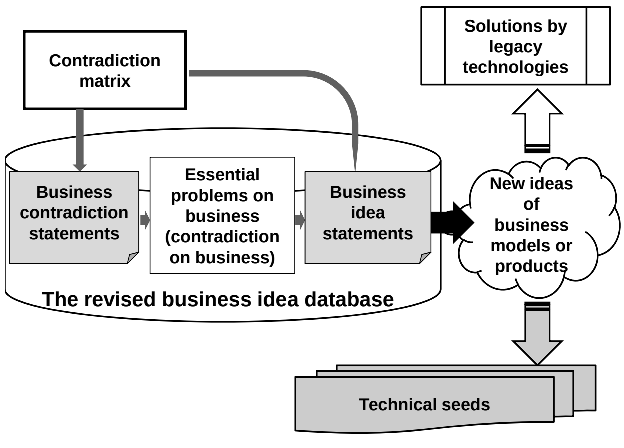


Figure 2: Concept of the revised business idea database

Figure 2 shows a concept of the revised business idea database. It is composed of two tables; a business contradiction statements table and a business idea statements table. The former is used for finding essential problems on business; the latter is used for generating new ideas of business models and products. Patterns of technology which were inputs to the original business idea database aren't used for the revised one any more. A new mechanism that generates technical seeds from business ideas is introduced, instead.

The original business idea database used 27 principles of invention extracted from 40 principles. The author classified business strategies beforehand, namely "expand business / products' functions", "concentrate business products' functions" and "change business process products' structure", then defined contradictions on business which were essential to business strategy [1][2]. Principles were translated to business idea statements but they were affected by business environment in 2003.

The revised business idea database is made from the same classification of business strategies and uses 27 principles of invention but they are retranslated for being good for long time. Table 1 shows 27 principles of invention with new business idea statements which are more general and universal than original ones.

3 THE REVISED BUSINESS IDEA DATABASE

3.1 Business contradiction statements

To assist finding essential problems on business from unknown business needs, or lurking risks, the author introduces business contradiction statements that encourage imaginations.

How to make contradiction statements

Business contradiction statements correspond to contradictions namely pairs of improving / degrading parameters which are bases of the revised business idea database. Firstly, basic contradiction statements are made from each pair of parameters. For example, from a contradiction based on 'power' vs. 'energy spent by moving object', a basic statement "It's highly influential without much efforts" is made. Secondly, several business contradiction statements are generated from each of basic statements. For example, business contradiction statements such as "It's noticeable but simple", "It's acceptable but unknown", and "It's unforgettable but usual" are generated from the basic statement mentioned above.

Table 2 shows business contradiction statements. Each statement is linked to a contradiction included in the revised business idea database. These statements remind users their potential needs on business.

How to use business contradiction statements

Imagine a situation that an importer wants to start new business. When he or she reads contradiction statements, 'It's unknown but acceptable' could make him or her imagine a potential business need. It might be imagined that a firm wants food imports into Japan from abroad be acceptable to Japanese in a case that safety of them has been unknown. It's a potential business need namely an essential problem.

3.2 Revised business idea statements

The revised business idea database is composed of two tables. The first half is the business contradiction statements table (table 2) mentioned above and the second half is the business idea statements table (table 3). They are combined with contradictions (pairs of improving / degrading parameters).

Tables 3 shows revised business idea statements made from principles of invention which are get from contradictions on business and translated to business idea statements according to table 1.

Figure 3 shows a process of getting business ideas from hidden business contradictions using the revised business idea database. It consists of 4 steps.

(1) Read contradiction statements and imagine an essential problem on business.

(2) Take an improvement parameter and a degrading parameter reversely from a contradiction statement using the business contradiction statements table.

(3) Use those parameters as input to the business idea statements table and take ideas written in business idea statements.

(4) Generate new ideas of business models or products from business idea statements. They are solutions of the essential problem imagined in (1).

For the example above, the revised business idea database gives "Capture essential point by removing insignificant details." based on 'partial of excessive action', "Make versatile, flexible, all purposed system." based on 'universality', "Do events periodically or take rests from usual tasks." based on 'periodic action' and "Utilize outside influence or external power and make friction." based on 'thermal expansion' as hints of business ideas. They suggest several solutions. For the example above "Use bush telegraph or various media for advertisements" or "Introduce competitive products and make conflicts" might be conceived.

Finding technical seeds is positioned after getting new ideas.

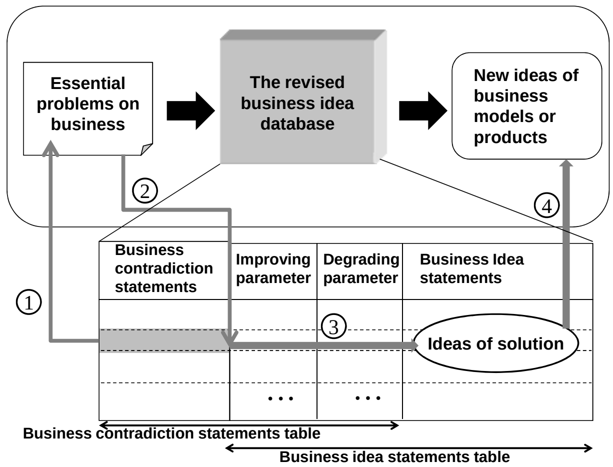


Figure 3: How to use the revised business idea database

3.3 Finding technical seeds from business ideas

The original business idea database included patterns of technologies which were used for extracting feasible business models or products from various options. The revised business idea database permits to produce various kinds of business ideas without winnowing candidate using current technologies. Produced ideas are classified into two categories; ideas which seem to be feasible with known technologies fall into one category and ideas which seem to be infeasible with them fall into the other one. Ideas in the latter category need new technical seeds.

To find technical seeds from new ideas of business models or products, the author attempted to introduce requirements analysis and definition techniques of software engineering. In a traditional requirement analysis method, analysts list many kinds of demands or requests in a field, classify them and get essential problems. Then they evolve feasible solutions. But a method adopted here is a top down approach which generates concrete requirements from new ideas of business models or products generated from the revised business idea database. A key issue is to make a To Be (ideal) model and an As Is (real) model from a new idea through requirement analysis (top down approach). It's based on a concept of Enterprise Architecture (EA) framework [3]. In a usual way of modelling based on EA framework, To Be model is made from As Is model. In a method adopted here, two models are made independently from the same idea.

There are several levels of gaps between a To Be model and an As Is model. Ways of bridging them are classified into two categories. Some ways can be realized with known technologies, others need new technologies. Latter cases could have possibilities of technical seeds.

Figure 4 shows a way of finding technical seeds from gaps between a To Be model and an As Is model. Two models are generated simultaneously. Each model is divided into four kinds of architectures. Business architecture is used for making business models. Data architecture, Application architecture and Technology architecture are used for making models which can be used for finding technical seeds. For As Is model, Data architecture defines what data is in place to support the business, Application architecture defines what application is in place to manage the data and support the business functions, Technology architecture defines what supporting technology is in place to provide an environment for applications that manage the data and support the business functions. For To Be model, Data architecture defines the data needed to support the business, Application architecture defines the application needed to manage the data and support the business function, Technology architecture defines the support technology needed to provide an environment for applications that manage the data and support the business functions. [3]

For finding gaps between models it's necessary to compare the same kind of architectures. If there are no usable technologies for bridging gaps, technical seeds might be lurking there.

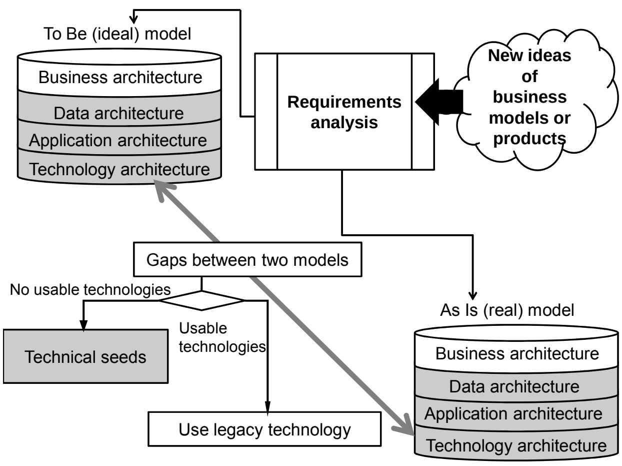


Figure 4: Find technical seeds based on requirement analysis

For the example mentioned above, the To Be model might be making profound impact on lifestyle and an As Is model might be a current advertisement. To bridge gaps between them a new medium which has special characteristics such as reliable, persuasive, or convincing is necessary. From other point of view, new technologies might enable to support with evidence, remove false information, or measure reliability.

4 CASE STUDY: TRAINING AND DEVELOPMENT

The author applied the revised business idea database to training and development tasks.

Background

A company-A is an IT consulting farm which has expanded sharply. Employees have been doubled in one year, from 300 to 600. The company-A is a subsidiary company of a mega farm. One third of employees are IT consultants who came from the parent company. One third are management consultants who came from global consulting firms. Others are IT engineers who came from engineering companies. They have different back grounds, different mind and different levels of the consulting skills. All employees need to learn the company-A's standard consulting mind and skills. Core members should have leadership and management skills as managers.

On the other hand, the company-A has not enough resources for training and development.

Essential problems

In business contradiction statements, "It endures pressure without a lot of effort." "It goes through many hardships but it's usual" fit to training and development of the company-A. An essential problem might be to make organization be tough as if employees dealt with business in a body without special effort.

Generated business idea statements

An improvement parameter related to the statement was 'Tension / pressure'. A degrading parameter was 'Energy spent by moving object'. The revised business idea database generated next four business idea statements.

(1) Approach with indirect way or make a detour to mitigate risks. (based on 'Spheroidality –curvature')
(2) Adopt agent, broker or mediate negotiator temporally. (based on 'Intermediary')
(3) Build in new devices or tricks for taking a business chance or mitigating risks. (based on 'Preliminary action')
(4) Utilize outside influence or external power and make friction. (based on 'Thermal expansion')

Concrete business ideas generated from business idea statements

The most noticeable statement on business was no.4 "Utilize outside influence or external power and make friction". The company-A includes many kinds of external man power, for example, management consultants from global consult farms, IT engineers from IT engineering companies, specialists of finance and others. It's possible for them to make frictions by exchanging trainers and trainees and stimulate each other. It's an evolution of 'learning organization' concept [4] which was spread in '90s. Key components of 'learning organization' are environment, process and action, and leadership for acceleration. The generated business idea might realize them automatically.

Finding technical seeds

As a technical point of view, the most noticeable statement was no.2 "Adopt agent, broker or mediate negotiator temporally". Figure 5 shows an example of mechanism to find technical seeds from a training & development case. To Be (ideal) model would be a set of autonomous coordinators of trainings. The human resource database would trigger appearance of coordinators. Each of them linked with trainers and trainees would support a training and would store information about it into human resource database. When the training would be finished it would disappear. As Is (real) mechanism might be a training entry and management system with a human resource database, which would be used for storing training histories. In an As Is model, training coordinators would be indispensable to plan, promote and operate training courses.

Gaps between a To Be model and an As Is model would be characteristics of autonomous, temporal and database driven. In each architecture, there could be technical seeds.

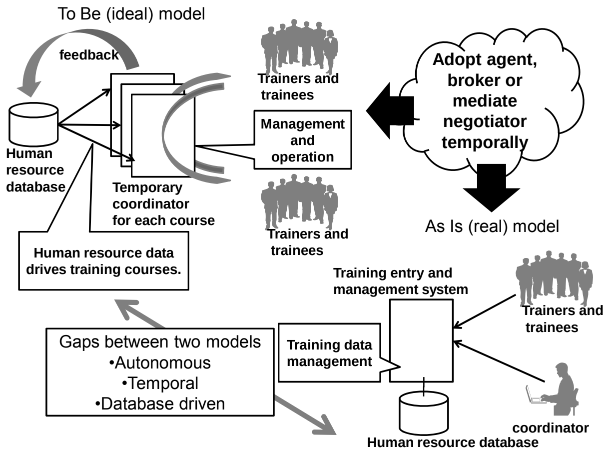


Figure 5: Finding technical seeds from a training & development case

5 SUMMARY

The business idea database made in 2003 was useful to support creating new ideas on business if users could find essential problems on business. But it's difficult for them to find unknown needs or lurking risks on business previously. The business idea database used patterns of technologies for extracting feasible solutions from various options. But it might restrict users' imagination and creativity.

The author revised the business idea database to improve creativity. The revised one has two features; one is preparing business contradiction statements to support reminding unconscious problems, the other is finding technical seeds from new ideas of business models or products using requirements analysis and definition techniques and Enterprise Architecture framework.

In the revised business idea database principles of invention are translated to more general and universal business idea statements than original ones.

To make readers comprehend the revised business idea database, a case of training and development of a company is presented.

REFERENCES

[1] A. Ishida, "Using TRIZ to Create Innovative Business Models and Products", ETRIA World Conference: TRIZ Future 2003.

[2] A. Ishida, "Innovation and quality need to go together for capturing value", ETRIA World Conference: TRIZ Future 2007.

[3] "Federal Enterprise Architecture Framework", The Chief Information Officers Council, September 1999.

[4] David A. Garvin, Amy C. Edmondson, Francesca Gino, "Is Yours a Learning Organization?", Harvard Business Review, March 2008.

CONTACT

Ms. Atsuko Ishida, Dr. Eng.

Technical Director

Hitachi Consulting Co., Ltd.

2-16-4 Konan, Minato-ku, Tokyo108-0075 Japan

E-mail: a.ishida@hitachiconsulting.co.jp

Phone: +81 (3) 5715-5139 - FAX: +81 (3) 5715-5510

Principles of invention	**Business idea statements**
Segmentation	Divide a system into different parts which can be moved flexibly.
Taking out	Divide a system into different parts and eliminate unnecessary parts.
Asymmetry	Old systems on old infrastructure and new systems on new infrastructure are intermingled.
Universality	Make versatile, flexible, all purposed system.
Asymmetry anti-weight	Divide a system into parts and add or change functions of them to optimize on the whole.
Preliminary action	Build in new devices or tricks for taking a business chance or mitigating risks.
Beforehand cushioning	Save space for mitigating risks.
Equipotentiality	Make flat organization and avoid volatile situation.
The other way round	Include various viewpoint such as stakeholders' view or minorities' view.
Spheroidality-curvature	Approach with indirect way or make a detour to mitigate risks.
Dynamics	Introduce parallel processing or use an autonomous distributed system for increasing flexibility.
Partial of excessive action	Capture essential point by removing insignificant details.
Another dimension	Change from flat shape to hierarchical one with slopes or hills.
Mechanical vibration	Vary usual process with events or structural reforms.
Periodic action	Do events periodically or take rests from usual tasks.
Skipping	Mitigate risks or troubles with speedy action.
Feedback	Get feedback from customers. If it's done already change feedback process.
Intermediary	Adopt agent, broker or mediate negotiator temporally.
Self-serving	Use long-lived components and recycle them.
Mechanics substitution	Stimulate sensibility and have influence on user's consciousness.
Pneumatics and Hydraulics	Defend against incidents or risks by expanding business temporally.
Colour change	Be contents visible by changing characteristic or including other contents.
Discarding and recovering	Purify or restore contents using extra mechanism.
Parameter change	Change a form of information or ways of accumulation or dispatching.
Phase transition	Hire outsider or expose to external pressure to change rigid organization.
Thermal expansion	Utilize outside influence or external power and make friction.
Strong oxidants	Enter outsiders to stimulate or make chemical reaction.

Table 1: Business idea statements (translated from principles of invention)

Business contradiction statements	Improving parameter	Degrading parameter
It endures pressure but its size is small. It goes through many hardships but it remains small.	*Tension/ pressure*	*Volume of moving object*
It endures pressure without a lot of effort. It goes through many hardships but it's usual.	*Tension/ pressure*	*Energy spent by moving object*
It's noticeable but remains small. It's acceptable but remains minority. It's unforgettable but little something.	*Power*	*Volume of moving object*
It's noticeable but simple. It's acceptable but unknown. It's unforgettable but usual.	*Power*	*Energy spent by moving object*
It's strong in niche area and not affected by depression. It's specialized in small area but not affected by environmental deterioration.	*Force*	*Tension/ pressure*
It's strong in niche area but noticed by many people. It's specialized in small area but acceptable on the whole.	*Force*	*Power*
Organization becomes slim but isn't affected by depression. Several business domains are detached but the remainder isn't fragile.	*Volume of moving object*	*Tension/ pressure*
Organization becomes slim but remains noticeable. Several business domains of a company are detached but it is acceptable.	*Volume of moving object*	*Power*
It promotes energy conservation and isn't affected by depression. Operation is simple and usual but it is sustainable.	*Energy spent by moving object*	*Tension/ pressure*
Operation is simple and usual but is unforgettable. It promotes energy conservation but remains powerful.	*Energy spent by moving object*	*Power*
Operation becomes speedy but its mechanism isn't complex. It moves faster without extra device.	*Speed*	*Complexity of device*
Operation becomes speedy without a lot of effort. It moves faster without extra energy.	*Speed*	*Energy spent by moving object*
Waiting time is reduced without extra device. Quick response is realized but mechanism remains simple.	*Waste of time*	*Complexity of device*
Waiting time is reduced without extra resource. Quick response is realized without a lot of effort.	*Waste of time*	*Energy spent by moving object*
It's easy to use without extra device. Its quality of use is increased but it remains simple.	*Convenience of use*	*Complexity of device*
It's easy to use without extra energy. Its quality of use is increased without a lot of effort.	*Convenience of use*	*Energy spent by moving object*
It becomes versatile but mechanism remains simple. Its flexibility is increased without extra device.	*Adaptability*	*Complexity of device*
It becomes versatile without a lot of effort. Its flexibility is increased without extra energy.	*Adaptability*	*Energy spent by moving object*
The process becomes fully automatic without extra device. Manual jobs become decreased but its mechanism remains simple.	*Level of automation*	*Complexity of device*
The process becomes fully automatic without a lot of effort. Manual jobs become decreased without extra energy.	*Level of automation*	*Energy spent by moving object Italic*
It lives long time without extra device. It has long lifecycle but its mechanism remains simple.	*Durability of moving object*	*Complexity of device*
It lives long time without extra energy. It has long lifecycle without a lot of effort.	*Durability of moving object*	*Energy spent by moving object*

Table 2: The revised business idea database (Business contradiction statements)

Improving parameter	Degrading parameter	Business idea statements
Tension/ pressure	*Volume of moving object*	Make versatile, flexible, all purposed system. Change a form of information or ways of accumulation or dispatching. Build in new devices or tricks for taking a business chance or mitigating risks.
Tension/ pressure	*Energy spent by moving object*	Approach with indirect way or make a detour to mitigate risks. Adopt agent, broker or mediate negotiator temporally. Build in new devices or tricks for taking a business chance or mitigating risks. Utilize outside influence or external power and make friction.
Power	*Volume of moving object*	Change a form of information or ways of accumulation or dispatching. Make versatile, flexible, all purposed system Enter outsiders to stimulate or make chemical reaction..
Power	*Energy spent by moving object*	Capture essential point by removing insignificant details. Make versatile, flexible, all purposed system. Do events periodically or take rests from usual tasks. Utilize outside influence or external power and make friction.
Force	*Tension/ pressure*	Vary usual process with events or structural reforms. Mitigate risks or troubles with speedy action. Save space for mitigating risks.
Force	*Power*	Do events periodically or take rests from usual tasks. Change a form of information or ways of accumulation or dispatching. Vary usual process with events or structural reforms. Utilize outside influence or external power and make friction.
Volume of moving object	*Tension/ pressure*	Make versatile, flexible, all purposed system Change a form of information or ways of accumulation or dispatching. Hire outsider or expose to external pressure to change rigid organization. Utilize outside influence or external power and make friction.
Volume of moving object	*Power*	Change a form of information or ways of accumulation or dispatching. Make versatile, flexible, all purposed system Include various viewpoint such as stakeholders' view or minorities' view. Vary usual process with events or structural reforms.
Energy spent by moving object	*Tension/ pressure*	Get feedback from customers. If it's done already change feedback process. Approach with indirect way or make a detour to mitigate risks. Use long-lived components and recycle them.
Energy spent by moving object	*Power*	Make versatile, flexible, all purposed system Do events periodically or take rests from usual tasks. Utilize outside influence or external power and make friction. Vary usual process with events or structural reforms.
Speed	*Complexity of device*	Build in new devices or tricks for taking a business chance or mitigating risks. Stimulate sensibility and have influence on user's consciousness. Old systems on old infrastructure and new systems on new infrastructure are intermingled. Purify or restore contents using extra mechanism.
Speed	*Energy spent by moving object*	Divide a system into parts and add or change functions of them to optimize on the whole. Introduce parallel processing or use an autonomous distributed system for increasing flexibility. Change a form of information or ways of accumulation or dispatching. Enter outsiders to stimulate or make chemical reaction.

Table 3: The revised business idea database (Business idea statements)

Improving parameter	**Degrading parameter**	**Business idea statements**
Waste of time	*Complexity of device*	Make versatile, flexible, all purposed system. Defend against incidents or risks by expanding business temporally.
Waste of time	*Energy spent by moving object*	Change a form of information or ways of accumulation or dispatching. Enter outsiders to stimulate or make chemical reaction. Do events periodically or take rests from usual tasks. Vary usual process with events or structural reforms.
Convenience of use	*Complexity of device*	Be contents visible by changing characteristic or including other contents. Use long-lived components and recycle them. Make flat organization and avoid volatile situation. Change from flat shape to hierarchical one with slopes or hills.
Convenience of use	*Energy spent by moving object*	Divide a system into different parts which can be moved flexibly. Include various viewpoint such as stakeholders' view or minorities' view. Adopt agent, broker or mediate negotiator temporally.
Adaptability	*Complexity of device*	Introduce parallel processing or use an autonomous distributed system for increasing flexibility. Defend against incidents or risks by expanding business temporally. Utilize outside influence or external power and make friction. Stimulate sensibility and have influence on user's consciousness.
Adaptability	*Energy spent by moving object*	Do events periodically or take rests from usual tasks. Change a form of information or ways of accumulation or dispatching. Defend against incidents or risks by expanding business temporally. Include various viewpoint such as stakeholders' view or minorities' view.
Level of automation	*Complexity of device*	Introduce parallel processing or use an autonomous distributed system for increasing flexibility. Adopt agent, broker or mediate negotiator temporally. Build in new devices or tricks for taking a business chance or mitigating risks.
Level of automation	*Energy spent by moving object Italic*	Divide a system into different parts and eliminate unnecessary parts. Be contents visible by changing characteristic or including other contents. Include various viewpoint such as stakeholders' view or minorities' view.
Durability of moving object	*Complexity of device*	Build in new devices or tricks for taking a business chance or mitigating risks. Old systems on old infrastructure and new systems on new infrastructure are intermingled. Defend against incidents or risks by expanding business temporally. Introduce parallel processing or use an autonomous distributed system for increasing flexibility.
Durability of moving object	*Energy spent by moving object*	Stimulate sensibility and have influence on user's consciousness. Make versatile, flexible, all purposed system. Change a form of information or ways of accumulation or dispatching. Vary usual process with events or structural reforms.

Table3: The revised business idea database (Business idea statements) (cont.)

TRIZ contribution to the solution of the paradox during the homogenization of molten glass

Pavel Jirman[1], Bohuslav Bušov[2]
[1]The Technical University of Liberec, Czech Republic
[2]The Brno University of Technology, Czech Republic

Abstract

Homogenization of molten glass before hot forming is one of the most important operations to achieve a high quality of glass. Homogenization is provided mainly by a mechanical way (mixing by stirrers) which has a lot of disadvantages and problems. However, it is the most effective way at present. For a long time tests with thermal mixing have been made which means that a better motion of molten glass by a change of temperature is being searched. There exist a lot of patents and a lot of implementations of equipment. However, the effectivity similar to mechanical mixing has not yet been reached.

Also the trends of evolution of the TRIZ method predict that the transition from a mechanical to a thermal field should be more effective. Therefore, this forms the paradox of the glass homogenization development. The TRIZ method analysis helped to find the reason of lower effective thermal mixture at present and designed the idea how to overcome this paradox. A demonstration of this analysis is the subject of this article.

Keywords

TRIZ, technical system (TS), homogenization of molten glass, contradictions, SuField Analysis

1 INTRODUCTION

Production of glass products includes a lot of operations. It concerns glass melting, hot forming and cold working of glass. Homogenization of molten glass is a part of molten glass preparations - see Figure 1. Homogenization of molten glass before hot forming is one of the most important operations for achieving high quality of glass. The homogenization decreases the temperature difference in molten glass and removes inhomogeneity in molten glass.

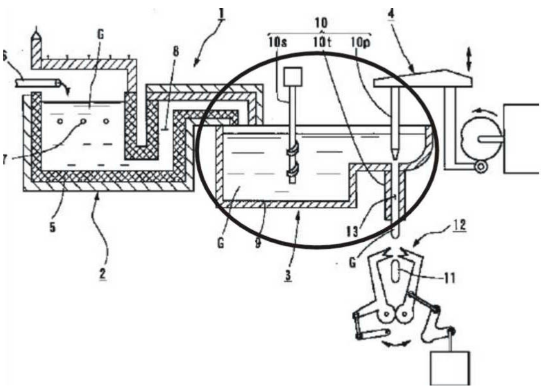


Figure 1: Glass melting with homogenization before forming

Homogenization is done mainly by a mechanical way (mixing by stirrers) which has a lot of disadvantages and problems [1]. Nevertheless, it is the most effective way at present. Mechanical mixing equipment - stirrer – presents a simple technical system, including 4 parts - energy source, transmission, mixing tool and control - see Figure 2. Mixing of molten glass is the function. Stirrers are placed in the feeder channel or in the working part of tank furnace.

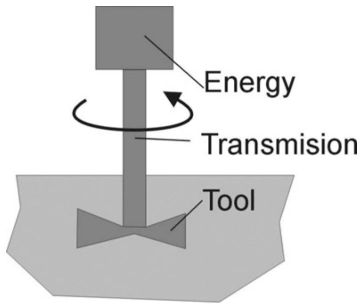


Figure 2: Technical system of mechanical mixing - stirrer

Although there was a tendency to replace a mechanical mixture by other possible ways during the development of stirrers in the past, bigger efficiency of mixing has not been reached. The problem analysis using the TRIZ method shows the reasons of a lower efficiency and shows the directions of a possible solution.

2 HISTORICAL DEVELOPMENT OF HOMOGENIZATION WITH MECHANICAL STIRRERS

Historical development of stirrers went from stirrers with simple mixing tools to stirrers with complicated mixing tools. Further, the number of stirrers was increased and at the end complicated shapes of stirrers were created which filled the whole space of homogenization units. We can see a transition MONO-BI-POLY

If we look at the development of stirrers from the view of the geometrical design development or trend of design transition to another dimension [2] we can see which way geometry of curves, surfaces and space layout of stirrers was changed in homogenization units so that they fulfilled this trend - see Figure 3. and Figure 4. Material of the stirrer tool was historically changed from ceramic over molybdenum to platinum.

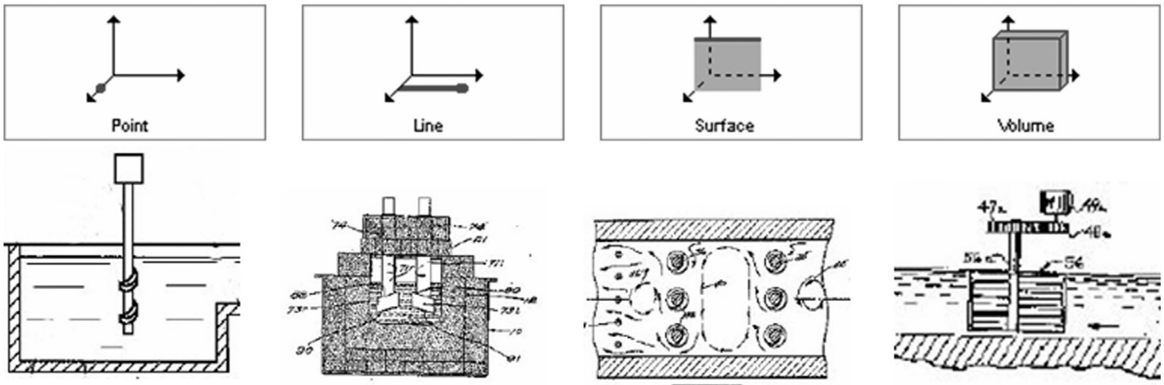


Figure 3: Chronological development of stirrers from the view of lines, surfaces and space transition

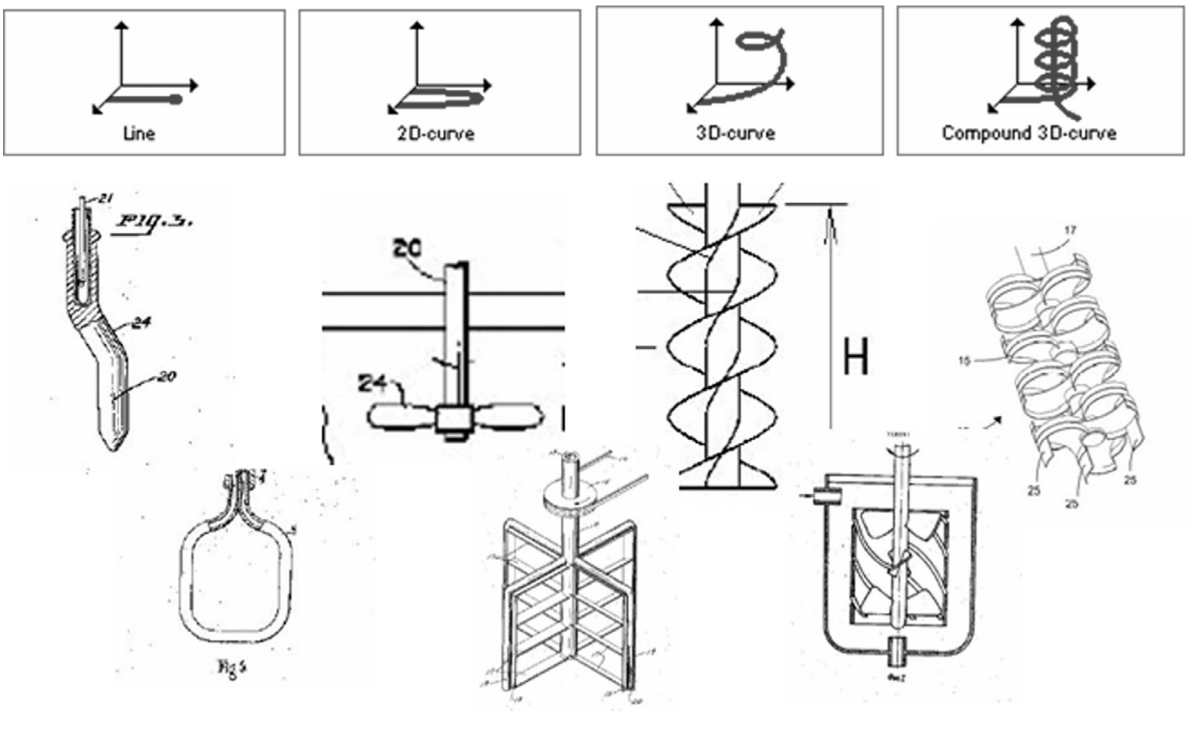


Figure 4: Development of stirrer tool from the view of geometric evolution of linear constructions

We can show also the S-curve of stirrer tool development, where it is possible to consider the efficiency of molten glass mixture as the main parameter (for achieving high quality of molten glass in the output from homogenization units) - see Figure 5. From the S-curve it is possible to observe that mechanical mixture achieves the physical limit. Further development of stirrers lays in overcoming the growing contradictions concerning mechanical mixture or in transition to a higher principle.

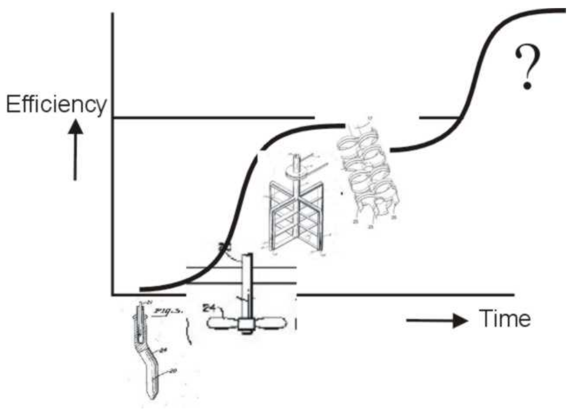


Figure 5: S-curve of stirrer tool development

3 CONTRADICTION OF MECHANICAL STIRRERS DEVELOPMENT

Optimization of stirrer tool shape and distribution of stirrers in homogenization units were realized. This optimization was supported by physical and mathematical simulation. Nevertheless, further rising of efficiency of mixture and qualities of molten glass were not reached. Irregular evolution of system parts originates contradictions which TRIZ method can identify and offer tools for its overcoming [3].

Technical contradictions (TC) of mechanical mixture are possible to be defined as follows:

TC1 - increasing of mixture efficiency is reached by a higher number of stirrers which decreases the space for flow of molten glass

TC2 - necessity of cool transmission of more stirrers causes undesirable heat removal

It is possible to find several principles to overcome mentioned technical contradictions in the Contradiction Matrix. For example Principe 10 - Preliminary action, or Principe 14 - Spheroidality -Curvature. However, these principles do not give the satisfactory immediate solution and therefore it is necessary to proceed by further definition of ideal solution and physical contradictions.

Ideal solution (IS): molten glass should be mixed by itself, by the help of own sources or sources from the nearest surrounding.

By this way it would be possible to get rid of the necessary transmission and undesirable cooling of molten glass would be lower. The purpose is to activate molten glass as a mixture tool.

If it is not possible to find an own internal source in the mixed molten glass sufficient for mixing then it will be necessary to find an external source.

Then it is possible to define the physical contradiction (PC):

PC - some elements of mixture have to be there to mix the molten glass and some elements of mixture cannot be there because they need transmission which cool molten glass and decrease the space for flow of molten glass.

Indeed it is possible to look for overcoming the PC in recommendations concerning transition in time, in spaces or in structure, however, it is better to use a strong tool of the TRIZ method - SuField Analysis

4 OVERCOMING OF CONTRADICTION AND SOLUTION OF MIXTURE PARADOX

SuField Analysis, which is one of the TRIZ methodology tools, is possible to be used for overcoming the defined contradiction [4]. First, we will present SuField model for mechanical system of glass molten mixture - see Figure 6

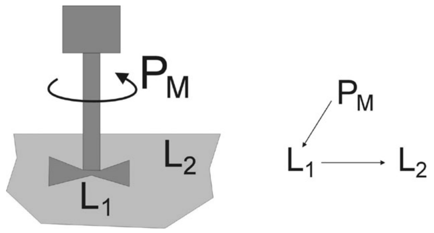


Figure 6: Initial SuField model for mechanical system of glass melt mixture

Mechanical field P_M (electric motor is the source) turns the screws L_1 which mix molten glass L_2.

From the trends of the fields development we know that the MATCHEM formula says that a field development usually proceeds from Mechanical over Thermal, CHemical to ElectroMagnetic fields.

Longterm tests with thermal mixing are being explored which means a better motion of molten glass by the change of temperature is being searched. There exist a lot of patents and a lot of implementation of equipment - see Figure 7. There were used additional thermal sources which increased glass molten stream. Additional thermal sources in the mentioned figure are provided in forms of electrodes that are distributed either horizontally or vertically in the feeder channel, or they can be inserted inside of the molten glass flow.

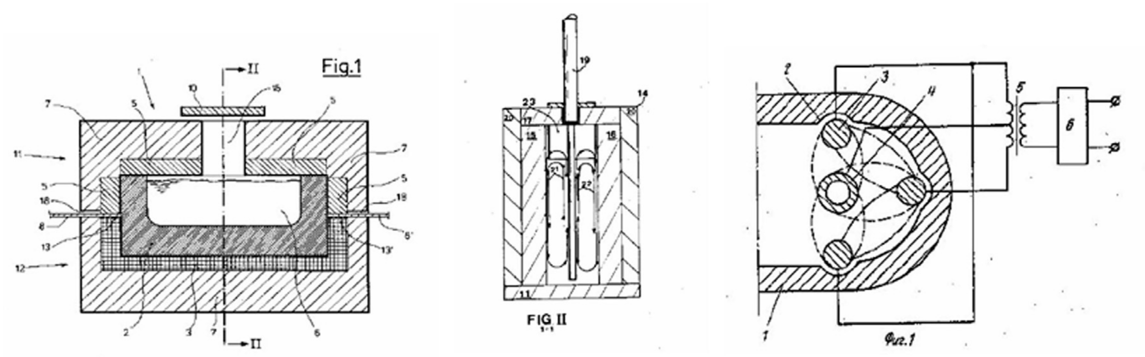


Figure 7: Patents concerning homogenization by thermal mixing

However, realization of these patents in practice did not bring satisfactory intensity of mixture although the trends of TS development in TRIZ method show that transition to thermal field should be more effective. By thermal mixture higher effectiveness of mixture than by mechanical mixture was not reached and in addition these systems were more energy demanding. Paradox of molten glass homogenization lies in the lower efficiency of thermal field which should have a higher effect according to the trends of the field development.

Where is the problem of the mentioned paradox?

Mixture of molten glass by thermal fields according to these patents in reality presents an incomplete system - see Figure 8. Substance (element) L_1 is missing.

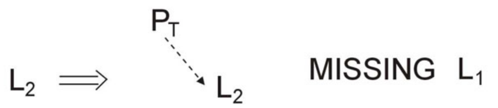


Figure 8: Incomplete system of thermal mixture according to the patents

It is the same problem as if we want to support molten glass directly by thermal field instead of by original rollers in the flat glass production. In reality in new way of production of flat glass by "float process" there were the original solid rollers replaced by molten tin [5] which acts as the needed missing substance (element) L_2 - see Figure 9.

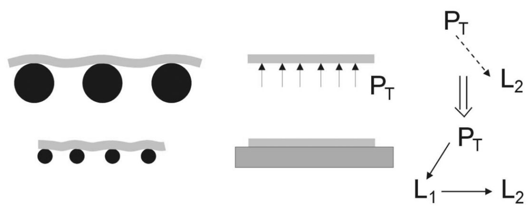


Figure 9: Transition from rollers to molten tin in the flat glass production by "float process" = real transition from mechanical to thermal field

A similar idea is also possible to be used by analogy for solving of molten glass mixture by thermal field. To increase the intensity of mixture by thermal field it is impossible to use only the thermal field of molten glass itself but it is necessary to use another external source of energy and connect it with the substance (element) L_1, on which this source will act - see Figure 10.

The idea is possible to be presented in a following way. Noninductive thin plates will be set into the feeder channel and organized in the flow direction not to block the molten glass flow. It is possible to make holes in the plates and place metal elements in forms of bimetals into them on which it is possible to act by an inductive field. Warming up of elements will cause their deviation. This deviation will change the molten glass flow and its mixture. Molten glass will mix itself by its flow with a help of the thermal field acting on an element added into the molten glass.

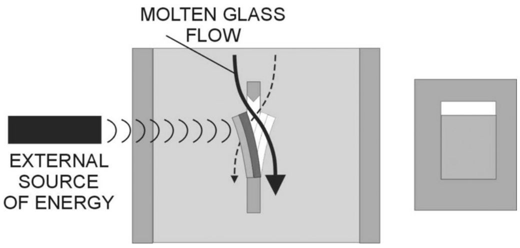


Figure 10: Mixture of molten glass by thermal field with use of external source of energy

This solution by analogy corresponds also to the example - remove ice from airplane propeller [2] - see Fig.11, where microwave heater does not heat the ice but the nickel layer on the propeller surface.

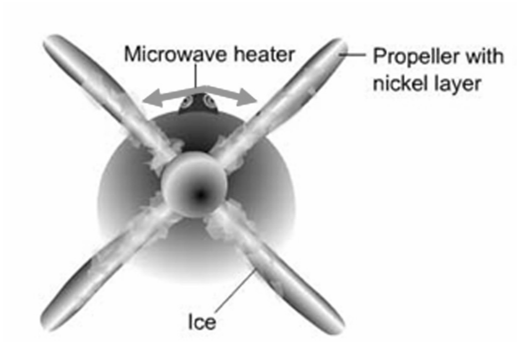


Figure 11: Analogy of the use of thermal field from the example of removing ice from airplane propeller

Further progress in exploitation of trends of fields development lies in using an electromagnetic field. There are test being made in this area at present which insert electric current into molten glass and try to use the Lorenz force initiated by the magnetic field.

5 SUMMARY

The TRIZ methodology tools help us not only to solve given problems but also understand some connections in the development of technical systems.

It was also in our case where using SuField Analysis from the TRIZ methodology helped us to understand small efficiency of homogenization by thermal mixture and to propose an improvement.

At the same time it was possible to deduct further trends of homogenization development by using more effective fields, for example electromagnetic.

REFERENCES

[1] Jirman, P., "Evaluation of development of feeders and stirrers from the view of creative method TRIZ" Glass feeders colloquium, published by Crystalex Nový Bor 2005

[2] TechOptimizer^{TM}, version 3.5, Invention Machine

[3] Altschuller G.S., "Najti ideju", Novosibirsk 1986, published by Izdatelstvo „Nauka", Sibirskoje otdelenije

[4] Salamatov, Y., "Chance for adventure", Petrozavodsk, 1991, ISBN 5-7545-0337-7

[5] Jirman P., Busov B., „Development of the Technological System Tool as a basis TRIZ prediction ", Proceedings of the 7th triz-future conference, Franfurkt 2007, published by Kassel university press, ISBN 978-3-89958-340-3

CONTACT

Pavel Jirman

The Technical University of Liberec
External lecturer

U Rybnika 11,
466 01 Jablonec nad Nisou – Czech Republic

E-mail: jirman@glass.cz,
Phone: +420 483 329 005

Bohuslav Bušov

The Brno University of Technology
Faculty of Electrical Engineering and Communication,

Technická 8,
602 00 Brno – Czech Republic

E-mail: busov@feec.vutbr.cz
Phone: +420 541 142 318

FROM KNOWLEDGE TO SUSTAINED REVENUE BUILDING A BUSINESS MODEL

Albert van der Kuij
Sensata Technologies Holland BV, Electrical Protection Europe, The Netherlands

Abstract

This article starts to describe an inside to out approach for creating ‘perceived’ value (functionality) by balanced flow of resources in a business system like that of Sensata. At the beginning the author’s stance to create new products and services based on choices supported by knowledge and assumptions, and the use of innovation tools is explained. TRIZ plays a central role in this process. Through characteristics of personal and business success, the transition process of knowledge to value for the customer is dealt with. In case value creation is sustainable, the reward is sustained revenue. The value creation process is translated in a phased DfSS format breathing TRIZ.

Keywords

ETRIA, TRIZ Future Conference, Business Resources, Passion, Added Value

1. INTRODUCTION

This article, and the presentation I will give at the TRIZ Future Conference 2008, represents my experiences, knowledge and thoughts on business systems obtained while working within the SENSATA organization and through communications with employees of other companies. More and more I find myself using the lenses of TRIZ, as wonderful means to look at system variations and flows of resources in an integrative way. Becoming aware of evolution potentials, while focusing on what is important.

Since I am relatively a freshman in TRIZ, I take the opportunity at the ETRIA future conferences to report on what I have learnt. Started at the Frankfurt conference (reference [3]) and hopefully continuing on a yearly basis. The article, neither the presentation are intended to be of scientific nature, but hopefully a source for inspiration and a basis for starting fruitful discussions on innovation.

Besides financial means to support what I am most passionate about, my family, I value the passion for transition of knowledge into new realities, or ideas to new products/services. In general, acknowledged to be, one of the vehicles of a company to add substantial value in a market environment. Potentially resulting in high financial rewards, but mostly overshadowed by business as usual (operations) due to a dense mist of risks, avoiding at least some ships of the armada hail anchor to explore new lands beyond the horizon. Could TRIZ be the instrument to demystify our mission, or at least be a piece of the puzzle?

For about four years ago, I hit limit, developing products in a traditional way; designing according successful patterns existing within the company. Making a close fit to customer requests by trial and error, with capabilities at hand in the company and being rather conservative with it. My flow felt blocked – passion for designing was dripping away.

I was looking for revolving my perception towards the way of designing products. In that process several analytical and brainstorming techniques to create innovative products came along, but in general these were too vague. I didn't have the feeling that I could connect with what I was doing.

Through some internet search and business contacts, I learnt about the existence of ASIT (Advanced Systematic Inventive Thinking). However the basic concepts draw my interest, the algorithmic way of just applying 5 tools (unification, multiplication, division, break symmetry and object removal tools) to learn about the internal potentials of the system and see what the created has to offer (function follows form motto) were not meeting my expectations of innovation. The sparks of passion while discussing ASIT were wonderful, but my thirst wasn’t quenched and my hunger wasn’t alleviated, I was on the quest for more!

Fortunately ASIT appeared for me to be an offspring from TRIZ. In the three years studying and working with TRIZ, I experienced it to be general knowledge of dynamical transformation of system recourses (like matter, energy, information, money and people) to create value as perceived by humans. Especially the dynamic nature of TRIZ was what I was looking for.

ASIT and other innovation tools I have tried are pre-molding situations - crystallizing complex work into a certain form. This static view is resulting in easy to use tools, but I wonder about obtaining high quality results in system improvement. TRIZ dynamics makes it rather complex, but matching needs when using the brain forming ‘new’ connections. Creating intimate relationships between parts and its environment that unbound resistance of resource-flows in a useful context.

TRIZ works as a tool to transform the user (internally directed), to be open for all kind of possibilities, removing psychological inertia. TRIZ is also a tool used to crack systems (externally directed), analyzing it and becoming knowledgeable about its functionality (useful changes in resource flows); finding creative solutions by redirecting resources (resolving contradictions). Solutions needed to be synthesized and verified in tests. The analysis, creation and synthesis cycle is enabling the designer to penetrate the system deeper and deeper, in a cyclic way. Making the designer or design team intimately connected with the object of development. I am sure when passion for innovation, focus for importance and the persistence to succeed is there, results will come.

The follow up of this article is mainly focused on the segmented transition (adding value at every step) from company’s assets including customer system knowledge towards delivering products (sensors in the case of SENSATA) that add substantial value to the customer system and therefore money (or information) in return. I want to propagate the value of in to out development being connected to the market, rather then being a slave of the environment. This is a fundamental choice and I believe made in too many occasions based on fear rather then on trust.

2. DEFINITION OF SUCCESS

I lately saw an interesting TED review by Richard St. John (reference [5]) on a research about personal success. During 7 years, 500 successful people were interviewed giving their opinions on what they defined to be their features of success. A list of 8 characteristics was the result:

PASSION

The drive to success comes not from outside, but from within, the energy called passion. Money, generally thought to be *the* factor of success, could be an important resource in success, but not more then that. Over focus on resources like money will imbalance the system, resulting in blocked flows, drying out the system. These blocks could give you a lousy and empty feeling, a feeling of not belonging to the system. What counts is the passion of being, creating something 'unique' in relation to.

SERVE

The parts that you fuel with your passion should find its route to the outside (relate with it by action). Serve by creating added value to the system. Trust that you add value by acting and learning sourced from within. Embedding the part in the system, make it secure in it. Make this world a better place by fitting variation to connect with the outer world. Passion and serve (heart and mind) could result in a flow that is called money, external approval of what you are bringing to the world. But the trick is not to be blinded by it and use it to let resources flow!

FOCUS

Focus on parts where your passion is. Know what to do and what to delegate to other passionate people. Create organic structures (people nets) to accomplish your vision, your vision to evolve the world. Keep track and be prepared to learn the lessons to be learnt.

WORK

The wind is not always in the direction of what you have envisioned to reach. You have to be prepared to make small steps on the road. A great end result may be reached to take consecutive small steps, but in the right direction. Passion makes this hard work a joy even when you are road blocked.

IDEAS

Create something unique by having ideas that are in your area of passion. And focus on this area will naturally lead to ideas, ideas to improve. Act on the ideas, and strive to make them come true. Learn while acting and see what you like and what you do not like. Be agile and prepared to change direction and ask for support from other people when in need.

EXCELLENCE

Excellence is in a way a metric of connection. Striving to have the best relation to the in and the outside, letting resources flow free. It takes ideas, a lot of hard work - practice to relate, relate with you and at the same time with community.

PUSH

Succeeding also means discipline. Human nature is to do things the easy way, but sometimes you need to go the long way, take the road with the most resistance to accomplish what you are looking for in the end. Consciously looking for the contradiction and solve it. Be your own mom to practice music or to complete your homework.

PERSIST

Believe in yourself to withstand critics from outside. Do not be naive to believe all there is, is cooperation. There are people that want to sink your ship, don't matter what you are offering. Persistence is making contact to people with whom you can build a give and take relationship. At the other hand critics could offer perceptions that contradict – or opportunities for growth.

Looking at the above list, it is remarkable that almost the statements on success are directed from in to out, even the serve part. The central theme is evolving passion and be true to it. I believe that a successful business could be defined alike.

Are not a lot of resources spoilt by over focus on the competitor, the profit margins and revenue growth? The first is opening the trap for 'me too' solutions. The money part is avoiding taking risks, being an entrepreneur. Making yourself belief the world is rigid, while the flow is making you reduce cost, a symptom that investments do not credit the value created, and finally resulting in obsoleting your business from the system?

A company should have a clear vision, imaging the passion of the organization. That passion should be worked out by positioning it between suppliers and customers. So being an enriching part of the web. Being an addition of substantial value in the flow of resources and because you are a resource yourself you have to keep flowing, having passion to improve the functionality of the customer system continuously.

3. BUSINESS FUNCTIONALITY ADDED VALUE TO RESOURCE FLOWS

In the below list I describe resources, that are of importance in business processes. Business goal could be defined adding value in the market, adding value to resources from within, but that is just a stage. Added value erected and recognized is rewarded by receiving money in return. With this money, supply of resources could be paid. Resources needed to add value.

MATERIAL

Raw materials are harvested from mother earth. Harvesting takes efforts and energy. In process steps, energy is applied by tools, raw material become parts. Parts assembled and worked become products. Products placed within a system. The system is forming a functional part of super systems.

ENERGY

Energy is harvested from the earth/sun. Energy supplied to materials in products, changing its flow. The product is tooling the subject, generating a new state when needed (function).

PEOPLE

Humans perceive the world and creating a new world with the brain and the hands. Cooperate together in teams, organizations to combine talents, creating critical mass to erect value a single individual is not capable of. Build an existence, survive in the world and get offspring, but also working at self actualization.

INFORMATION

Humans are making observations in the environment. Gathering data to form patterns called facts. Weaving the web of facts together, called information. Making information more specific for a certain situation forming knowledge.

MONEY

Humans have made a 'general' agreement, this agreement is called money. Money is represents value of resources. This intermediary is offering people a certain level of freedom to acquire resources when needed.

The time resource is playing part in the value adding (function) or subtraction (failure) process. Due to mass, viscosity, spring and resistance effects changes require time (mechanical analogue). Time needed to transit from an initial state to a new 'equilibrium' state. Time a metric of flow.

4. TRANSITION OF KNOWLEDGE IN SUSTAINED REVENUE

In the old days, a product was conceptualized, made and set in operation in an ad hoc fashion. However today 'technical' world is is more complex and requires intelligent design. Being conscious of what one is trying to obtain and act to find an optimal way to realize that.

Before communicating with the customer, one should do some homework. Being prepared, having a model of the customer system at the conscious level. Refining it, by buying a system and doing some experimentation, is also very beneficial. When communicating to the customer, information can be verified and integrated in the model right away.

A flow of activities is directed to come from the weak system points or 'failures' (no or too less functionality, inefficiency, unreliability, unsafeness, pollution of environment and too high investments) to products that add features, increase quality of the function or reduce investments for the customer.

Cover the weak or 'customer needs' and the 'model', or the awareness of the current gap, are the starting points for a positive reinforcing knowledge loop and a negative, goal seeking capability loop (see figure 1). Knowledge is intrinsic value that should be put into action to become real value.

Together they compose a S-curve, improving in time the interface (closing the gap – reducing tensions) between customer needs and the capabilities the company is developing (here called product, but this could as well can be a service or a process).

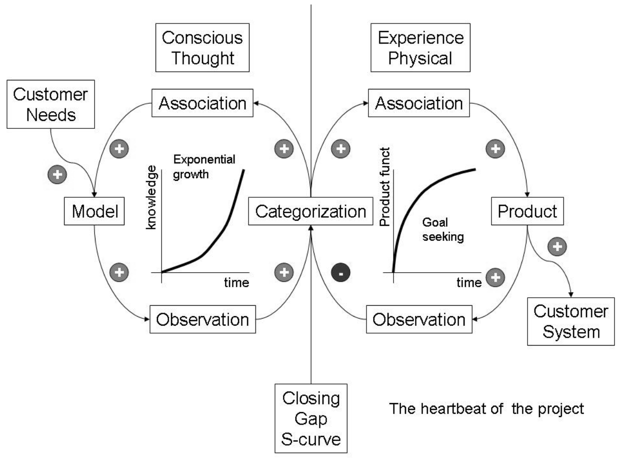


Figure 1: Causal looping (S-curve composition) of transfer from knowledge (intrinsic value) to product (extrinsic value).

Association in the physical plane is making the product. Observation is reviewing how it is behaving under certain conditions. Results are categorized so it can be used in association with the model. An idea is leading to a new model and thought experiments are new observations. In this way one is looping, evolving the interface between 'customer' at the one and 'supplier' at the other hand.

The S-curve is fragmented in smaller S-curves. First build functionality performance, and then improve quality of the function, followed by reducing costs. But also because of relation shifts of 'customer' – 'supplier' (customer-marketing, marketing–design engineering, design engineering–process engineering, process engineering–production) interfacing the S-curve is built of several smaller curves (see also figure 2).

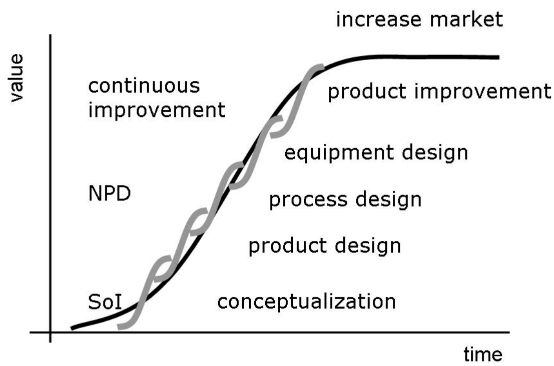


Figure 2: S-curve segmentation by shift of interfacing to erect a quality product.

CONCEPTUALIZATION

This phase is called Sea of Ideas (SoI) within Sensata. It is the interface between the customer and the marketing department. A phase in which external Critical to Qualities (CtQ) are translated to functional specifications and constraints (internal CtQ) of a product/service to be developed. Defining functional opportunities (task needs) for the company at a customer or in a market segment. Model & test prototypes function for system evolution and ways of fitting the supplier capabilities to the customer needs.

The value of an opportunity depends on the capabilities of the company (floating on organizations passion) at the one hand and customer importance and satisfaction of a task/system constraint at the other. The output of this phase should be a concept (selected from several functional ideas by experimentation) that fits the Voice of the Customer, Voice of the Business and the Voice of Technology in win-win ways. This phase with its high information / knowledge content can easily take a span of years and is crystallized in a Business Plan approaching harvesting time.

NEW PRODUCT DEVELOPMENT

This phase, abbreviated NPD, is developing the selected product concept into a production line in 3 stages (product design, process design and man/tooling/materials to be used in a production line. Critical to Quality parameters of the customer system should be guided down to having a production that meets customer expectations. In this phase knowledge is converged in a materialized production line (or a process for servicing customer …etc…) making products out of raw materials. NPD spans from a few months in smaller projects to a few years for large ones.

Design Phase:

During this phase product characteristics like dimensions and field characteristics (how does the product behave under the influence of a field) are developed by a design engineer based on communication interfacing with the marketer. The product having a field in, a field through and a field out (see figure 3), adding value in the job and outcomes. The environment is setting the constraints (like available space / maximum costs / corrosive conditions …etc…).

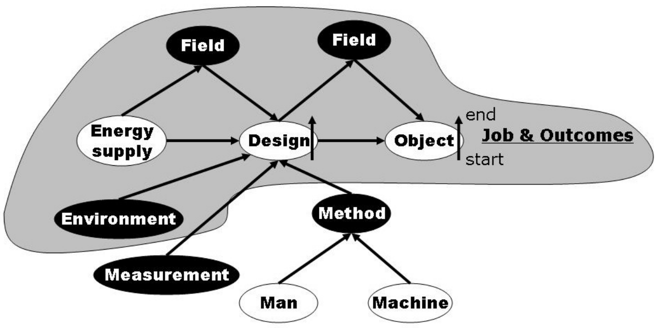


Figure 3: The Substance Field representation of a product design adding value for the system.

Process phase:

During this phase the methods (energy transfer, energy interfacing and timing) are designed to add value to the material forming the product by a process engineer based on interfacing the design engineer. The method is adding value to the material creating the product design. The constraints are set again by the environment in this case around the method. Noise on the method is generated by the environment, the measurements performed and the operators and tools in the line. The measurements are reflecting a safety net, catching failures that occur in not robust designs, processes and production means.

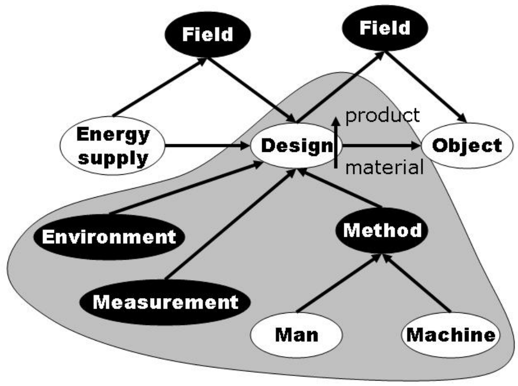


Figure 4 : The Substance Field representation for method and production of a design.

Production phase:

During the production phase the line is built through specifications of the method for the equipment (machine) and process books for the operators (man). For the equipment this could mean again a design phase at another company, however due the cost reasons and delivery time, mostly standard equipment with some special tools are purchased.

CONTINUOUS IMPROVEMENT

Continuous improvement is defined after completing NPD, so at the time production is ongoing. This phase is mainly directed to increase yield, reduce costs of production and keeping customers satisfied. For the latter this mostly boils down to controls measures filtering out specification failing products covering up complaints.

For the major part, the long term revenue is depending on the added value, the product is creating in the market. However for short term revenue a strong sales team is a must, but also this should be backed up with great products.

5. TEMPLATE FOR VALUE CREATION IN DMADV FRAMEWORK

At Sensata we work currently at implementing DfSS (Design for Six Sigma) in combination with TRIZ to our SoI (Sea of Ideas), NPD (New Product Development) and Continuous Improvement processes. We striving for changing towards a method as laid down in reference [2] (See figure 5).

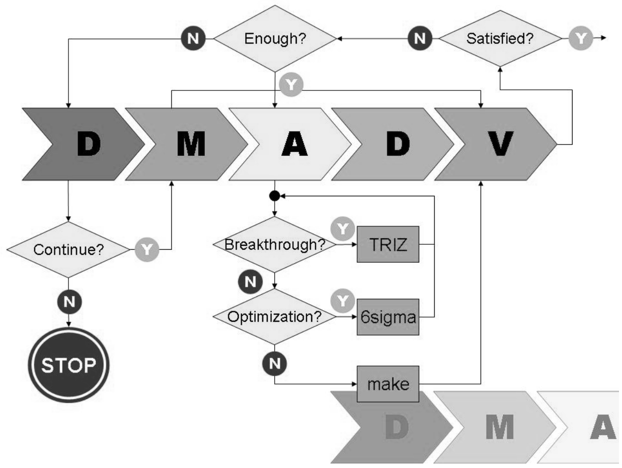


Figure 5: Framework for using DfSS (DMADV) together with TRIZ.

Focus is first on finding opportunities in the market (Define phase), then the interfacing is defined in the Analyse and the Design phase in combination with the Define phase of the next level.

In the Analyse phase one can judge on obtained insights to use TRIZ to overcome contradictions or statistical optimization (six sigma) of capabilities present or use capabilities as already available.

Making the product is linking the 'higher' level to the 'lower' level. Coming from the system to the concept to the product, to the process to production as depicted in figure 6.

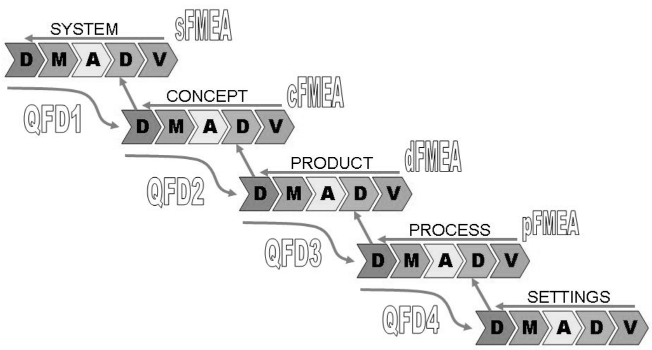


Figure 6: DMADV (Define, Measure, Analyze, Design and Verify) flow down of critical parameters in combination with QFD and FMEA tooling.

Planning the parameter flow down can be done with QFD (Quality Function Deployment), while verification of parameter web is done with DoE (Design of Experiments) filed into the FMEA (Failure Mode Effect Analysis) tool.

Bottom line is when the company is making products with passion (using tools in a passionate way) linked to needs of the customer and with help of passionate suppliers the reward will come!

ACKNOWLEDGMENTS

I want to thank the TRIZ community for the open mindedness sharing a lot of ins and outs on the subject. Especially I want to thank Valeri Souchkov for the interesting bimonthly discussion sessions in Enschede. And for his great support, getting TRIZ introduced in the SENSATA organization. Resulting in perceiving systems in a way we never did before.

REFERENCES

[1] Braun W., "The system archetypes", 2002.

[2] Kai Yang, "Innovation through DFSS and TRIZ", presentation, Wayne State University, USA, 2006.

[3] Kuij, van der, A.J.H., "Introduction of TRIZ in the Sensata Technologies Holland Organization", Proceedings of the triz-future conference, Frankfurt, 2007, ISBN 978-3-89958-340-3.

[4] Radeka K., "Why Six Sigma experts are wrong for product development – Here's the proof", PDMA Visions Magazine, June 2008 Vol. 32 No. 2.

[5] St. John R., "8 secrets of success", TED presentations at www.ted.com, 2005.

[6] Ulwick A.W., "What customers want: using outcome driven innovation to create breakthrough products and services", 2005, McGraw-Hill, ISBN 0-07-140867-3.

6. CONTACT

Sensata Technologies Holland BV

Electrical Protection Europe

Ir. Albert van der Kuij

Legislation/New business development

P.O. Box 43

7600 AA Almelo

The Netherlands

E-mail: a-vdkuij@sensata.com

Phone: +31 (546) 879564

FAX: +31 (546) 873431

Wisdom of creating learning through TRIZ

HeeChoon Lee[1], KilYong Shin[2] ,Youngmin Lee[3], Nikolay Shpakovsky[4]
[1]Business Innovation Division, POSCO, Korea
[2]Hot Strip Mill Department, POSCO, Korea
[3]Wire-rod Deptment, POSCO, KOREA
[4]TRIZ-profi, Moscow, Russia

Abstract

Many have been fascinated by the TRIZ methodology because of its affluent analogical clues and its intangibility in the process of problem solving. Nevertheless in reality this surprising tool has not been widely accepted as a problem solving tool. Why has this been the case? The main reasons can be divided into two categories; ① jumping into contradiction at initial stage, and ② little understanding of TRIZ as an idea generation tool. It is clear that emphasizing contradiction without problem analysis makes extracting conceptual solutions more ambiguous. Nevertheless, TRIZ experts ask, 'what is the contradiction?' I agree that the TRIZ methodology can generate breakthrough ideas not in subordinate relationships but in reversed relationships. But management wants to see the in-out value of TRIZ results, asking 'Where is the Breakthrough Idea?" The above two sentences are TRIZ killers. This article introduces a new TRIZ success story at POSCO, including a novel TRIZ Roadmap and case studies.

Keywords

TRIZ, roadmap, DSDI, 6Sigma

1 INTRODUCTION

After a number of TRIZ projects were launched at POSCO, one of the leading companies in the iron and steel industry, they failed to show their in-out value. Even some feasible solutions defined within the projects did not draw much interest from the management. Analyzing these projects, I identified two main drawbacks of the TRIZ projects. One is, ironically, a contradiction, and the other is IFR (Ideal Final Result) with respect to an implementation view.

Unlike Six sigma, a unique point of TRIZ is a demand to define a contradiction to pursue a solution of a higher level. TRIZ experts tend to pass over the discordance between business impact and a contradiction. In other words, a solution of a higher level based on resolving a contradiction doesn't always provide us with a greater business value.

Inexperienced TRIZ experts used to query project leaders about core contradictions at initial stage, however to no avail. Problems can be solved by overcoming contradiction or by controlling other methods. If the project leaders knew the core contradictions, they might have had some feasible solutions already in place. What can happen in this case? They don't need the TRIZ methodology in handling their own problems. It is quite difficult for management to understand the unique points of TRIZ.

No one denies IFR, which is one of the major TRIZ concepts. The problem depends on value created by implementation. During a given period, what the management really wants to see is value relating to core capability. Unfortunately, the TRIZ roadmap doesn't show how to implement breakthrough conceptual solutions. The question is whether drawing a conceptual solution only itself satisfies management. If not, I suggest a new platform of TRIZ which starts at initial problems and ends with implementation of conceptual solutions.

2 NEW PLATFORM OF TRIZ

A need for a new roadmap to enforce the analysis of initial problems and the implementation of conceptual solutions gets stronger. To comply with this need, POSCO developed two types of project roadmaps as shown in figure 2-a.

Focusing on a quantum jump, POSCO combined TRIZ thinking process with six sigma roadmap DAMIC / DFSS and developed TRIZ DSDI (Define → Solve → Design → Implement) roadmap respectively. By introducing the "Define" stage as a starting point, a contradiction does not create a key role in handling problems. Problems are treated from the business aspect. With Six sigma benchmarking, breakthrough ideas generated from the TRIZ thinking process could be easily implemented. Figure 2-a shows a combined Six sigma as a form of idea generation and TRIZ roadmap implementation. Some examples based on this newly developed TRIZ platform are also included in this paper.

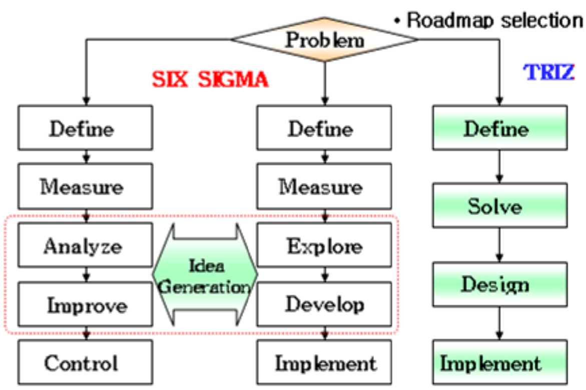


Figure 2-a new platform of TRIZ

3 CASE STUDY: 1. ELIMINATION OF RED-SCALE

The POSCO's wire-rod product as shown in figure 3-(a) is contaminated with red-scale caused by oxidization (figure 3-(b)). The project started with RCA (Root Cause Analysis) to define a core problem. Without the RCA procedure it was not easy for an engineer to pinpoint core contradictions. The question arose: "Where is my TC (Technical Contradiction)?" I want to stress that before asking about contradiction, RCA or other analysis activities such as the 5 Whys and Logic Trees must be performed, since In some cases problems can even be solved before recognizing contradictions. Based on the new TRIZ platform, the kernel of the problem was examined at the "Solve" stage. Usually, at the "Solve" stage application of some scientific approaches was also required.

Figure 3-(a)

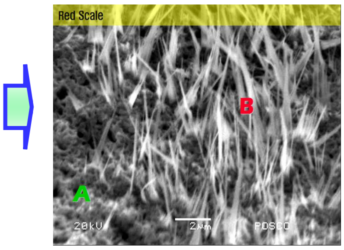


Figure 3-(b)

After thorough analysis, a contradiction model and a conceptual solution model as shown in figure 3-(c) could be drawn.

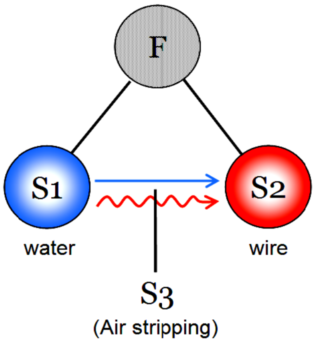


Figure 3-(c) Substance-Field Model of red scale

At this stage, the normal TRIZ process tends to translate a conceptual solution to more detailed concepts; for instance, water droplets positioned in the deep interior of the wire-rod surface could be easily eliminated by pressure difference. What will happen? Probably, most of the conceptual ideas will disappear in a couple of weeks. Adding the TRIZ process with the design and implementation stages, feasible solutions could be implemented and they can demonstrate their 'value' as shown in figure 3-(d).

Figure 3-(d) Product of wire-rod after improvement

4 CASE STUDY: 2.ELIMINATING FLAWS ON HOT STRIP

POSCO's hot strip plate product experienced some folded parts caused by a strip loop as shown in Figure 4-(a). To eliminate the loop phenomenon, the project started with RCA (Root Cause Analysis) to draw out the core problem. In this section I want to mention the differences between the TRIZ methodology and other methods of problem solving. Ordinary engineers can easily imagine the feasible solution: that is, if movement of the front part is maintained at a higher speed compared to the speed of the rear part, the strip loop will disappear. But the speed of the front part is limited because of scratches that can appear on the surface of the strip. The normal approach is to formulate the relation between speed and the pitch of roller as shown in formula 4-(a), which was presented by Japanese steel company JFE at AISTech conference of 2007.

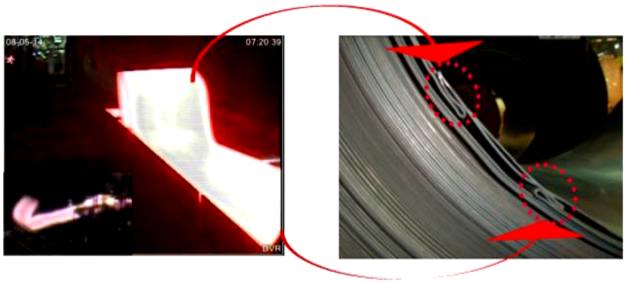


Figure 4-(a) Flaws of a product caused by strip loop

$$v_c = \frac{\pi}{L}\sqrt{\frac{EI}{\rho A}}$$

Formula 4: Critical speed of hot strip

Where, Vc= Critical strip speed, L = ROT table roller pitch,

p = Density of strip, E = Young's Modules

A = Strip area, I = Second moment of area.

The Six sigma approach focused on optimizing the Vc with intensive data analysis. On the other hand, TRIZ methodology can produce a breakthrough idea as a result of resolving contradictions which will be independent from the correlation between Vc and L. The conceptual solution of this problem could be derived from paper. If a paper shapes cyme, the loop phenomenon will disappear. Like in the previous example, at the design and implementation stages the shape of the strip is changed to cyme and flattened at the final coiling line as represented in Figure 4-(b)

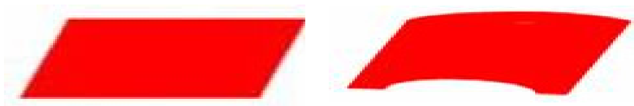


Figure 4-(b) Changing shape of strip

The TRIZ roadmap reinforced with "Design" and "Implement" stages enables obtaining breakthrough conceptual solutions to be positioned at overwater. I believe the 'wisdom of creating you' depends on how one can recognize his problem from analogical clues and implementation. Figure 4-(c) shows the product which has no defects by removing the strip loop.

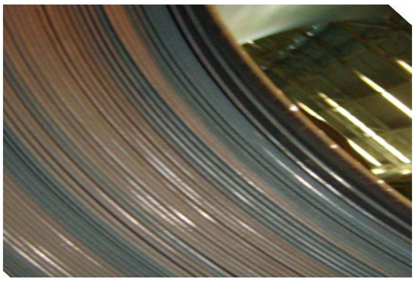


Figure 4-(c) Product of hot strip removing loop

5 SUMMARY

Unlike the previous creative thinking methods such as brainstorming, six colour thinking hats, PMI and SCAMPER, the TRIZ process reinforced with implementation was introduced for a future quantum jump. As I discussed in this paper, a DSDI roadmap which benchmarked Six-sigma was quite successful. Although everyone may agree that TRIZ methodology can generate breakthrough ideas not in the subordinate relationship but in a reversed relationship, we, the TRIZ practitioners must not forget that management wants to see a practical value of results obtained with TRIZ. With a view towards business, more successful results from TRIZ will be needed for future markets. I want to leave a message: ‘All the doors you passed through this morning were once walls.’ I think that’s a good summary of the way of thinking for TRIZ practitioners.

ACKNOWLEDGMENTS

I extend my sincere thanks to all who contributed to this project: including Dr. Shpakovsky, MyongRong-Kim, ManSoo Kim, YoungIl Kim, Changsung Jang and the all members of business innovation division.

CONTACT

Hee Choon Lee

Business Innovation Div, POSCO

Posco center, 892 Daechi4-dong, Gangnam-Gu Seoul Korea

E-mail: lhcglen@posco.co.kr

Phone: +82 (2) 3457-5580 - FAX: +82 (2) 34571978

Method for Quantitative Evaluation of Innovation Tasks for Technical Systems, Products and Processes

Pavel Livotov
TriS Europe GmbH, Germany

Abstract

The paper is addressing the main needs of the industrial sector regarding early stages of innovation process, product development and inventive problem solving. The proposed method includes a formalized identification and quantification of system functions and properties as well as of corresponding innovation tasks. For each identified function the level of its current performance, priority and measurable value of its innovation potential are estimated. A new approach is proposed for calculation of the ideality level of technical systems. Method is illustrated by example of its application for innovation concept development of a packaging line for food industry. Opportunity for identification and quantitative evaluation of innovation tasks for processes and for non-technical systems is outlined.

Keywords

Technical System, Innovation Potential, Innovation Strategy, Quantitative Analysis, Ideality Level, TRIZ

1 INTRODUCTION

This paper is addressing the main needs of the industrial sector regarding the early stages of innovation process, product development and inventive problem solving activities.

As well known, the description of initial problem situation with TRIZ includes system analysis with definition of positive and negative functions and properties of significant system components, continued by contradiction analysis [1]. Contradiction analysis results in the identification and prioritising of innovation tasks to be solved. This initial phase of innovation process often faces serious difficulties within working teams, which are often unable to find a consensus in understanding of origins of contradictions and to select a set of innovation tasks, which are crucial for successful innovation. This fact often leads to weak innovation strategies or to a “solving a wrong problem” phenomenon.

The proposed method includes formalized identification and quantification of system functions and corresponding innovation tasks. For each function, its priority, the level of its performance and measurable value of innovation potential are estimated. A new original approach is proposed approach for calculation of the ideality degree of whole technical system. Additionally method allows to identify and to measure following function clusters:

- core functions with insufficient performance,
- core functions with high level of performance,
- over-engineered functions.

Based on this analysis, innovation strategies that lead to a significant measurable innovation and growth of system ideality can be systematically developed. The quantitative method helps also to anticipate market opportunities of innovation concepts in the very early stages of the innovation process - already in the phase where the innovation strategy and tasks are formulated. It structures the innovation activities, focusing them on the tasks that are essential for market success, reducing innovation costs and risk of poor investments.

The paper demonstrates how this method was applied for developing of innovation strategy for a packaging machine in food industry.

The method can also help to identify and evaluate innovation opportunities for processes and as well as for non-technical systems.

2 METHOD

The method is demonstrated step-by-step on example of innovation tasks formulation for a packaging machine.

2.1 Definition of innovation tasks

Description of all essential components of technical system with their useful functions and all undesired or negative properties is the basis for the formulation of complete list of all thinkable innovation tasks. These tasks can be separated in two groups:

- further improvement of positive functions or properties,
- elimination of negative functions or properties.

For example, two following functions/properties (one positive and one negative) of a product packaging line in the food industry deliver two innovation tasks:

function / property		*innovation task*
high number of run product formats (*positive*)	➔	increase number of product formats
high energy consumption (*negative*)	➔	reduce energy consumption

Understanding functions and properties as system characteristics significant to users working process and assuming that functions and properties are finite in number, the mentioned list of corresponding tasks can be rather long including 30...80 or more positions. A meticulous functional analysis of system components makes possible to capture almost all relevant functions and properties. In some cases this analysis can be extended by field studies including user interviews or user observations.

2.2 Tasks priority and performance level

The priority or importance of formulated innovation tasks has to be defined by expert group quantitatively using following scale from 0% (lowest priority) to 100% (highest priority) with for example interval of 25%.

For objective evaluation an expert group should consist of about 30 technical experts, engineers, sales managers etc. (internal experts) and/or of at least 30...60 users of analysed technical system (external experts). Comparative analysis of internal and external evaluation may be practicable and reasonable.

Furthermore the expert group have to evaluate current performance level of each function using following scale from 0% (no performance) to 100% (ideal performance). Definition of measurable ideal values for each function and corresponding innovation task is of high significance in this step of the process. For example, for tasks mentioned above following ideal values, corresponding to 100% of performance, can be proposed:

innovation task		*ideal value (100%)*
increase number of product formats	➔	unlimited number of run product formats
reduce energy consumption	➔	no energy consumption

Quantitative market surveys and customer interviews can be used additionally for final estimation of tasks priority and performance values:

innovation task		*priority*	*performance*
increase number of product formats	➔	84% (*high*)	45% (*low*)
reduce energy consumption	➔	62% (*medium*)	66% (*medium*)

2.3 Calculating ideality of technical system

Based on captured data we calculate the performance level of the whole technical system, which can be interpreted as measurable definition of the system's ideality. In the fact the proposed formula (1) considers the complete list of positive and negative functions (properties) of technical system as well as estimated weights (i.e. priority) and current performance level of functions.

$$\text{Ideality} = \sum_{i=1,n} \frac{Z_i\,(X_i + aX_i\,(X_i - Z_i))}{\sum_{i=1,n} (X_i + aX_i\,(X_i - Z_i))} \qquad (1)$$

where
X_i - priority of a technical function, 0…100%;
Z_i - performance of a technical function, 0…100%;
n - number of technical functions, e.g. n=30…80;
a - regression coefficient, e.g. a=0,5…2,0.

The performance of technical function can be also interpreted as satisfaction level of corresponding customer need. In this case the ideality (1) can be understood as a total satisfaction value of a system. The ideality value of 100% corresponds to a technical system, in which all known needs are performed absolutely to a highest thinkable ideal level. The proposed formula is based on the mathematical model originally described in [2].

Numerous versions of the ideality formula, which defines ideality as the sum of useful functions divided by the sum of harmful functions plus costs, are well known in TRIZ literature. Even if formal complications caused by different dimensions of members (functions and costs) can be overcome with the help of coefficients, the ideality value of the absolute ideal system in accordance to this formula is infinite. This fact hinders the quantitative ideality comparison of at least two technical systems. On the contrary, the proposed calculation method (1) gives the opportunity to benchmark ideality level of any technical system against its competitors.

2.4 Innovation potential of tasks

To one of TRIZ postulates belongs a statement that technical systems are developing towards growth of their ideality [3], [4]. The equation (1) delivers information about current ideality value. Accountable evolutionary potential of technical system in terms of presented approach is a difference value between 100% and current ideality (1).

This innovation potential is non-uniformly distributed between identified innovation tasks. In other words, each task possesses its specific (partial) innovation potential, depending on task's priority and current performance of underlying function. Innovation potential of a task Y_i can be calculated as its maximal contribution to ideality growth, which can be obtained in case of ideal solving of this task with performance of 100%:

$$Y_i = \frac{X_i + aX_i\,(X_i - Z_i)\,(1 - Z_i)}{\sum_{i=1,n} (X_i + aX_i\,(X_i - Z_i))} \qquad (2)$$

where
Y_i - innovation potential of task in %;
X_i - priority of a technical function, 0…100%;
Z_i - performance of a technical function, 0…100%;
n - total number of technical functions and tasks;
a - regression coefficient, e.g. a=0,5…2,0.

If the performance of technical function is interpreted as satisfaction level of corresponding customer need, the innovation potential demonstrates the role of each innovation task in total growth of satisfaction with whole system.

Some calculation results for innovation strategy and concept formulation of a packaging line for food industry are summarized as a case study in Table 1 below. Innovation tasks, sorted in accordance to their potential, help to bundle innovation activities, focusing them on the most essential aspects. The top three innovation tasks in this example have a total innovation potential of 10,5%.

Solving of these tasks will increase calculated ideality value (1) of packaging line from 67% to 77,5%. These tasks define the innovation strategy and their solutions will shape promising innovation concept of packaging line with higher ideality level and innovation success.

innovation task	*priority*	*perfor-mance*	*innov. potential*
increase number of run product formats	84%	45%	3,8%
tolerate higher size deviation of product	75%	50%	3,5%
avoid contamination of primary packaging	75%	58%	3,2%
tolerate density deviation of product	79%	80%	1,6%
increase line productivity	78%	82%	1,5%
reduce compressed air consumption	70%	74%	1,2%
...	...	...	...
reduce energy consumption	65%	76%	0,6%
reduce noise and vibration level	62%	76%	0,5%

Table 1: Choice of innovation tasks for a packaging line.

2.5 Typical clusters of innovation potential

One and the same technical system, e.g. packaging line, can be utilized under different conditions (e.g. in different plants, for different product types or packaging materials). In each application of the system the priority and performance values of innovation tasks can be different. One can classify various application cases into four typical clusters in accordance to corresponding combinations of priority and performance values for each innovation task:

- cluster 1: high priority functions with high performance,
- cluster 2: high priority functions with low performance,
- cluster 3: low priority functions with high performance,
- cluster 4: low priority functions with low performance.

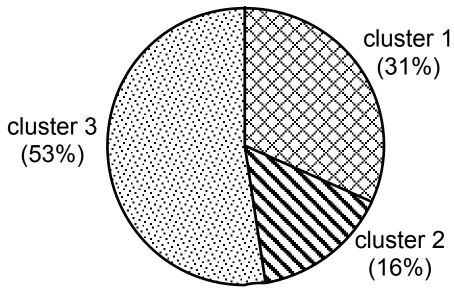


Figure 1: Example of clusters for innovation task.

Clustering example of 25 different application cases of packaging line for innovation task “Reduce consumption of compressed air” is illustrated in Figure 1.
Task “Reduce consumption of compressed air” shows for 16% of applications high priority combined with low performance (cluster 2): innovation efforts here are highly recommended.

For 31% of applications (cluster 1) the already achieved high level of performance has to be kept. And finally for the majority of applications (cluster 3, 53%) reduction of compressed air consumption is of low priority by already high level of performance: no innovation activities are recommended here.

The size of the clusters mentioned above has an effect on innovation potential values (2). The corrected values of innovation potential Y^*_i for each task can be calculated with help of following empirical formula:

$$Y^*_i = k\, Y_i\, (1 + C_{1i} + 2C_{2i} - C_{3i}) \qquad (3)$$

where
Y_i - innovation potential of task in %, calculated with (2);
C_{1i} - standardized value of cluster 1, $C_{1i} = 0\ldots1$;
C_{2i} - standardized value of cluster 2, $C_{2i} = 0\ldots1$;
C_{3i} - standardized value of cluster 3, $C_{3i} = 0\ldots1$;
k - normalizing coefficient.

Such correction of innovation potential helps to increase calculation accuracy if capturing of priority and performance values for innovation tasks was performed by interviewing of users or customers.

3 SUMMARY

This paper presents a new quantitative method for calculation of ideality degree of technical systems and for selection of most promising innovation tasks for directed system evolution. We understand the innovation strategy for technical system, product or process as bundle of innovation tasks with the highest innovation potential. Depending on degree of their ideality, innovation tasks may require disruptive or sustainable solutions. Based on this analysis, innovative concepts that lead to a significant measurable growth in customer value and satisfaction can be systematically developed.

4 REFERENCES

[1] Livotov P., Petrov V., “Innovationstechnologie TRIZ. Produktentwicklung und Problemlösung“, Handbuch. TriSolver Consulting, 2002, Hannover, 302 S., ISBN 3-935927-02-9.

[2] Livotov P., “Differentiating the role of TRIZ in sustainable and disruptive innovation process,” in Proceedings of the TRIZ Future 3rd World Conference, ETRIA, Aachen, 12.-14.11.2003.

[3] Altshuller G.S., Creativity as an Exact Science. The Theory of the Solution of Inventive Problems, Gordon & Breach Science Publishers, 1984. ISSN 0275-5807.

[4] Petrov V., “The Laws of System Evolution”, Proceedings of the TRIZ Future 1th World Conference, Bath, 7-9 November 2001, p. 109-128, ISBN 90-77071-01-6.

5 CONTACT

Pavel Livotov, Dr.-Ing.
TriS Europe GmbH,
D-30175, Hannover, Germany
E-mail: p.livotov@tris-europe.com
Phone: +49 (511) 811 200 40
FAX: +49 (511) 811 200 45

Creating A Meta/Mega/Micro Market Trend Hierarchy: Trying To Understand Populations Better Than Populations Understand Themselves

Darrell Mann[1], Yekta Özözer[2]

[1]Systematic Innovation, United Kingdom
[2]ABC Consultancy Ltd, Turkey

Abstract

The paper describes the main outputs from a long-term piece of research aimed at finding the underlying patterns in the thousands of observable consumer and market trends present in the world at any one time. By applying TRIZ principles, we describe for the first time how it has now been possible to find an underlying structure behind these trend patterns. The first part of the paper describes this structure. In the second part we show how it becomes possible to use the underlying patterns to make more robust predictions about things that will happen in the future.

Keywords

Systematic Innovation, TRIZ, Spiral Dynamics

1 INTRODUCTION

TRIZ has done an impressive job of collating discontinuous evolution patterns in technical systems. In order to successfully use this knowledge, however, it is also important to know which of the possible jumps are most relevant to the prevailing market and customer conditions. Answering questions of market relevance demands a knowledge of the markets that thus far TRIZ researchers have not studied adequately. While many others outside the TRIZ world have made attempts at uncovering and mapping market trend information [1][2][3][4], no one has yet seemingly produced anything approaching a reliable and systematic capability. The aim of this paper is to describe some of the key findings from a long-standing programme of research on consumer and market trends in which a team of dedicated researchers have been attempting to assemble a unifying trend theory.

Even a crude examination of the world of consumer trend watching will reveal literally hundreds of apparent directions and patterns. A more systematic region-by-region, industry-by-industry analysis will reveal several thousand. In large corporations there are frequently whole departments of people whose job it is to collect and catalogue these patterns. When it comes to making productive use of them, though, we can see very little evidence of them being used in any kind of effective predictive sense. This failure to understand the ebb and flow of markets is, according to our research, one of the principle reasons why 98% of all attempted innovations will ultimately prove to be commercial failures [5].

The starting aim of the commissioned programme of research, then, was to begin to understand why apparently logical and societally visible trends could somehow cause companies to generate such a high proportion of failed products and services.

While certainly making no claim that we are able to ‘predict the future’ in any kind of traditional understanding of the phrase, one of the main objectives of the research following on from the high level aim was to explore how the market trend patterns, no matter how fuzzy, when combined with TRIZ discontinuous evolution patterns, could be used to do a significantly more robust job of helping organisations to develop commercially successful innovations.

2 BEGINNING AT THE BEGINNING

With a research undertaking as big as this, one of the first challenges is to work out where to start. In specific tasks conducted on behalf of clients, we have demonstrated that significant benefits can be accrued through use of the Perception Mapping tool to understand the relationships between different trends [6]. Because specific projects are able to work with a relatively small subset (typically 50-60) of the overall total number of trends, meaningful answers can be achieved in an exercise that typically can be done by a group in one to two days. Until the start of this piece of work, however, no one had previously attempted to map the interrelationships between ‘all’ of the known trends. This, then, was where we decided to begin this programme of research. Figure 1 shows the top left hand corner of what turned out to be a very large (1000+ by 1000+) matrix in which we began mapping relationships between different trends.

In all, three different types of relationship were mapped during this research:

1) Situations in which one trend ‘leads to’ another trend (denoted with an ‘L’ in the matrix, so that, to take the example from the top left of the matrix, the trend towards increasing Uniqueness is seen to lead to a desire for more Authenticity)
2) Situations where one trend ‘leads to’ another according to circumstances. ‘Circumstantial leads to’ connections were labelled with an ‘~L’ in the Matrix, so that, for example, Still Being Home At 35 *can lead to* increasing Individuality, but the correlation is dependent on other factors.
3) Situations where two trends are in direct conflict with one another. These conflicts were marked with an ‘X’ on the matrix. A clear example of conflicting trends is that between parallel drives towards increasing Individuality and increasing Tribalism.

We already know from our previous work that trend conflicts denote excellent innovation opportunities [7]. Products that successfully resolve these market conflicts tend to be very successful. iPod, for example, was neither the first nor the best MP3 player in the world, but it was the first one – by making the link with iTunes – to resolve the ‘Individuality *and* Tribalism’ trend conflict.

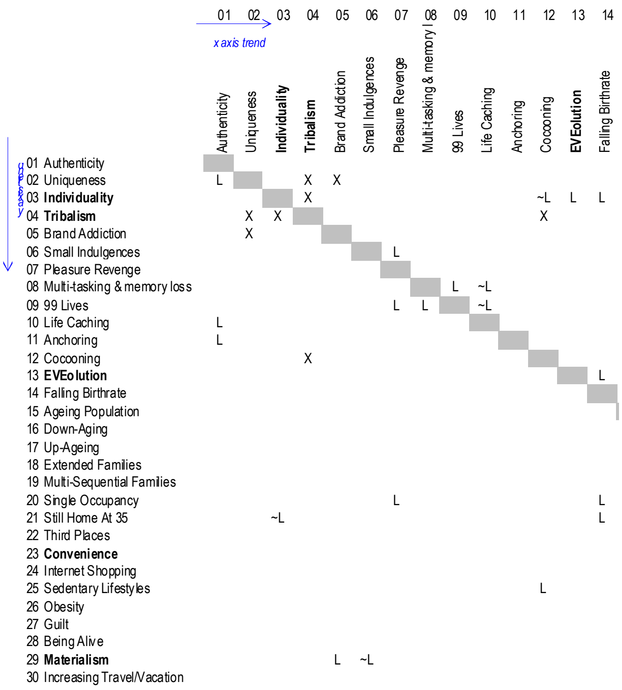


Figure 1: Partial view of trend interaction matrix

What the ‘leads to’ part of the picture began to reveal for the first time was a map showing a distinctly hierarchical relationship between the individual trends. Figure 2 illustrates a partial view of the overall relationship map that gradually emerged from the analysis.

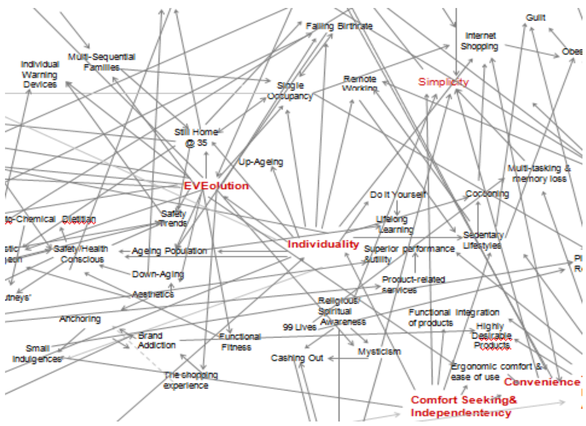


Figure 2: Partial View Of Trend Relationship Map

What even this small portion of the total map begins to show is the emergence of a distinct pattern of ‘sink’ and ‘source’ trends. The Individuality trend, for example, may be seen as the source driving a host of other trends. Conversely, the Simplicity trend is an outcome and consequence of other trends.

In more global terms, what began to appear was a series of patterns describing a distinct hierarchy of trends.

3 TOWARDS A META-LEVEL TREND PATTERN

Having begun to observe a hierarchy in the trends, we felt we needed some kind of framework into which that hierarchy would sensibly fit. Given the recurring theme of space-time-interface throughout the TRIZ/Systematic Innovation story (Figure 3), this was where we started looking for patterns.

As indicated in the figure, the three-dimensions quickly began to correlate quite elegantly with high level differences we observed from the various sink and source trends in our 1000+ trend map. Perhaps the most obvious of the three dimensions was the one relating to TIME. Trends are inherently time-based – ebbing and flowing over the course of months, years, and in some cases, decades.

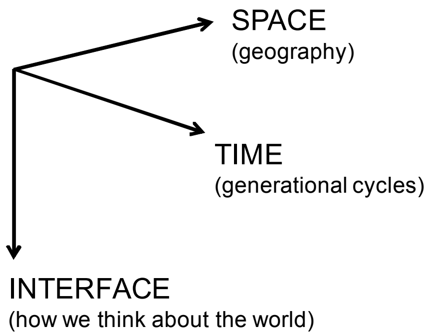


Figure 3: Space-time-interface dimensions and connections to market trends

We quickly hypothesized that these time-related trends might correlate to different generations and generational cycles. Having made that connection, it didn’t take too much to extend the hypothesis to incorporate the archetypal generational differences uncovered by the Fourth Turning research of historians Strauss & Howe [8]. Now a regular feature in the ‘Generations’ section of the Systematic Innovation e-zine [9], the more we look at the four generation archetypes described in the Fourth Turning, the more we began to think they made an excellent foundation upon which to build this dimension of our trend map.

Next most obvious of the space-time-interface dimensions seemed to be SPACE. Looking at differences in trends that might relate to this dimension, it quickly became apparent that geography was an important discriminator. Actually, what we also saw was that, looking back in history, geography was much more important in distinguishing trends than it seems to be today. Sure, we can still see significant geographic differences, but also – perhaps due to the flattening of the Earth caused by near-ubiquitous access to the Internet and hence light-speed visibility of what everyone else on the planet is doing – a lot of similarities. A simple example: while difficult to see any real resemblance between the Baby Boomer generation in the West and equivalent aged people in the East, it is very easy to see strong similarities between members of the Generation Y cohort across the globe. Generation Y, indeed, may just turn out to be the world’s first universal generation.

Least obvious of the space-time-interface dimensions, then, was INTERFACE. As defined elsewhere in the Systematic Innovation story, ‘interface’ is all about the connections between things rather than the things themselves. The best correlation we were able to make between this definition and something that might help us to map market trend patterns were the different thinking levels uncovered by Clare Graves’ Spiral Dynamics research. Rather than describing what people thought about, that correlation was built on the knowledge that the different levels of the Spiral were defined by how people thought about and structured their knowledge. Spiral levels, in other words, are defined by how people think about themselves in connection to the world in which they live.

Having defined the three dimensions, we then had to set about testing whether each dimension gave us a way to map the thousands of known trend patterns and, more importantly, the tens of sink and source trends. Very quickly into this testing process, we saw that the TIME and INTERFACE dimensions gave an ability to draw a two-dimensional map into which nearly everything we were looking at seemed to fit. We show the basic two dimensional grid below in Figure 4:

Figure 4: Time-interface dimensions and connections to generational cycles and spiral dynamic thinking levels

Having seen how this framework has allowed us to map almost everything we have observed in the world of trends, the main problem we are now going to have to face for the remainder of this paper is convincing you the reader that this framework might be something that can apply generically to all trends. Even if we could find a way of illustrating each of the thousands of trends we have tested in the grid, we'd still have the problem that you the reader may not be familiar with those trends or, to turn the story the other way, be familiar with trends that we haven't shown and wonder why we haven't included them.

All in all, we're in something of a no-win situation on this one. The best we can do, we've therefore decided, is to present a few examples and hope they are sufficiently convincing to prompt you to make your own evaluations. Every day, we're trying to find things that don't fit the pattern. We invite you the reader to do the same.

Meanwhile, here is a small selection of examples to show the range of ways they can be connected to the Figure 4 grid. We'll start with a couple of examples from one of last year's better trend books, 'Karma Queens, Geek Gods and Innerpreneurs' [10]. The trend in question is one the book's authors title 'Middlemen'. Middlemen are young males, who've been brought up by parents who have generally indulged them, they have had access to much of what they desire, and as a consequence, now they are in early adulthood they have not yet 'grown up'. Their lives are largely hedonistic and driven by an expectation that they will always be able to do exactly as they please. As shown in Figure 5, people like professional skate-boarder (!) Tony Hawks, and the characters in last year's big hit film 'Knocked Up' are archetypal 'middlemen'. They belong to the 'Hero' Generation Y cohort.

As indicated in the figure, these 'Middlemen' are a very accurately encapsulated sub-set of members of the Generation Y cohort (a 'Hero' generation in Fourth Turning terms) who have either never passed or have regressed to the 3rd 'Feudal' level on the Spiral (highly ego-driven, not particularly caring of other peoples' feelings). The triangular-shaded area in the grid is intended to show that this is a trend confined to the male half of the category defined by the whole box.

Figure 5: 'Middlemen' market trend on generation-spiral framework

Next up, Figure 6 shows a trend uncovered in another book, this time the excellent 'MicroTrends' text from Mark Penn [11]. Archetypes for the Ms Independent trend are absolutely the characters from the Sex In The City TV show – very materialistic, often manipulating and determined to get what they want. Ms Independents are simultaneously members of the Generation X cohort, and women thinking at the Orange, 'Scientific' level on the Spiral.

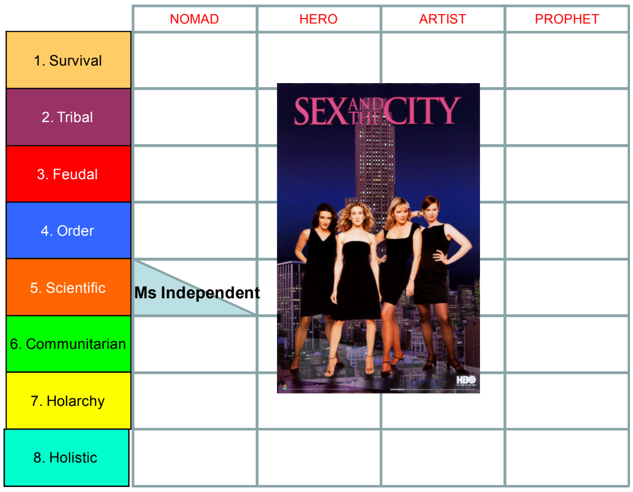


Figure 6: 'Ms Independent' Market Trend On Generation-Spiral Framework

Figure 7, next, depicts the 'Karma Queen' trend from the title of Reference [10]. Karma Queens are by definition female – hence the half-shaded box in the Figure again – but this time women who have generally been successful in life and are now looking to 'give something back'. Archetypes, as shown in the picture, are famous women adopting Third World babies. Read Rentel's description of the trend and you will quickly see that this is a phenomenon originated by Baby Boomer ('Prophet' generation) women, typically entering mid-life, thinking at the Green 'Communitarian' level. Also interesting with this trend is that we are seeing a degree of carry-over from one generation to the next. The faint shading of the Green box for the Generation X 'Nomads' intended to show that we are also beginning to see the Karma Queen trend extending to Communitarian thinkers in the generation after the Boomers that began the trend.

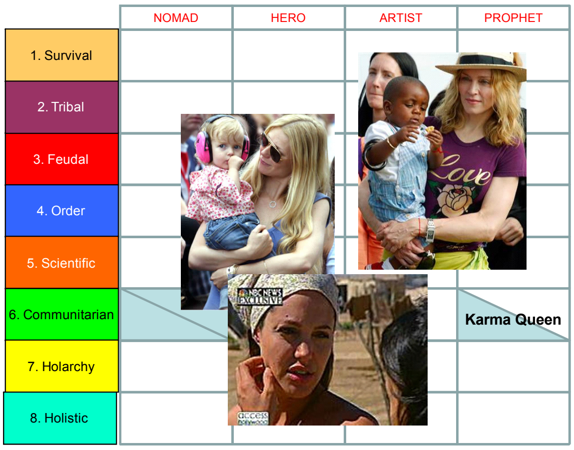


Figure 7: 'Karma Queen' Market Trend On Generation-Spiral Framework

An interesting thing to think about regarding this trend and the Ms Independent pattern described earlier, is that, as speculated by Microtrends, trends that start in one small niche can very easily spread to wider parts of society. In this sense, the Karma Queen concept, although it may be expressed a little differently by Nomad than Prophet generations, is still fundamentally a Level 6 'Communitarian' phenomenon.

As a final pair of examples, we take this idea a step further by looking at the Innerpreneur and Parentocrat trends. Innerpreneurs – as illustrated in Figure 6 – turn out to have little if any link to any generational characteristics. Rather, they are characterized by groups of people thinking at Level 7 on the Spiral.

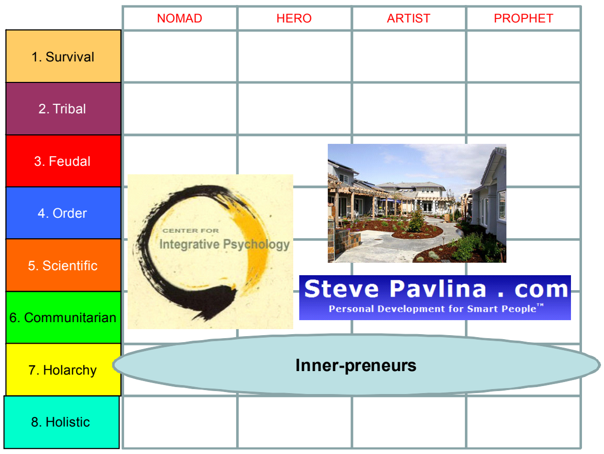


Figure 8: 'Innerpreneur' market trend on generation-spiral framework

If Innerpreneurs provide an example of trends that are more Interface-oriented than generational, Parentocrats (Figure 8) are much more closely aligned to generational cycles. The Parentocrat trend, as it turns out, is very accurately predicted by the Fourth Turning definitions of the different generations. To a large extent in fact the whole generational cycle theory is predicated on the idea that different generations have certain characteristics because of the way that they were raised by their parents. Parentocrats, being very (over-)protective of their offspring will – if the Fourth Turning theory holds true – produce a new generation of 'Hero' parents who will in turn be so over-protective that they will smother their offspring, who in turn will then turn into an 'Artist' generation.

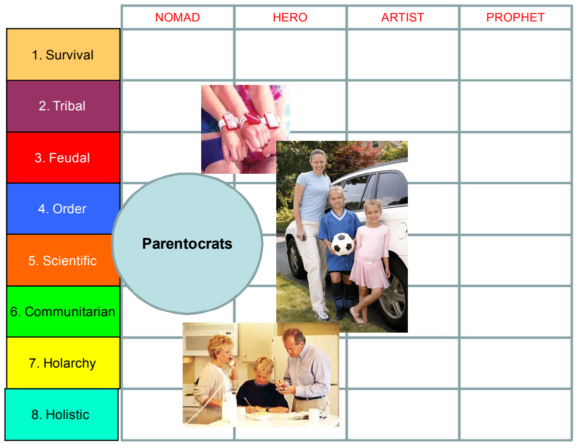


Figure 9: 'Parentocrat' market trend on generation-spiral framework

What Figure 9 highlights is the fact that, while the Parentocrat trend is fundamentally centred in the Nomad generation, parents across multiple Levels on the Spiral have adopted their own versions of the trend characteristics.

While recognizing that trends can spread across several boxes in this TIME-INTERFACE 2D view of the world, we can't entirely forget about the impact of the SPACE dimension. We see many clear examples of how geography can have a big impact on trends. What we tend to see, however, is geography impacting the flavour of a trend rather than the trend itself. Figure 10 illustrates a finding typical of this phenomenon. Think back to the Middlemen trend for a second. Music plays a significant role in this generation and its current desire for hedonistic pleasure. The precise form of music they will identify with, however, is seen to be strongly biased regionally. The Figure this time shows the results of some intriguing research mapping preferred beats-per-minute (BPM) in music across young people in different parts of the UK.

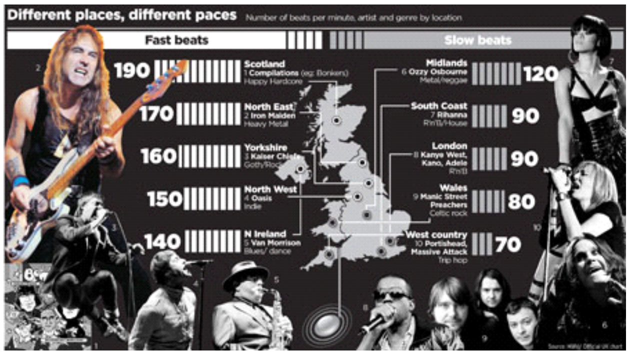


Figure 10: Effect of region on preferred music BPM

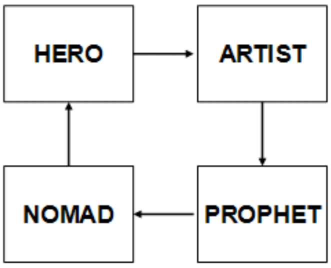
As in so many other areas of life, Figure 10 describes a very distinct North-South divide in the UK. In this case, Northerners are seen to have a preference for faster, heavier beats, while the South swings to the slow, laid-back, chilled-out end of the spectrum. A Generation Y youth can be hedonistic at a heavy metal gig in Newcastle just as well as a surfer-dude at a trip-hop rave in the South West, but try and transplant them from one place to the other, and you've probably got trouble on your hands is what this geographical pattern is trying to tell us.

In the final analysis, the ability of the Generational Cycles to predict what future trends will be is a good start for what we are looking at. Our aim, if you can remember all the way back to the beginning of the paper is to build a framework that, first, helps us to understand the underlying pattern of past and present trends, but then goes on to allow us to predict trends that haven't happened yet. We believe that with the three SPACE-TIME-INTERFACE dimensions, we have uncovered something that gives us a very good opportunity to achieve this aim.

4 FROM ANALYSIS TO SYNTHESIS

Analysing what has happened in the past and showing that it fits into a framework is one thing. Being able to use this framework to predict the future is quite another. This final section of the paper, then, shows how we are beginning to use the trends to do the latter job.

One of the big things working in our favour was the recognition made by the authors of the aforementioned Fourth Turning text that there are some very distinctly repeating generational patterns. As suggested by the time dimension on the Figure 4 matrix, the biggest of these patterns repeats every four generations. Figure 11 presents a crude summary of the various different generational characteristics at different stages of life.



	0-20	21-41	42-62	63-83
HERO	protected	heroic	hubristic	powerful
ARTIST	suffocated	sensitive	indecisive	empathic
PROPHET	indulged	narcissistic	moralistic	wise
NOMAD	abandoned	alienated	pragmatic	tough

Figure 11: Summary of generational characteristics at different life stages

Also important with these generational cycles, if they are to be used in a predictive sense, is placing them onto an actual calendar time axis. The most visually helpful way of doing this seems to be the age-versus-calendar-year picture illustrated in Figure 12.

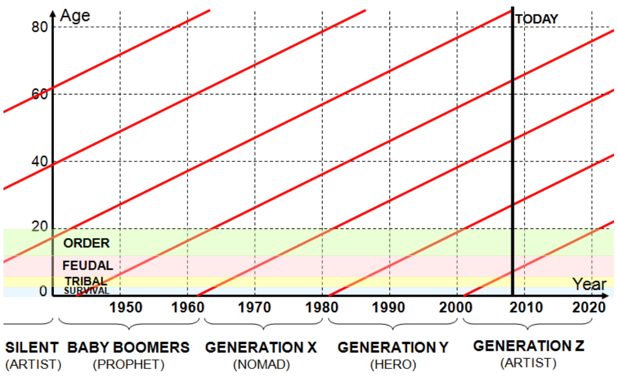


Figure 12: Generational boundaries as a function of calendar time (UK/US)

The most significant parts of these pictures (interested parties can download an electronic copy of the basic template from Reference [9]) are the boundaries between different generations. More specifically, from a predictive perspective the important parts of the picture occur at the intersections between the generational boundaries and a moment in time at which we are looking to make predictions. The figure, for example, shows that in 2008, there are important generational transitions occurring for 8, 26, 45 and 62 year old people. The actual picture is, of course, somewhat more fuzzy than the one shown, but the important implication of these generational boundaries is that if we are responsible for designing products or services for any of these age-group people, according to the generational boundary, we are in the midst of a significant generational shift. This in turn implies that the way we've been doing things will not necessarily be the way we should be doing things in the future.

By way of an attempt to bring a coherent end to the paper, let us consider just one of these transitions and use what we have learned from the earlier trend mapping exercise to make a few testable predictions about certain upcoming events.

One of the most interesting characteristics of the current cohort of 26 year olds is that they are at the stage of life where they are beginning to settle down into long term relationships, and are also likely, whether in a relationship or not, to be contemplating moving into their own house or apartment. This market, according to Figure 12 is currently undergoing a shift from a Nomadic Generation X cohort to a Heroic Generation Y cohort.

Figure 11 suggests that members of Generation Y were protected through childhood and, at 26, are in the middle of their 'heroic' phase. In terms of their position along the Spiral, at 26 years old, the majority of people are at the Feudal, Order or Scientific stages. Generation Y males, if we look back at the Figure 5 'Middlemen' trend, because of their protected upbringing, are highly likely to spend a significant proportion of their life at the Feudal level on the Spiral. Figure 13, then, identifies the places in the trend grid we need to be interested in if our job is to predict the emerging whims and desires of this emerging group of 26 year old customers.

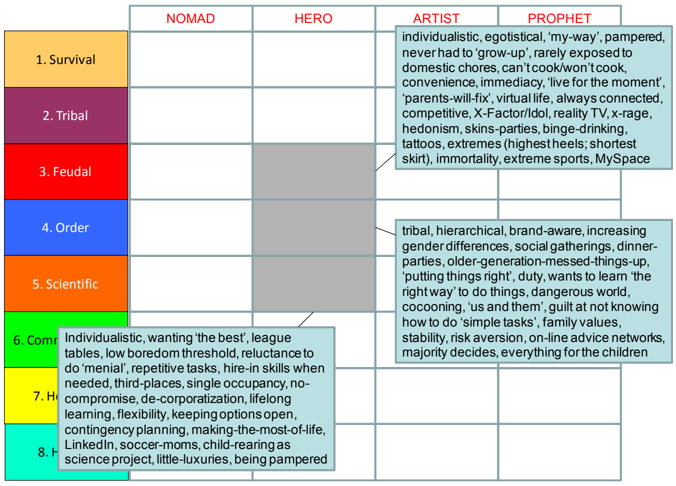


Figure 13: Driving characteristics of emerging 26 year old cohort

If we now say that we are interested in predicting what sorts of, say, fast moving consumer household products this emerging cohort is likely to be interested in, we can begin to speculate on the likely outcomes of the trend patterns that drive these consumers. Here are just a few small predictions that might emerge from such an analysis:

- 'Professional' use cleaning and household products visibly advertised as such.
- On-line social learn-to-cook/recipe-share networks.
- (On-line video streaming of tutorials, etc to cookers).
- Strong drive for self-clean/self-iron, etc
- Apartments with 'no' kitchen (Feudal), 'family' kitchens (Order), 'trophy kitchens' (Scientific).
- 'Learn-to-cook' restaurants/eating-experiences.

- Franchised professional home-cleaning/ironing/cooking services with a recognizable brand presence.
- Convenience foods with error-proof user customization ('home-cooking' that is actually cheating but doesn't feel like cheating).
- Celebrity-chef endorsed takeaway/delivered meals.
- Celebrity-chef endorsed kitchen utensils/equipment.
- Five-portions-a-day 'positive poisoning' convenience foods.
- On-the-move lunches and dinners/ 'power-eat' foods.
- Niche-function convenience foods – in the car, pre/post-exercise, stress-reduction.
- Extreme foods (Feudal – 'ultra-spicy', ultra-sour, etc) (Order – more 'good bacteria' type products) (Scientific – extreme neutraceuticals/performance-enhancing).
- Disposable difficult-to-clean cooking containers.
- Partial-wash/freshen-up cleaning products ('get a second day without guilt').

We will leave the reader to speculate on some of the contradictions that these ideas and the Figure 13 trends from which they emerge create, and how we might set about designing products and services to resolve them. For companies operating in the FMCG sector, these contradictions quite possibly represent the biggest opportunities for generating breakthrough new products.

5 PUTTING IT ALL TOGETHER

We have attempted to cover a lot of ground in this paper, one result of which is that we have only been able to dig more deeply in a very small area. Undoubtedly future publications on this subject will take the opportunity to focus on more specific applications of the results that have emerged from the research. As far as the high level, meta, mega and micro level trends are concerned, we are presently putting the finishing touches on a book on the subject. As ever, our predictions about when our books will be published are often wayward to say the least. That minor detail aside, we are hoping that the book will be published during the first quarter of 2009.

Our involvement with the fuzzy world of market trends actually began a few years ago when we started shifting the focus of our attention from predicting what will happen in the future to the order-of-magnitude more difficult question of when it will happen. While the prospect of 100% guaranteed innovation success rate is a long way from being a practical reality, we already believe we have a demonstrated capability that can significantly increase the odds of success above the current 2% global innovation success rate.

We believe we have found an underlying pattern that both structures and explains the myriad consumer and market trends that we see around us. In essence, the whole TRIZ philosophy has been about studying large amounts of data and distilling patterns from that data. All we are in effect doing when we shift the focus from technology to markets is to extend the scope of that pattern finding challenge. We hope that others in the TRIZ community will join us in the journey to turn the early seeds presented here into a full-blown science.

REFERENCES

[1] Naisbitt, J., 'Mindset: Reset Your Thinking And See The Future', Collins, 2007.

[2] Popcorn, F., Hanft, A., 'Dictionary Of The Future: The Words, Terms And Trends That Define The Way We'll Live, Work And Talk', Hyperion, 2002.

[3] Hill, S., 'Sixty Trends In Sixty Minutes', Brandweek, John Wiley & Sons, 2002.

[4] Gloor, P., Cooper, S.W., 'Coolhunting: Chasing Down The Next Big Thing', Amacom, 2007.

[5] Pfeffer, J. , 'What Were They Thinking?', Harvard Business School Press, 2007.

[6] Mann, D.L., 'Hands-On Systematic Innovation', 2nd Edition, Chapter 9, IFR Press, 2007.

[7] Mann, D.L., 'Unleashing The Voice Of The Product And The Voice Of The Process', paper presented at TRIZCON, Louisville, 2006.

[8] Strauss, W., Howe, N., 'The Fourth Turning: An American Prophecy', Bantam, 1998.

[9] www.systematic-innovation.com

[10] Rentel, R., Zellik, J., 'Karma Queens, Geek Gods, And Innerpreneurs', McGRaw-Hill Professional, June 2007.

[11] Penn, M.J., Zalesne, E.K., 'Microtrends: The Small Forces Behind Today's Big Changes', Allen Lane, 2007.

CONTACT

Darrell MANN

Director, Systematic Innovation

5a Yeo-Bank Business Park, Kenn Road, Clevedon BS21 6UW UK

E-mail: darrell.mann@systematic-innovation.com

Phone: +44 1275 337500

FAX: +44 1275 337509

Yekta ÖZÖZER

Director, ABC Consulting Ltd

E-mail: yekta.ozozer@abcdanismanlik.com

Phone: +90-532-584 14 01

Smart Materials Solve Contradictions: Connecting The Right Materials Solution To The Right Market Need

Darrell Mann
Systematic Innovation, United Kingdom

Abstract
In the paper, we propose that the primary value of any smart material comes from its contradiction-resolving abilities, and that the key to successful commercialisation of any smart material involves making the right links between a contradiction-solving material and a market need for that contradiction to be solved. The paper is divided into two halves. In the first half of the paper we discuss the theoretical basis behind the contradiction-resolving importance in the innovation story and show that while it is already clear that a number of smart materials are technically ready for the market, it is rather less than clear that many markets are ready for them. In the second half of the paper, the attention turns to a number of mini-case study examples showing how smart material capabilities can and have been matched to real contradiction-eliminating market needs.

Keywords
TRIZ, Phase Change, Non-Linear

1 INTRODUCTION

The designer of a suspension system for an automotive application faces a difficult choice when it comes to specifying the optimum type of damping fluid. Sometimes the requirement is for a high viscosity; sometimes it is for low. When that designer makes the trade-off calculations to choose the right viscosity of fluid, they miss an enormous innovation opportunity, since the ‘ideal’ damping fluid would possess both high *and* low viscosity.

In a similar vein, the designer of a bullet-proof vest has a difficult choice to make when making a choice to find the optimum material. On the one hand the material needs to be very stiff; on the other it needs to be flexible. The ‘ideal’ material would again possess both characteristics.

Every time one of these designers makes the decision to ‘optimise’, they miss a significant opportunity to create a breakthrough solution that is ‘ideal’. Designers are not traditionally taught to think about materials that are viscous *and* non-viscous, flexible *and* stiff, big *and* small, red *and* blue or any other pair of conflicting design criteria, and as a consequence rarely think beyond design strategies that seek to ‘optimise’ material properties.

Smart materials like electro-rheological fluids or shape-memory alloys or thermochromic inks present engineers and designers with the potential for paradigm-changing design solutions. They do this precisely because they present ways to solve these ‘X and –X’ contradictions.

For the most part, however, these smart materials tend to be the output of academic research programmes. This in turn frequently results in potentially excellent platform technologies that are unable to make the transition to successful commercialisation. This happens, firstly, because university laboratories are rarely places that allow for demonstration of full-scale manufacture capability, and, secondly, because there is often little ability to see or control a particular application of the basic platform technology. The first problem leads to materials that are viewed by industry as ‘too expensive’, and the second problem frequently leads to fuzzy and unclear IP situations. One of the biggest problems here is that the patents on a basic materials platform technology are bound by the same rules as patents for specific application of the platform technology. In crude terms, patenting the platform technology buys 17 years of protection. In too many situations, unfortunately, this proves to be insufficient time to enable the patent owners to make a return from the applications that flow from it.

The net result is a significant gulf between basic research and commercial realisation, with neither the industry nor industrial worlds asking the right questions. By way of quantifying the extent of the problem, a recent study [1] indicated that the average return for applied university materials research is around $3 for every $100 invested. As an investor this figure would tend to send a message that money is better spent elsewhere. A big part of this paper, then, is trying to better understand the roots of the problem and to make suggestions that might help to bridge the gulf. We start the discussion on the industry side of the equation, and the problem of designers that tend to operate with an ‘optimum’ as opposed to ‘ideal’ mindset.

2 WRIST REPLACEMENT

Figure 1 illustrates an x-ray of a typical wrist replacement. Usually prompted by the onset of chronic arthritis, wrist replacement surgery has one of the worst track records for durability across the range of all joints that surgeons are able to replace. Of the 30,000 or so wrist replacement operations carried out in the UK every year, almost half are replacement-replacements, where a surgeon is replacing a previous replacement that has somehow failed.

Figure 1: X-Ray Of Typical Wrist Replacement

One of the main problems, as may be seen from the figure is that a lot of metal is required and there isn't a lot of bone around to hold it. The problem is further complicated because, unlike, for example, hip replacements, wrists have to cope with a much wider range of loads. A hip joint spends nearly all of its time in compression, and when it is in tension, the load is limited to the weight of the leg. A wrist joint, on the other hand, experiences both tension and compression loads on a regular basis. In both cases, these loads can exceed the weight of a person's whole body.

Although wrist replacement joint engineers might not explicitly recognise it, they are caught in the middle of a challenging contradiction. The main problem area is the tapered pin inserted into the prepared end of the radius. When the joint is in compression (such as, say, when the patient is doing a push-up exercise), it is desirable to distribute the loads over as much of the taper as possible in order to minimise the likelihood of splintering the radius. Conversely when the joint is in tension (such as when the patient is doing a pull-up exercise), the taper is a bad thing, because it becomes very easy to dis-lodge the pin. One possible remedy to this problem, of course, is to tell the patient they shouldn't do pull-ups or lift heavy objects anymore. Well, if that sounds like a pretty big compromise to expect the patient to make, it is ultimately not too far different from the compromise that the joint designer is also making.

By recognising that a taper is a good idea for the compression case, an optimization-focused design strategy now sets about 'optimizing' the taper angle. If the designer was made aware that every time he or she started conducting sophisticated mathematical design calculations to find the optimum anything, they were missing a big opportunity, then we might start making some innovation progress.

Figure 2 illustrates what the contradiction-aware designer might see when looking at this wrist replacement problem:

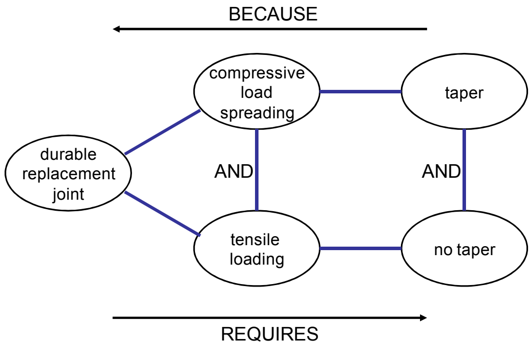


Figure 2: Wrist Replacement Joint Contradiction

It is difficult for anyone – TRIZ-aware or otherwise – to contemplate a problem statement that says we want a design solution that has a taper *and* doesn't have a taper. But, of course, that is exactly what we need to be thinking about if we are to create some kind of a breakthrough solution to the problem.

One of the reasons the Figure 2 template [2] is useful, is that it offers the problem solver several contradiction resolution opportunities. Essentially each of the six lines in the picture represents a conflict or contradiction. Fail to solve one of them, and we still have five other possibilities. Were the designer to start with the 'taper and no taper' physical contradiction, they would immediately be presented with the usual separate-in-space, separate-in-time, etc strategies. Recently, these strategies have been complemented with a model that allows a problem solver to map the eligible separation strategies to the Inventive Principles that are most likely to help resolve the contradiction [3]. The eventual model is illustrated in Figure 3:

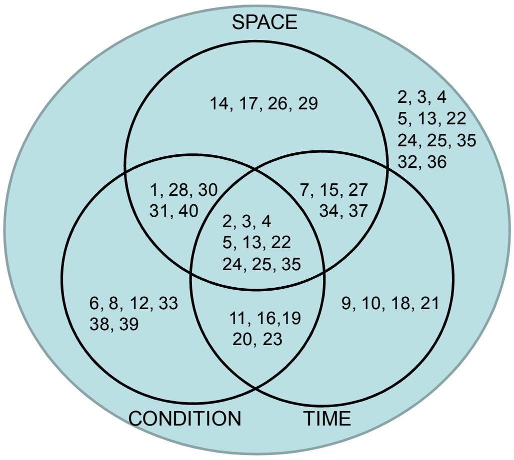


Figure 3: Mapping Physical Contradiction Resolution Strategies To The 40 Inventive Principles

For this particular wrist replacement 'taper-and-no-taper' problem, all three of the time, space and condition resolution strategies appear to be possible, and so the place to start looking for the most relevant Inventive Principles is at the region at the centre of the figure where all three regions intersect. What this means is that the most likely Principles to solve the wrist replacement problem – based on the thousands of problem solvers that have travelled a similar road before us – are 2, 3, 4, 5, 13, 22, 25 and 35.

Although it might not look or feel like it, Principle 35 is the one that is trying to point problem solvers in the direction of smart material solutions. As discussed in [4], Principle 35 is simultaneously the most frequently recommended Inventive Principle and the one that is the least well applied by problem solvers. When applied to the 'taper and no taper' problem, it is easy to see why – simply telling a designer to 'change one of the design parameters' is only slightly better than useless in the vast majority of cases. The missing piece in the jigsaw, or rather the biggest mis-interpretation of this Principle is that it is often viewed as a call to optimize 'a parameter', whereas in actual fact – since TRIZ is fundamentally not about optimization – it is a call for problem solvers to adjust parameters far enough that a non-linear shift in performance occurs. Figure 4 shows an example of the sort of way in which this strategy is most effectively applied.

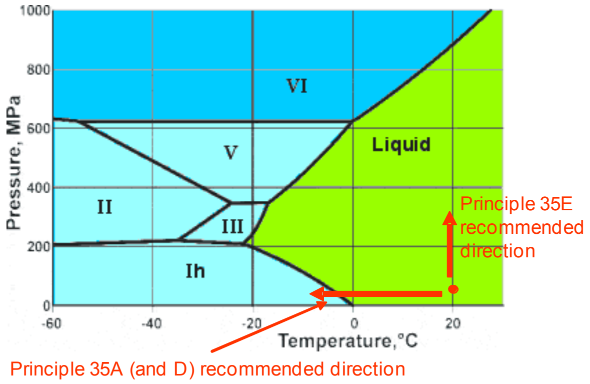


Figure 4: Parameter Changes Across Phase-Boundaries

Having made the connection to non-linear shifts, it is necessary to work out what parameters are required to be shifted. A very good way to do this involves looking back at the Figure 2 template and examining 'what changes' between the two extremes of the contradiction. So, what changes between tension and compression in the wrist joint? Well, for one thing, the loading makes a switch from negative to positive. Strain also changes, and if strain is changing, so is the size of the hole in the bone. Stress is changing, which in turn means pressures are changing.

Next, we need to explore if any of these changes are relatively different between the bone and the metal replacement joint. The reason for this is that any differences between the two materials may well cause problems. Having asked this question, it very quickly becomes apparent that there are many differences between the properties of bone and titanium. Not least of which is the fact that their stress-strain characteristics are very different. And not only different, but different in different ways as loading transitions from compression to tension. Ultimately, the differences reduce down to a difference in Poisson's Ratio characteristics. In actual fact, the Poisson's Ratio behavior under tension of bone is the exact opposite of that of titanium and other metals: 'stretch' bone and, at first, it gets fatter (i.e. it has a negative Poisson's Ratio). Stretch titanium, on the other hand, and it gets thinner (i.e. it has a positive Poisson's Ratio).

So far so good. Having found a number of differences between what was there in the original healthy joint and what the surgeon is going to replace it with, and having picked up the idea of transitioning boundaries as a means of solving contradictions, we are in a position to conduct a targeted search for a 'smart material' solution. And, ideally, one in this case, where under tension we achieve a negative Poisson's Ratio, and under compression we achieve a zero or slightly positive Ratio.

Are there solutions to this problem? Are there materials that are able to change their Poisson's Ratio properties? It doesn't sound too likely. Afterall, we can go to any materials textbook and discover that every material has a nice neat, single-value Poisson's Ratio printed next to it. The answer, however, turns out to be yes, auxetic materials and/or structures, if appropriately configured, are amply able to do the job. Auxetic structures that are able to vary their Poisson's Ratio properties according to different conditions have been observed for some time now. Alas, so far, no-one has made the connection between problem and potential solution. From the designer's perspective, we propose here, it is because the wrong problem has been specified. More on that subject later. In the meantime, it will be useful to see whether it might be possible to generalize what has happened in this wrist replacement problem to all types of physical contradiction problems involving physical materials and objects:

3 A GENERALISED MODEL

The wrist replacement contradiction is by definition a mechanical problem. Any smart material solution to this problem requires the material to respond to in different ways to different conditions. The key word in that sentence is 'respond'. The important question that goes with it is 'what type of response does this situation require?'

The next question that needs to be thought about is, what is changing that can act as a stimulus to create the desired response. The key word in that question being 'stimulus'. In the case of the wrist replacement problem, the primary stimulus is load. Changing load, therefore, acts as a stimulus that prompts to trigger a changing Poisson's Ratio response. In general terms, this is a situation where we have a mechanical stimulus and are looking to trigger a mechanical response.

The reason for thinking about the world in this kind of stimulus-response manner is that it allows us to make a very simple and effective way to classify smart material solutions. Table 1 presents the results of arranging known smart materials in this way. Across the top of the table is a range of different kinds of response that a designer might wish to achieve. This is usually the place to start when looking at the table since it focuses on the outcome we are looking to achieve, and therefore the type of problem we are trying to solve. The 'stimulus' column down the left hand side of the table then prompts the user to think about what is changing (or what could be changed) in the system in order to trigger the desired response. The range of different classes of stimulus is intended to remind users that there are a number of possible options. In the wrist replacement problem, as in any situation where we are trying to create an 'ideal' solution, the idea is to make use of a stimulus that is already present in the system. What the list reminds us, is that if there is no existing stimulus, there may be things we could add to the system.

response→ ↓stimulus	electrical	magnetic	optical	thermal	mechanical	chemical
electrical		magneto-electronics, spin-electronics, spintronics	electro-chromic, electro-luminescent, electro-optic, piezo-chromic, Kerr Effect, Pockel Effect	thermo-electric (Peltier)	piezo-electric, electro-strictive electro-rheological electro-kinetic	electrolysis, electro-chemical, bio-electric, electro-migration
magnetic	magneto-electronics, spin-electronics, spintronics Hall Effect		magneto-optic, piezo-chromic	magneto-thermal	magneto-strictive, magneto-rheological	nuclear-magnetic-resonance, magneto-chemical
optical	photo-conductive	opto-magnetic	optical bi-stability	photo-thermic	opto-mechanical photo-acoustic	photo-chemical, photosynthesis, photo-catalyst
thermal	thermo-electric, super-conductivity, Radiometer Effect pyro-electric	Curie point	thermo-chromic, thermo-luminescent		shape-memory	
mechanical	piezo-electric, electrostrictive	magneto-strictive	mechano-chromic, rheo-chromic		rheopexic, auxetic, shear-thinning, dilatants, non-Newtonian, pseudo-plastic	
chemical		magneto-chemical	colour-change, litmus, luminescence	exo-thermic endo-thermic		catalysis

Table 1: List of known ‘intelligent’ or ‘smart’ resources.

The best way to think of the table is as a list of key-words that can be used to instigate and guide a more detailed Internet or patent database search to find actual solutions. In the wrist replacement case, the box at the intersection between desired mechanical response and input mechanical stimulus indicates that auxetic materials are already an established solution in some applications. All of the entries in the Table – which we don’t claim to be comprehensive at this point in time, merely ‘a hopefully ‘useful start’ – comprise materials or materials systems where the kind of non-linear ‘phase-change’ behaviour illustrated in Figure 4 has been achieved.

4 ANOTHER EXAMPLE

Figure 5 illustrates an example of a rather more simple use of one of the smart materials identified in the table. The picture illustrates a ‘self-timing’ egg. The incorporated smart material solves a common problem with boiled eggs that we all like our eggs cooked a certain way, but we often get a result we weren’t expecting. The reason we get our eggs cooked incorrectly more often than not is that we all cook our eggs using an ‘optimization’ rather than ‘ideal’ mindset. That you probably don’t recognise this fact is a good indication of how difficult and insidious the optimization-versus-ideal shift can be.

Figure 5: ‘Self-Timing’ Egg

We have all of us thought about the egg problem as an optimization problem because we all know how long we like our eggs cooked for. Alas, we have all remembered one (optimized) number (‘a four minute egg’), when of course, no two eggs are the same. What the self-timing egg solution does is effectively says, wouldn’t it be nice if my specific egg in my specific pan ‘tells me’ how cooked it is.

The desired response, thinking to Table 1 is ‘tells me’. The table presents a number of possibilities here. Most likely the simplest of those possibilities, and certainly the choice made by the owners of the Figure 5 solution, is optical’. The next question, then, is what are the available stimuli that might trigger the desired response. Again, as with the wrist replacement problem, we need to look at what is changing in the system. Again as far as the owners of the solution were concerned, the simplest and most obvious change is in the temperature of the egg.

Look up optical response from thermal stimulus in Table 1, and the first answer in the list of possibilities is thermochromic. Which is precisely the solution adopted by the self-timing egg inventors. Or rather, almost (as ever, there is always a 'yes, but') because what makes the solution especially powerful is that it contains two subtly different thermochromic inks, each with a slightly different colour change trigger temperature. Hence, the word 'soft' (as shown in the Figure) is triggered at one temperature, and the word 'hard' is triggered at another, slightly higher temperature.

5 FROM THE MATERIAL SCIENTIST'S PERSPECTIVE

In many ways the self-timing egg and the wrist replacement joint cases provide two ends of a spectrum as far as the materials scientist is concerned. In the wrist replacement case, the medical devices industry may well be guilty of defining the wrong problem, but one of the reasons they have been thinking in optimization rather than contradiction-solving terms is that they know how difficult it is to prove to the regulatory authorities that the solutions they are proposing are safe. Tweaking the shape of a titanium pin is a far easier thing to prove is safe than some new form or structure of titanium. Proving a new material is safe can involve several years of expensive validation testing.

Applying a bit of thermochromic ink to an egg-shell on the other hand merely needs the connection between the solution and a real problem to be made. If the designer gets the self-timing egg solution wrong, the consequence for the customer is an over-cooked egg. The joint designer, on the other hand put simply has the responsibility for the quality of a patient's life sitting on his or her shoulders.

There is a rather splendid quotation in John Naisbitt's latest book [5] 'don't get so far ahead of the parade that no-one knows you're in the parade anymore'. This quote gets right to the heart of the scientist's dilemma in the world of smart materials. If the basic patent on a platform material technology protect your IP for 17 years (there are various tricks and strategies that can be applied to extend this period, but, for argument's sake we will stay with this number since it doesn't significantly alter the form or extent of the dilemma). The moment patents are filed, the clock is ticking in terms of commercialising and achieving a return on the investment that created the basic material. This means that unless applications that can be brought to market well inside the 17 year window, the basic material technology has limited if any value. Thermochromic inks are fundamentally simple and inexpensive, so their transition to market for a host of applications has been relatively simple. Despite many years of effort on auxetic materials, looking at the other end of the spectrum, there are still virtually no commercialised applications. Despite the often profound benefits they present to designers in a host of situations.

Perhaps a good example of an organisation 'getting it right' is Dow Corning and the 'Active Protection System' (APS) material solution spun out of research at Imperial College in London – Figure 6.

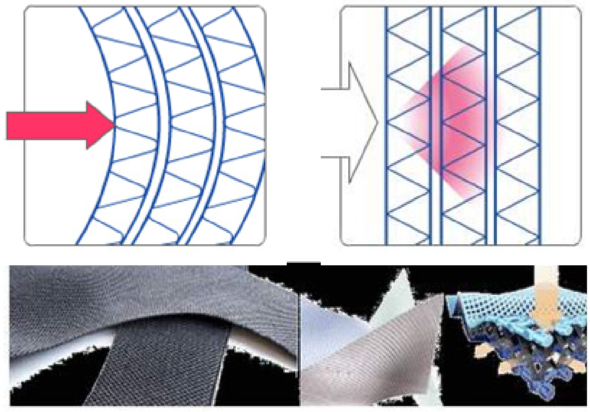


Figure 6: Dow-Corning Active Protection System

APS is a material system that is flexible under low loading conditions (top-left part of the figure), but which becomes very stiff when subjected to a high impulse load (top right). In terms of Table 1, APS is, like the afore-mentioned auxetics, a material that achieves a mechanical response to a mechanical stimulus. The material is in fact a very elegant example of a shear-thickening dilatant silicone coating.

The material has a potential role to play in any situation where the 'flexible and stiff' contradiction is present. Having patented the basic platform technology the race is now on to find appropriate applications for the technology. Being aware of the contradiction being solved has allowed the researchers to target a number of possible applications, the ultimate of which currently appears to be in things like bullet-proof vests.

Proving that the material is suitable for such a demanding application, of course, requires time and significant resources. A very good strategy therefore is to identify shorter-term niche applications. A good example here – and perhaps a poster-child demonstration of just how hard the whole innovation timing task is – is the application in shin-pads for soccer players.

Making a few thousand shin-guards doesn't sound like a great reason for investing in the productionisation of the APS material, but what it may well do very admirably is provide a very high profile advertisement to let others in other fields know about the material. Plus it provides for the acquisition of real world data on the durability and effectiveness of the material – information that will be vital in supplying the necessary evidence that will be required by the regulatory bodies for the more challenging applications of the material.

This author knows nothing of the actual Dow Corning strategy for APS. We do, however, work with a number of universities struggling with the issue of successfully commercialising their smart material platform technology research. There can never be a simple answer to the problem. But what can be said with certainty is that the problem almost always has a contradiction at its heart, and that, as a consequence, thanks to the TRIZ research, someone, somewhere will already have solved the contradiction. Figure 7, finally, highlights one of the frequently used solutions to the commercialisation contradiction:

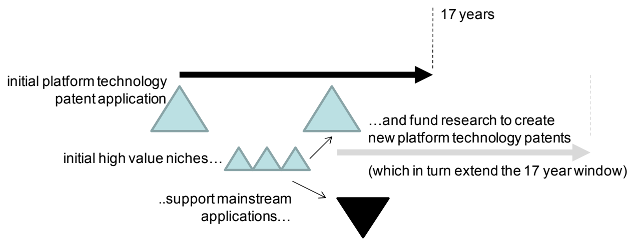


Figure 7: Smart Material Innovation Timing

Everything in this picture stems from the 17 years that the original patents 'buy'. (An immediate alternative that emerges here is for universities to consider not patenting, but rather keep their smart material formulations a trade-secret until such times as the first commercial possibilities are close to fruition.) In simple terms, if the patent game is going to be played, the aim is to generate revenues that pay for the research that in turn permit new and better platform patents to be constructed, which in turn, then keep moving the 17 year time window far enough into the future that the mainstream applications have sufficient time to get to the market and begin generating the revenues that will pay for the pensions of all involved.

6 PUTTING IT ALL TOGETHER

The paper has discussed the gulf between smart material solutions and successful commercial exploitation. The gulf exists because both materials scientists and designers and engineers frequently come to the story with the wrong mindset.

Designers and engineers need to begin thinking about contradiction-solving as a part of their job. They also need assistance to make it easy to find possible candidate solutions to the contradictions they find. Table 1 of this paper is intended to act as a first step towards making a more direct connection between contradiction type and available solutions.

For materials scientists, the challenge is more about managing the transition from basic material technology to successful commercialisation. As ever, all dilemmas are contradictions, and in turn all contradictions can be solved. The key to their resolution in the case of smart materials has a lot to do with finding sufficient high-value niche applications that will generate sufficient revenues to enable the research that will in turn open up the mainstream applications.

REFERENCES

[1] Graff, G.D., 'Managing University And Government IP', Commercialisation and Technology Transfer Seminar, 'Leveraging IP For Wealth Creation', Kuala Lumpur, December 2007.

[2] Mann, D.L., 'Evaporating Contradictions: Physical And/Or Technical', TRIZ Journal, March 2007.

[3] Systematic Innovation E-Zine, 'Re-Thinking The Physical Contradiction Solution Strategies', Issue 76, July 2008.

[4] Systematic Innovation E-Zine, 'Effective Use Of Principle 35', Issue 58, January 2007.

[5] Naisbitt, J., 'Mindset: Reset Your Thinking And See The Future', Collins, 2007.

CONTACT

Darrell Mann
Director, Systematic Innovation
5a Yao-Bank Business Park, Kenn Road, Clevedon BS21 6UW United Kingdom
E-mail: Darrell.mann@systematic-innovation.com
Phone: +44 1275 337500
Fax: +44 1275 337509

Applying TRIZ/USIT to A Social & Technical Problem: Auto-locking Door System of Apartment Building

Toru Nakagawa and Arata Fujita
Osaka Gakuin University, Japan

Abstract

Students' discussions were guided with TRIZ and USIT to solve an everyday problem. The security problem of the auto-locking door system of apartment buildings needed to be solved in the human psychology and social behaviour first and then it must be ensured by the technology. The mechanical & physical system of the door has been shifted to an IT & logical system.

Keywords

Case study, Security, USIT, Cause-effect analysis, IT system

1. INTRODUCTION

This is a case study report of solving an everyday problem by guiding students' discussions and constructing a system of conceptual solutions. TRIZ and its simplified & unified process USIT have been used in this study in a rather informal manner.

In my thesis-work class of Osaka Gakuin University, every student is required to find and solve an everyday problem for his/her thesis. Since our undergraduate students in the Faculty of Informatics do not have technological specialty yet, we think common and familiar problems in our daily life are suitable to address. I advise the students to have problems individually but to discuss and work on the problems together for stimulating ideas and understanding more deeply.

The present problem is related to the security of an auto-locking door system at the entrance of an apartment building. Arata Fujita is living in a big apartment building with his parents in Osaka City and feels some insecurity with the door system. It is widely known that the current standard technology of auto-locking door system does not prevent unauthorized persons from entering. Any person can enter the door simply following a resident by pretending to be a resident.

In the seminar class, I guided the discussions by Fujita and other four students on the causes of the problem and on possible solution ideas. Discussions were mostly recorded with Post-it Notes and summarised step by step. The thesis work by Arata Fujita was posted in [1].

Then Toru Nakagawa worked further to build up the conceptual solution. The whole process of analyzing the problem, generating ideas, and constructing a solution was reported by Nakagawa and Fujita in the 3rd TRIZ Symposium in Japan, 2007 [2]. Presentation slides in Japanese and in English, and a full paper in Japanese are presented/published in the Proceedings and are also posted in my Web site "TRIZ Home Page in Japan".

The present paper is based on the work [2] and rewritten in English so as to clarify our thinking.

2. SETTING THE PROBLEM

2.1 Start of the work

Arata Fujita brought in this problem as his thesis topic. At that time there were several criminal news stories broadcast on TV. A child had been fallen from a high storey of an apartment building; a girl was injured by somebody in the corridor of a high-rise residence, etc. Unknown criminals are supposed to enter the residential building even though the entrance door has a standard auto-locking door system.

Everybody knows from their experience that typical auto-locking door systems are not secure enough for preventing unauthorized persons from entering. Any person can easily slip in through the open door just after a preceding resident. It is difficult for us to stop such a person, even if we are on the spot and suspicious about the person.

So we have chosen this as a good problem to solve.

2.2 Confirming the focus of the problem

Typical apartment buildings have various security means. Not only the entrance door locking system, but also the overall structure of the building, structure of elevators and staircases, concierge and monitoring system, interphone between entrance and flats, door locks of each flat, etc. For the nature of security, we have to maintain all these means one by one.

Nevertheless, we have found in discussion that the entrance door lock system is the most important means and yet has the commonly known defect.

In a typical auto-locking door system, the residents are requested to show authentication of entering the door by means of keys, ID cards, or even finger prints. Visitors, on the other hand, are typically requested to talk on the interphone with the resident in the flat for obtaining temporary authentication. The resident, talking (and viewing) through the (video-)interphone, may send the unlock-door order to the system.

However, an unauthorized person can slip in through this entrance simply by following a preceding resident who opened the door. A closing door will open again when the person pushes it lightly. Once such a person enters there can be various forms of risks.

With this understanding, we have decided to focus our efforts on the problem of solving the security defects of the auto-locking door system at the entrance of the apartment building.

2.3 Problem definition

We have used USIT (Unified Structured Inventive Thinking) [3] as the main process for problem solving. The discussions at the initial stage may be summarized in the style of Problem Definition in USIT.

(a) Unwanted effect

At the entrance of an apartment building, unauthorized persons can easily enter through the auto-locking door system and threaten security.

(b) Task/goal

To ensure the security of the apartment building by preventing unauthorized persons from entering the auto-locking door.

(c) Sketch of the problem situation

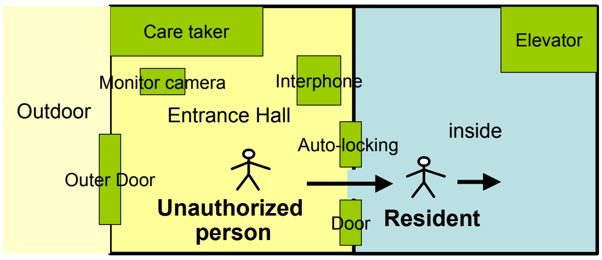


Figure 1: Problem situation.

(d) Plausible root causes

The unauthorized person, behaving like a resident, can enter the open door by simply following a resident.

(e) Minimum set of relevant objects

Entrance door, lock control system, an unauthorized person, a resident who goes ahead

3. ANALYSIS OF THE PROBLEM

In the stage of problem analysis, we have used various methods in a flexible way. The analysis processes are described in a logical way as follows:

3.1 Space and time characteristics analysis

Typical characteristics in space are drawn in the sketch, Figure 1. The inner door has the auto-locking system. While the door is open after the entrance of a resident, an unauthorized person can enter by walking a few meters behind.

The duration of the door opening is typically about 10 seconds. The resident, sometimes with baggage and with children, can enter the door smoothly and safely. The heavy door opens and closes slowly. The closing door can be reopened easily by pushing it back lightly.

All these operations are performed for the sake of safety as well as security.

3.2 Current security methods in the auto-locking door system

Current security methods in common and in advanced systems are discussed and surveyed at this stage.

(a) Methods of identifying a resident

There are various ways of proving to be a resident for authentication. Possessing/showing keys, card keys, IC cards, RFID, etc. Biometric authentication with finger prints, palm vein patterns, face recognition, etc. may also be used in some advanced cases.

(b) Methods for visitors

Visitors are not allowed, as a rule, to enter without being approved by a resident. Typically, at the video-interphone just before the inner door, the visitor pushes the apartment number of the resident to be visited. The resident, talking with the visitor on the phone and checking the person through the video, may approve the entrance and send a signal to the control system to unlock the door. If the resident does not approve, the door will not be opened.

(c) Methods for opposing unauthorized entrance

As stated in 2.3, the present problem is the entrance of an unauthorized person through the 'already open door'. In some cases, a concierge or a guard watches and can prevent it. In many other cases, video monitors are set and the monitor screens are either viewed in real time or recorded for later reviewing. These devices are either expensive in human resources or are not effective if they are unattended for a period of time.

3.3 Thinking from the side of offenders

When we consider security, we usually think how to prevent from, protect or defend against something wrong. But thinking in the other way, i.e. from the side of offenders, is also useful. Such a way of thinking is called subversion analysis in TRIZ, but actually has been a well known method in the art of war since ancient China.

Thus in the class, I guided the students to temporarily take the position of offenders and to think how to enter the door without being suspected. I encouraged them to keep saying their ideas and recorded the ideas on Post-it Notes. Then the cards are posted on the whiteboard and are grouped and rearranged according to their intentions. This is a quick and informal application of the KJ Method (or Affinity Diagram Method) originally developed by Jiro Kawakita [4].

Such offending ideas may be summarized (in the upper-level summary cards of the KJ Method) as:

- Unauthorized person should behave just like a resident.
- He can slip in through the open door at the proper time.
- Once inside the door, the person can go anywhere and can do anything.

3.4 Root-cause analysis (1) duration of open door

As discussed in the space and time characteristics analysis, the rather long duration of the door being open is clearly one of the root causes of the present problem.

In the door operation, safety is the crucial criterion even over security; thus the door should not be shut quickly. This is the fundamental contradiction in this problem.

3.5 Root-cause analysis (2) psychology of the residents

From the beginning we noticed that the residents allow the unauthorized persons to slip in through the open door. The residents sometimes suspect such persons and some other times do not suspect them at all. So we need to analyze the root causes of the psychology of the residents.

I guided the students to talk about their own thoughts and feelings in such a situation, and I asked them 'why?' from time to time.

The main points may be summarized as:

- Residents allow the unauthorized persons to get in.
- Because I thought he/she would be a resident.
- Because I didn't think he/she a malicious person.
- Because we cannot distinguish whether a person is malicious or not.
- Because usually we assume our community is formed of good people.
- We don't know what to do even if we suspect the person to be malicious.
- If we suspect the person to be malicious, and he/she is not, we could be in trouble

In essence, the present system implicitly requests the residents to judge whether the unfamiliar person is malicious or not, and the residents do not want to take the risk of misjudging and getting into a trouble. The essence of the difficulty is that the present system implicitly requests the residents to make an impossible judgement.

3.6 Root-cause analysis (3) happening of meeting two parties

In the above discussion, there arose a question 'Even though we understand the need to be aware of suspicious cases, we do not know what to do.'

So we went further to discuss 'what should we do when we happen to meet other people at the entrance door?' During this discussion it became clear to us that the (social) rule for the present auto-locking door system is not effective for (or does not cover) such a case. The present system does not clearly say what to do; this means that there is no standard social manner applicable in such a case.

Suppose we meet a person at the entrance whom we do not know to be a resident or not. In order not to allow an unauthorized person to enter, we should behave at least not to assist him to enter. But it means not behaving kindly and also means behaving unkindly.

Formally, we should say (either explicitly or implicitly) the person, "Please wait for a while till the door is closed. Then get the authentication on the control board and open the door for yourself." This statement is quite different from the kind/polite way we usually show in case of a public entrance. This difference is so large for ourselves and for the person that it would be possible to make the person angry and run into a trouble.

Thus one more root cause here is the lack of the social rule for the cases that two (or more) parties meet by chance at the auto-locking entrance door of apartment buildings.

3.7 Understanding the overall structure of the problem

During these analyses from multiple points of view, we have memorized various facts, observations, views, solution ideas, etc. in a large number of Post-it Notes. For the purpose of understanding the overall structure of the problem, we first applied the grouping technique of the KJ Method and obtained 20-30 higher-level cards.

Then we displayed them all on the board and tried to construct the overall structure of the problem. The KJ Method and the RCA+ Diagram Method [5] were useful in this process. The result is shown in Figure 2 [1].

The cards (1) - (4) express some of the present methods. The cards (5) - (17) are related to the description of the present problem and its causes. The arrows among them show the cause-effect relationships in the way of RCA+ (though not rigorously). The cards (18) - (27) describe some solution ideas.

Figure 2 contains rich information in a compact and yet structured form. The whole problem analysis can be understood by reading the cards in the order shown in ( ) together with the relationships between them.

3.8 Understanding the essence of the problem

Summarizing the whole analysis, the essence of the problem can be described as follows [by using the card numbers shown in Figure 2].

The principal reason for the threat to the security of apartment buildings at the entrance door is the fact (7):

- '(7) Unauthorized person can enter the door easily at a good timing when it is open (by a preceding resident).'

This threat (7) is not avoidable due to three main reasons. They are:

- First, '(8) The auto-locking door is kept open/unlocked for about 10 seconds.'

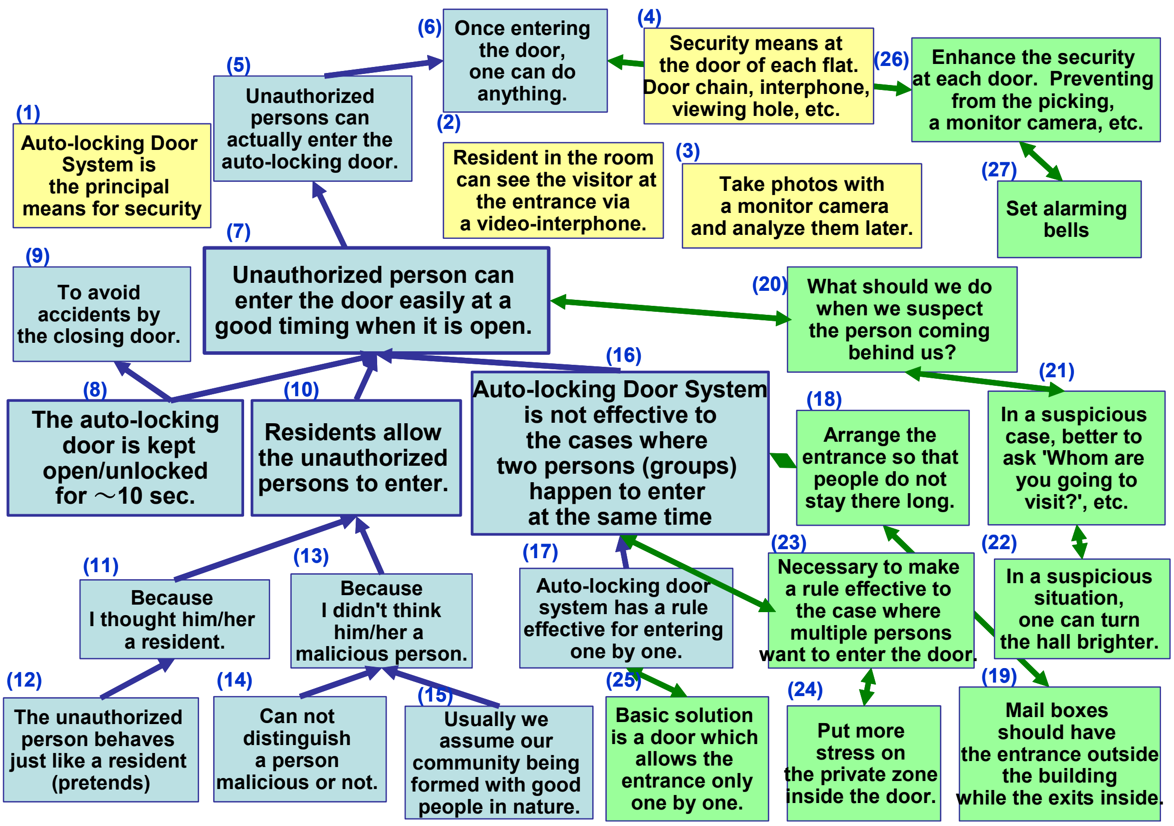


Figure 2: Overall structure of the problem.

- Second, '(10) Residents allow the unauthorized persons to enter.'
- Third, '(16) Auto-locking door system is not effective to the cases where two persons (or groups) happen to enter at the same time.'

Thus, clearly, we have to eliminate all these defects in our design of a new solution system. The above three defects are related to technology, psychology, and social behaviour, respectively.

4. GENERATING IDEAS AND CONSTRUCTING SOLUTION CONCEPTS

During the analysis we have obtained various solution ideas as partly shown in Figure 2. This kind of idea generation is a natural process, because when we find specific causes, defects, weak points, etc. we often find solution ideas, effective or not, as immediate reactions.

As the next step, we have examined such ideas more closely and expanded our range of solution ideas. During this stage we have tried to figure out ideas so as to expand the current state of technology and to think of new approaches in relation to our psychology and social behaviour.

We have used Post-it Notes again to memorize fragments of ideas and solution directions. By considering the relationships between such ideas, we have revealed possible logical structures among the solution ideas.

4.1 Solution ideas to the problem of 'Residents allow them to enter'

Among the three main causes of problem, we have found the problem related to the residents is most basic.

Figure 3 shows the cards related to this problem.

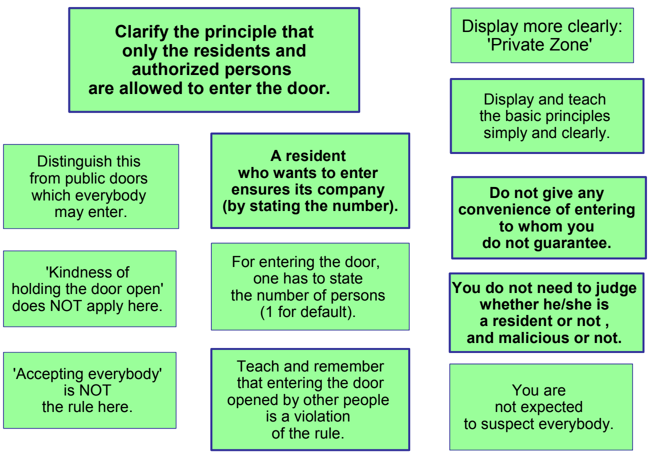


Figure 3: Solution ideas related to the residents.

(a) Distinguishing Private Zone Entrance from public one

The real basis of the solution was found to clarify the principle of the Private Zone. 'Only the residents and authorized persons are allowed to enter the entrance door of the apartment building.'

Of course this principle is understood by residents and visitors to some degree, but it needs to be emphasized more. Distinguishing private zone entrance from public zone entrance, e.g. the entrance door to a department store or a station building, is important. Holding a door open to an unfamiliar person coming behind is a polite and good manner for the public zone entrance but a dangerous and violating behaviour for the private zone entrance.

When a resident opens the door, It is natural and efficient to allow his/her company to pass through without any further handling of the lock. Whereas the resident should not allow any other non-residents.

(b) What the system should request the residents to judge?

The current system implicitly requests the residents to judge whether the person coming behind is a resident or not, authorized or not, and malicious or not. All these types of judgement are actually impossible, and hence the implicit requirements are not effective. So, in our solution, we have to avoid these types of judgement.

The resident can guarantee only his/her company. Thus the system should request the resident to show his own evidence (e.g. a key) and only to state the people under his/her guarantee, or more simply the number of such people.

Hence it is clear that any person, outside his/her company, who does not try to get authentication is violating the rule. The resident can recognize/judge it. However, requesting the resident for doing any defending or warning action is a different story. Defending the security and warning to the violating person are the jobs of not the (preceding) resident but the system itself.

In this manner we should eliminate the contradiction of implicitly requesting the residents to do impossible judgement and to take a risk of unwanted trouble.

4.2 Solution ideas to the problem related to the social rule.

As we have found before, we must make the social rule clear what we should do when two parties of people happen to enter the Private Zone entrance at the same time.

(a) Inconvenient rigorous rule does not work

In order to ensure the security rigorously in the present system, we should assume a rule that every party must get the authentication for themselves. But the authentication process can be performed only when the door is closed and locked. This means the second party may not enter the door opened by the first party but must wait until the door is closed and locked and then must get authentication from the system for themselves. Many people feel this rule ridiculous and want to pass through the open door without getting the authentication.

(b) Authentication need to be processed at any time

Thus our solution direction is clear. Any party should be able to get the authentication at any time without depending on the door being open or closed. This means that even when the door is open the second party should be able to make the authentication process as usual and should be allowed to pass through the open door following the first party.

In this manner, any person or party who is going to pass through the open door without trying its own authentication process can be regarded as violating the rule. Such violation can be noticed by the (preceding) resident, even though the resident should not be requested to give a warning to the violating person directly. Noticing the violation and giving warning to the violating person should be the job of the system.

(c) Our system need to be intelligent

For making such a process possible without losing the security, the new auto-locking door system must be intelligent. But at the same time we should not want it to be intelligent at the ideal (i.e., infeasible) level. At the moment we assume the authentication process uses keys, card keys, IC cards, finger prints, etc. for the residents. One step further in the intelligence of the system may be its ability to count the number of people who have entered through the door.

With this consideration, our new system should be able to accept the number of people in the party during the authentication process and should be able to allow the entrance of such a number of people together. It should be able to eitherforbid, prevent, warn, or notice the entrance of people exceeding the number.

(d) The new social rule

In summary, the new social rule must simply be: 'Every party must get the authentication for themselves, regardless of the door being open or closed.' Thus, trying to enter the open door without getting authentication is a violation of the rule. We should display this rule clearly and also make it widely known as a part of our solution.

4.3 Solution ideas to the problem of long duration of open door

(a) Confirmation of the safety-first principle

As we noticed before, the current policy of door operation is: 'The large and heavy doors are moved slowly to open or close and are operated on the safety side so as to avoid any accident or injury.' This policy is applied widely now as the results of lessons from many serious accidents beforehand.

At the initial stage of the present work, we had some ideas of operating small, light parts of the doors in much quicker mode. But finally we have abandoned such a direction of solution because of possible accidents and injuries.

Another possibility of solution direction was the gate system which enforces the entrance of people one by one. Such systems are used, for example, at the entrance gates of stations, theaters, amusement parks, etc., and typically related to some tickets. We have not chosen this direction, because it seems unsuitable for apartment buildings. *Note. 1

Thus our solution direction is to accept the current type of large and heavy doors operated slowly for the safety reasons and to make the door system intelligent.

Figure 4 shows the cards generated during the discussions of the solution ideas.

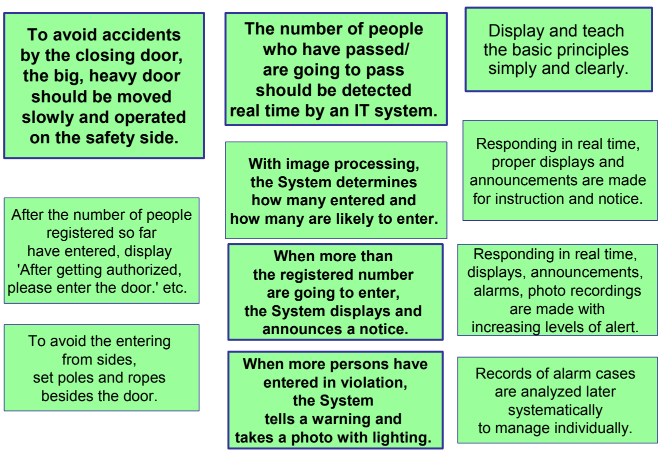


Figure 4: Solution ideas related to the door operation.

(b) Alternative actions on detecting a case of violation

One of the important choices in designing the entrance door operation system is the action to take when the system recognizes a person just violating the rule. Several alternatives may be:

- Physically forbidding the violation, i.e. physically block the person by closing the door or by any other means.
- Preventing the violation, e.g. giving an alarm or warning just before the violation and stopping the person to actually entering the door.
- Alarming the violation, e.g. when a violation occurs make a large alarm sound to call for attention by the caretaker, etc.
- Warning the violation, e.g., giving a warning message/signal to the person just before or after the violation
- Recording the violation, e.g., recording the violating action with a video camera or taking a photo of the violating person with flash light
- Noticing the violation, e.g. make a notice to the violating person that the violation is detected and recorded with video or photo.

We have decided that physically forbidding the violation is not a practical goal for us to pursue and is not necessary in our case because entering the door does not give any harm yet to the residents and there are some more safety means. On the other hand, all other actions listed above are supposed to be effective and hence should be introduced in the new system.

(c) Allow a declared number of people to enter

Our main idea so far obtained in sections 4.1 and 4.2 is to allow the entrance of a party (i.e. one or more people) by the authentication of the leader while the authentication should be processed at any time. For keeping the security in this process, we need to recognize the end of the party members. A simple, feasible, and yet effective way of achieving this is to count the people who enter through the door.

Thus the system request the resident (and also the normal visitor) to declare the number of people accompanied (e.g., 1 when the resident is alone). And the system counts the number of people who enter and tries to 'close' the door when the declared number of people have entered.

Here we must be careful that closing the real door quickly is not possible mechanically, not appropriate for safety reasons, and even not necessary because we are not trying to physically forbid the entrance by an extra person. So our solution here is to introduce a logical & virtual door closed to any person who tries to enter afterward.

(d) Virtual & logical door with intelligence

We have just reached the essence of our new system. We have a logical and virtual door (over the physical and real door) which is opened to a declared number of people by the valid authentication process and is closed just after the number of people have entered the door. The open/closed status of the logical door should be displayed at the door and guide/warn the people to follow the rule.

A simple mechanism of counting the number of people who entered is a (infrared) sensor system. This assumes a narrowed entrance passage to count the people one by one by means of infrared beams from the side.

A more advanced mechanism is the use of video monitoring with intelligent software of real-time image processing to trace the movement of multiple people and to count the number of people who have entered the door. This system can be used with relatively wide, open-style doors suitable for residential building. The current state of arts in image processing certainly has the capability of implementing such a system.

(e) Separation of residents and visitors in space

Another idea is to separate the zones for the authentication process between the residents and the visitors. (*Note 2.) For example, the residents should operate the control panel on the left to the door while the visitors on the right to the door. Thus any person who comes in the entrance hall has to declare first whether he/she is a resident or not by its standing position. Strange movement between these two sides will become apparent to the people around and to the system.

This separation is also useful because the visitors take time to call the resident in a flat with the interphone and to get authenticated by the resident whereas the residents can get authentication quickly just by showing their evidence, e.g. keys, cards, etc. and pushing the number of accompanied members.

5. CONCEPTUAL SOLUTION OF A NEW AUTO-LOCKING DOOR SYSTEM

On the basis of the ideas generated above, we have built a consistent set of conceptual solutions addressed to the present problem. We propose here an intelligent auto-locking door system for the secured entrance of apartment buildings. The system is schematically shown in Figure 5 and explained in the followings:

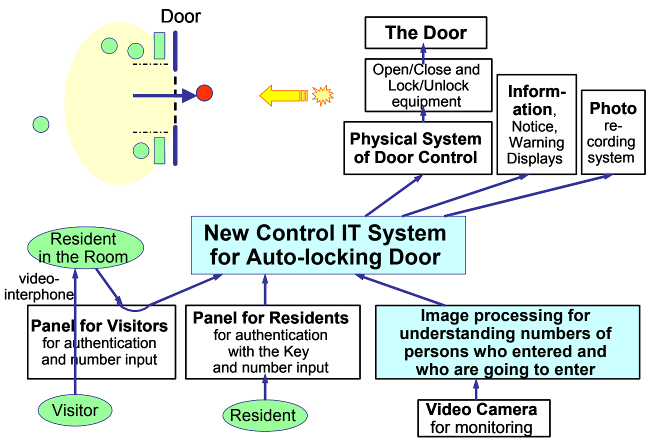


Figure 5: An intelligent auto-locking door system for the entrance at apartment buildings.

5.1 Display the rules and guidance clearly

(1) Permanent display in front of the door

- "Private Zone Inside This Door."
- "Residents and authorized persons ONLY are allowed to enter."

(2) Permanent display in front of the door:

- "You (or your party) must get authentication for yourself. Authentication process will be accepted whenever, independent of the door Open/Closed."
- "Even while the Door is Open, you must get the authentication. Entering the Door without authentication is a violation of the rule and law."

(3) Permanent display in front of the door:

- "Residents: <== Use the panel Left to the Door."
- "Visitors: Use the panel Right to the Door. ==>"

(4) Permanent display at the Left Panel:

- "For Residents: Insert your key, Input the number of your party at moment (1 if you are alone), and turn and remove the key. After getting the approval, you may enter through the door."

(5) Permanent display at the Right Panel:

- "For Visitors: Press the residence number you want to visit and talk with the resident via the video interphone. Get an approval by the resident, telling the number of persons of your party. After the indicator turns green, please enter the door."
- "Without turning the indicator green, YOU MUST NOT ENTER the door even if it is open."

5.2 Hardware and software components of the system

(6) Physical operation of the door and the lock:

The Door itself is operated slowly and safely, just as usual at present, by using the current mechatronic control system: It opens slowly, closes slowly, is unlocked for about 10 seconds, and re-opens in case of any obstacle for the sake of safety.

(7) An intelligent IT system controls the whole system:

The new IT system must have the real-time ability of counting the number of people who enters through the Door, and working with the panels for authentication it gives orders to the physical door control system. It is desirable to count the number of entering persons by use of an image processing method.

(8) Video monitoring and image processing:

The IT system monitors the people outside and inside the door with video camera(s) and counts in real time the accumulated number (e) of persons who have entered the door (since the door is opened this time) and the number of persons who are going to enter the door.

(9) Authentication system

The authentication system approves the keys, ID cards, etc. shown by the residents and accepts the declared number of members of the party. It also accepts the order of approval of a visitor party by the resident via dedicated lines from the residence. The authentication system tells the IT system its approval of declared number of people in real time. Thus the IT system recognizes the accumulated number (a) of approved persons (since the door is opened this time).

5.3 Software control of the virtual and real doors

(10) Main control parameter: $p = a - e$

The main parameter for controlling the door operations and displays is defined by $p = a - e$. This is 'accumulated number of authenticated persons' (a) minus 'accumulated number of persons entered the door' (e); thus it means the number of persons left to enter with authentication. This parameter is known in real time in the IT system.

(11) While $p > 0$, Open-Door.

While $p > 0$, the IT system gives the Open-Door direction to the mechatronic door control system and displays 'Please enter' at the top of the Door.

(12) While $p = 0$, Close-Door, Normal state.

While $p = 0$, the System gives the Close-Door direction and displays 'Please get authentication on the panel, right (for residents) or left (for visitors) for entering the door'.

This is a normal state. If the Door is open, it will start the closing motion. When the Door is closed and locked, the variables a, e, and p are reset to be 0.

(13) While $p = 0$, detecting a possible case of violation:

If the IT system detects any person is going to enter the Door, while p = 0 and the Door is unlocked, the system recognizes it as a possible case of violation. Then the system flashes the display (12) and make an announcement for notice.

(14) When *p* becomes negative, warning against violation:

When *p* turns to negative (and also when *p* increases its absolute value while $p < 0$), the IT system has detected a case of violation of the rule. Then it flashes a light and takes a photo from front of the person who has just entered the Door. And it displays and announces as 'Since more persons than those being authenticated have been detected to enter, a photo was taken for the security reasons. To avoid this inconvenience, please enter the Door after getting authentications.'

(15) Resetting *p* and Close-Door.

If nobody has entered for a certain period of time (say, 10 seconds) while $p \neq 0$, the IT system gives the Close-Door direction. When the Door gets closed and locked, the variables *a, e,* and *p* are reset to *0*.

5.4 Human management of the security

(16) Utilizing the operation records and photos:

The records of operations, especially the photos taken in the cases of violation, are analyzed every day by the managers/caretakers for the purpose of making appropriate means both individually and generally for enhancing the security of the building. Warning to any relevant party and reporting to police in serious cases may be among such actions.

6. DISCUSSION

After writing this paper, I tried to think the structure of the present problem again. For doing this, I first tried a tabular form of 'problem - root cause/root contradiction - solution'. But the logic behind is much more closely related among the rows of such a table. Thus I finally chose the diagrammatic representation, as shown in Figure 6.

The boxes in the second column are the main sequence of root causes. The arrows show the logical or cause-effect relationships among the facts in the present system itself. Boxes in the first (i.e. left) column shows various effects or problem phenomena. Boxes in the third and forth columns are the basic ideas of solutions and their further design decisions.

The safety of door operation is the fundamental requirement (or constraint) in this problem. Thus, the door needs to be closed slowly. Trials to close the door quickly violate the safety principle. The most basic solution concept in the present paper is the introduction of the virtual & logical door, which can be opened/closed quickly and intelligently under the software control.

The main design decision in the current system is found in the second box of the second column, i.e. "To authenticate a person when the door is closed". This design has two main limitations; a group of people are (implicitly) allowed to enter with one authentication and this authentication process can not be performed during the door open or unlocked. Since people cannot wait until the door closed, residents and good visitors often want to

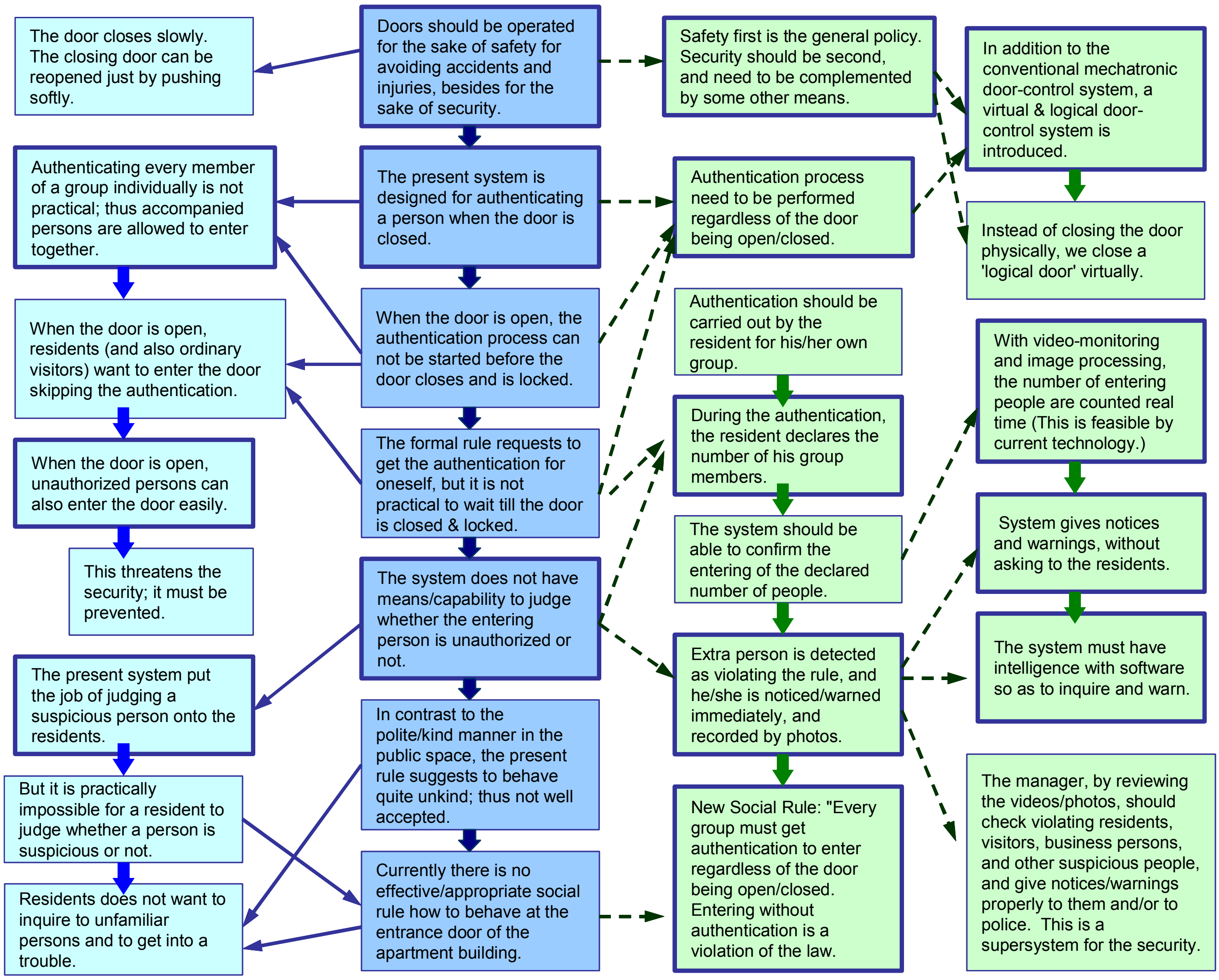


Figure 6: Structure of the whole problem and solution of the present study.

enter the already open door without waiting. This gives criminals the chance of entering the door by pretending to be ordinary residents.

The system does not have any means to distinguish residents and unauthorised people, thus it implicitly request the residents to make such distinction and to prevent the unauthorized persons from entering. However, this is a request of impossible tasks. Residents can not do and does not like to do such a job,. Thus, we have a security hall here as we all know well.

After understanding all these situations, our decision choice is clear. We make the authentication process available at any time regardless of the door being closed/open. And we try to clarify the group of people whom the system gives an authentication. The resident, leader of the group, is requested to declare the number of members of his/her group.

Hence we prepare a system which can count the number of people who have entered the door. This will be technically achieved by the video monitoring and the image processing. Extra persons who entered the door exceeding the authenticated number of people are regarded as violating the rule. Thus the system gives a warning and takes a photo of the person. For doing all these functions the system must be intelligent and operated in software.

With this new system, the social rule is now clear: "Every group must get authentication to enter the door regardless of the door being open/closed. Entering without authentication is a violation of the law." This social rule specifies only what one should do without mentioning on other persons behaviour. Thus this social rule can be followed smoothly by good residents and visitors.

One interesting findings: During most of the time of this work, this problem was thought to be related not only to technical but also, or even with more weight, to psychological and social aspects. However, Figure 6 revealed that everything came from the design choice in the present system. The design "to authenticate a person when the door is closed" has caused various effects in the technical system and various reactions to the people. Thus, the basic solution to the present problem is to choose a different decision in this basic point. I.e., "to authenticate a group of people at any time." This was made effective by the introduction of virtual & logical door controlled intelligently in real time by the software.

7. CONCLUSION

This paper has applied the TRIZ/USIT methodology to the security problem of auto-locking door system for the entrance of apartment buildings and has proposed a consistent set of conceptual solutions which is supposed to be practical and effective.

The analysis of this problem has revealed that a simple technical approach is not suitable at all but rather psychological and social approaches are necessary and more important. Thus the problem was analyzed from multiple aspects, including the psychology of resident to judge an unfamiliar person and the social manner in case of two parties meeting by chance at the entrance door. We have used different methods including TRIZ, USIT, RCA+ diagram, the KJ method (or the Affinity Diagram method) in the analysis.

We have revealed a number of root causes and corresponding contradictions and have solved them one by one to find basic directions for a new solution system. The process for proceeding to the solution is described in Section 4. Then on fragments of such ideas, a consistent conceptual solution was built as shown in Section 5. The final discussion in Section 6 has revealed a much clearer view of the whole problem and solution of the present study. Psychological and social aspects related to the present problem are understood as the effects or reactions to the basic choice in the technical system. Thus, on the basis of this overall view, the new basic choice in the technical aspect is expected to have solved most of the problems.

REFERENCES

[1] Arata Fujita: 'Case Study of Creative Problem Solving: How to Prevent Unauthorized Persons from Entering the Auto-locking Door of Apartment Building', Thesis, Osaka Gakuin University, Jan. 2007. (J)

[2] Toru Nakagawa and Arata Fujita: 'How to Prevent Unauthorized Persons from Entering the Auto-locking Door of Apartment Building: Applying TRIZ/USIT to A Social & Technical Problem', Third TRIZ Symposium in Japan, Held at Toshiba Kenshu Center, Yokohama, on Aug. 30-Sept. 1, 2007; TRIZ Home Page in Japan, Sept. 2007 (J & E).

[3] Ed Sickafus: "Unified Structured Inventive Thinking: How to Invent", Ntelleck, LLC, Grosse Isle, MI, USA (1997).

[4] Jiro Kawakita: "Hasso Hou" (Idea Generation Method), Chuo-Kouron, 1967 (in Japanese); "Zoku Hasso Hou" (Idea Generation Method, Continued), Chuo-Kouron, 1970 (in Japanese). The KJ Method is also called 'Affinity Diagram' in the New Seven QC Tools for Management.

[5] Valeri Souchkov, Rudy Hoeboer and Mathijs Van Zutphen: "TRIZ in Business: Application of RCA+ to Identify and Solve Conflicts Related to Business Problems", ETRIA TFC 2006, Held at Kortrijk, Belgium, on Oct. 9 - 11, 2006.

CONTACT

Toru Nakagawa

Osaka Gakuin University,

2-36-1 Kishibe-minami, Suita, Osaka, 564-8511 Japan

E-mail: nakagawa@ogu.ac.jp

http://www.osaka-gu.ac.jp/php/nakagawa/TRIZ/eTRIZ/

---

* Note 1. Usage of RFID seems to make this direction easier and more flexible for the residents. However, among the people having no proper RFID, the system need to distinguish the visitors to be approved from those not. For this purpose, the authentication process by the resident for his/her accompanying visitors at the gate and also by the resident in the flat via interphone system for his/her visitors coming at the entrance are necessary. Thus the procedures which are very similar to the one discussed later in sections 5 and 6 are also necessary in case of the gate system using RFID.

* Note 2. We owe this idea to the WG members of MPUF USIT/TRIZ Study Group. We thank Kunio Fukatsu, Takuo Maeda, and Fumiko Kikuchi for this idea.

Technological Route between Pioneerism and Improvement

Roberto Nani[1], Daniele Regazzoni[2]
[1] Scinte s.n.c., Ranica, Italy
[2]University of Bergamo, Dalmine, Italy

Abstract

This paper presents a systematic approach to determine the technological route between discovery, pioneering, radical creation and qualitative or quantitative improvement as the two extremities of a line of evolution regarding a certain inventive theme. The technological route is the result of a procedure based on a wide use of a patent search engine capable of Browsing Codes according to International Patent Classifications, and Clustering Texts to examine search results using linguistic technologies, and a tool able to analyse time data series to disclose their eventual logistic behaviour.

Said procedure consists of four main steps: (i) determination of the initial search algorithm based on the characteristics of reference subject, patent or group of patents; (ii) definition and calculus of Intellectual Property Density (IPD) on the base of bibliometric results of search; (iii) IPD fitting into logistic curves and (iv) definition of a quick and semi-automated way to gather some inputs for further product innovation.

The procedure still requires a minimum skill in patent searching and handling and search may have to be iterated some times before getting the desired outcome. By the way there is no need to read patents text and the time spent is comparable to a traditional search (i.e. according to EPO guidelines for search).

The results obtained consist in fostering both forecasting activities by identifying quantitatively main evolution phase and problem solving activities by giving a dynamic view of the state of the art so that future problems may be taken into account in today solutions.

One out of the several case studies already tested with this approach is presented with the aim of describing in detail each step performed.

Keywords

Patent Data Base (PDB), International Patent Classification (IPC), Intellectual Property Density IPD, logistic S-curves, emerging technologies

1 INTRODUCTION

Among TRIZ users the importance given to patent resources is far behind the mere protection of R&D results. Patents represent a starting point for new inventions and a huge resource for collecting information on the way contradictions have been solved and in which different field such solutions may be adopted. Moreover the worldwide patent database contains information about the technology evolution that can be extracted so that the level of maturity of a product or process can be evaluated.

The connection among patent resources and problem solving activities can be improved in order to provide the innovators with meaningful data in short times whenever a problem occurs. The amount of time needed and the unreliability of traditional patent search results cause problem solvers to under exploit patents derived data. To overcome this issue several attempts to make it better and more automated can be found in literature [3,6,7].

The aim of this paper is to differentiate from detailed and high resources time consuming approaches such as [3,7]. The novelty proposed consists in a simple and efficient experience-based approach to perform innovation driven patent investigations.

2 GOAL AND METHODOLOGY

The goal of this paper is to present an organized set of steps to clearly identify the patent state of the art of a certain product or technology, so that further research activities such as technological forecasting could be performed. The main reasons why this work has been carried out are the increasing demand of technology assessment based on patent information, and the growing industrial awareness of intellectual property as an asset to foster innovation.

The methodology is made up of four main steps as reported in Figure 1. The starting point is as general as possible and could simply be a request of information about the state of the art of a specific technology, a device or a function in a specific context. Once defined focus and boundaries of the matter to investigate on, the first step is performed. By browsing or searching in the patent classification the classes characterizing the matter are identified. Then a usual patent investigation is performed by crossing keywords and classes search. The procedure can be iterated several times to refine keywords on the base of the results obtained.

Once the patent set is satisfying, in step 2 some statistical-bibliometric analyses are performed. In particular patents distribution and patents classification over time are plotted. Afterwards, Intellectual Property Density (IPD) has been introduced by the authors as the ratio between the cumulated number of patents filed till a specific year and the count of 4 digits classes involved till the same year. According to the authors, IPD describes quite easily the general trend characterizing relevant innovations evolution. The first patents filed when a new invention appears disclose highly innovative devices or technology that may have a wide spectrum of application and potential fields of use [8]. As the patents leading the way are a few and they can be found in several different patent classes, the IPD of an emerging technology is quite low. During technology evolution the number of patents increases and they get more and more focused on sub-systems or details that are often classified in a small number of classes. As a consequence IPD in maturity stage is much higher. There is not scientific evidence that the curve plotting IPD over time has recurrent trend, by the way the experimental case studies accomplished so far have always produced qualitatively S-shaped curves.

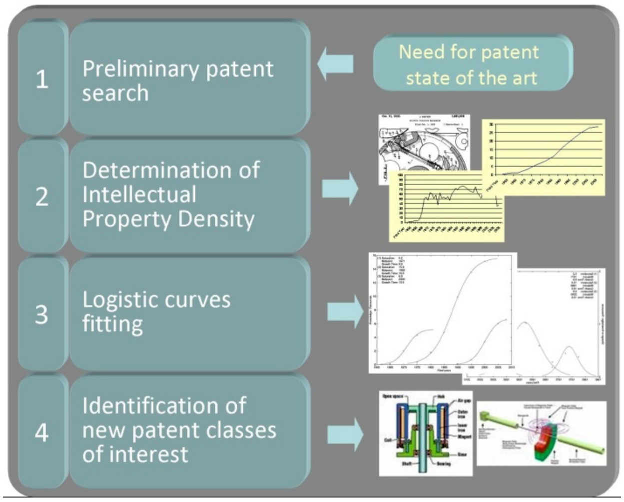


Figure 1: methodology steps

The third step of the paradigm consists in fitting the IPD data in logistic curves [1], [4], [5]. Data can be adequately filtered, if needed, to exclude peaks due to known reasons or to cut out the first or last figures. To do so we used a software package for analyzing logistic behaviour developed and shared by the University of Rockefeller (NY) called Loglet Lab. Loglet Lab allows to discern and analyze S-shaped curve or a succession of many S-shaped curves even if overlapped in time. If the patent set obtained in step 2 and its relative IPD trend results to be logistic, one or more curves can be found with minimal residuals. Each quantitative S-curve describes a generation of device or technology, giving precious data on mean and saturation times.

The results of step 3 can be exploited for at least two different kinds of activities. If the goal of the research is to understand the trends of evolution, further observations can be done to support strategic R&D activities planning. Future events can be foreseen by identifying the super-system conditions that influenced certain evolutions path despite of others, reasoning on the resources that will run out first or applying structured tool to perform a complete technological forecasting [8].

The second way the results achieved can be exploited concerns problem solving by deriving solutions from different domains. Step four describes a singular way to perform this task. Starting form an S-curve describing IPD density behaviour we may presume that the mean year is the one in which patents filed are mostly concentrated on the specific device or technology characterizing the curve. This can be explain by the fact that, when the technology reaches its maximum growth, the interferences of the previous and following technologies is the lowest. Thus when the technologies are strictly substituting one another (non concurrent in time) the interference is negligible. This approach is used to dramatically decrease the number of patent to work on, confidently not compromising the final result.

At this point a basic clustering algorithm is applied to the set of patents so that most occurring words are found and grouped in order to minimize cluster interactions. Depending on the number of patents and on their homogeneity different number of clusters can be found. Filtering clusters containing general terms is quite easy to identify one or two set of words characterizing the novelty. Then a new patent search is done using such words as keywords without imposing any class constraint.

The result gathered is considered in terms of patent class to identify commonalities with the starting matter, in terms of problem to address or solutions found.

The fourth step is quite complex but completely automated and its definition is derived by practical application. Actually, it is not time consuming and the advice achieved mostly lead to valuable results.

The following part of the paper is dedicated to the application of the steps described so far in order to give detailed guidelines to perform innovation oriented patent investigation.

3 METHODOLOGY APPLICATION

The following paragraphs report the application of the four step methodology to a real case study concerning textile looms. In particular the focus is put on the weft insertion technology of a weaving machine, which has the overall function of gripping a fibre and moving it along a specific path.

3.1 Step 1: preliminary patent search

To search for patents describing the state of the art of weft insertion technology the following Boolean algorithm has been used with a patent database [10]:

((gripper) <in> (TITLE,ABSTRACT,CLAIMS)) AND ((weft* OR thread* OR filament* <in> (TITLE, ABSTRACT, CLAIMS)))* (1)

returning about 6.500 documents of European, American and International patents and applications:

Collections searched: **European (Applications - Full text), European (Granted - Full text), US (Granted - Full text), WIPO PCT Publications (Full text), US (Applications - Full text)**

6,458 matches found of 11,531,757 patents searched

distributed according to International Patent Classification (IPC) in the following classes:

IPC-R Code- 4 digit	Items	%	Bar Chart
D03D D — Textiles; Paper; Weaving; Woven	776	8.1 %	
B65H B — Performing Operations; Transporting; Conveying	614	6.4 %	
B65B B — Performing Operations; Transporting; Conveying	448	4.6 %	
B25J B — Performing Operations; Transporting; Hand Tools	399	4.1 %	
B41F B — Performing Operations; Transporting; Printing	312	3.2 %	
A61B A — Human Necessities; Medical or Veterinary Science; H	283	2.9 %	
B65G B — Performing Operations; Transporting; Conveying	262	2.7 %	
E21B E — Fixed Constructions; Earth or Rock Drilling; Mining	245	2.5 %	
B25B B — Performing Operations; Transporting; Hand Tools	233	2.4 %	
B29C B — Performing Operations; Transporting; Working of PLA	212	2.2 %	

10 rows shown			
(Below cut-off)	5,769	60.4	...

Table 1: IPC distribution of patents of preliminary search

The final documental collection of the *"filamentary manipulation (gripping)"* is obtained by the following Boolean query that crosses the function "to grip" with the most representative classes:

(((d03d OR b65h) <in> IC) AND ((gripp) <in> (TITLE,ABSTRACT,CLAIMS)))* (2)

Collections searched: **European (Applications - Full text), European (Granted - Full text), US (Granted - Full text), WIPO PCT Publications (Full text), US (Applications - Full text)**

8,700 matches found of 11,531,757 patents searched

Step 2: patents analysis and IPD determination

According to the results obtained with the algorithm (2) the *"filamentary manipulation (gripping)"* starts its technological path on 1932 with a "gripper operating mechanism" (Figure 2). From 1932 to 2008 the knowledge of *"filamentary manipulation (gripping)"* characterizes filed patents and applications capturing electric, mechanic, chemic resources from the technological branches.

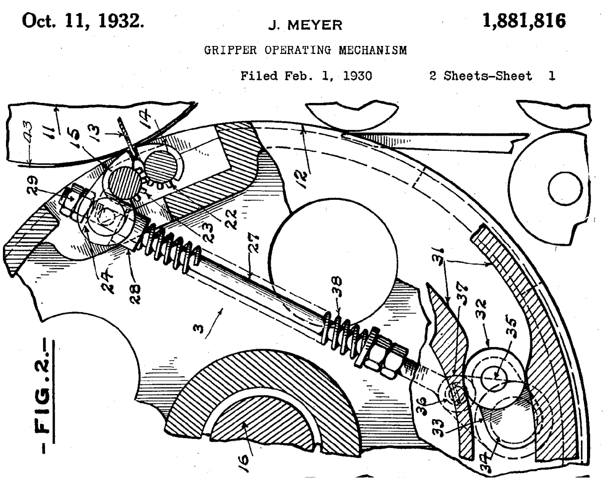


Figure 2: first patent considered concerning filamentary manipulation (gripping)

From the first patent to the last completed year data are collected and plotted in order to highlight:

- number of patents filed per year (Figure 3);
- number of 4 digits IPC classes in which patents are classified per year (Figure 4);
- Cumulative number of patents filed per year (Figure 5);
- Total count of classes in which patents have been classified per year (Figure 6).

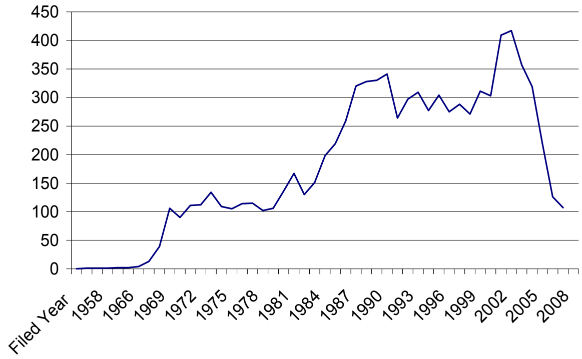


Figure 3: Number of patents per year

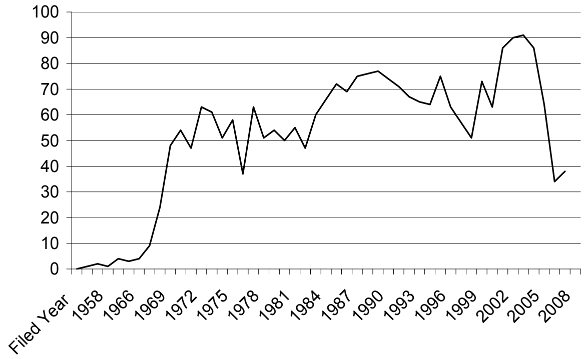


Figure 4: Number of involved IPC classes per year

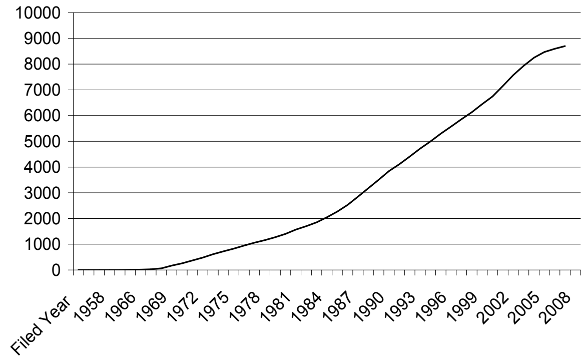


Figure 5: Cumulative number of patents filed per year

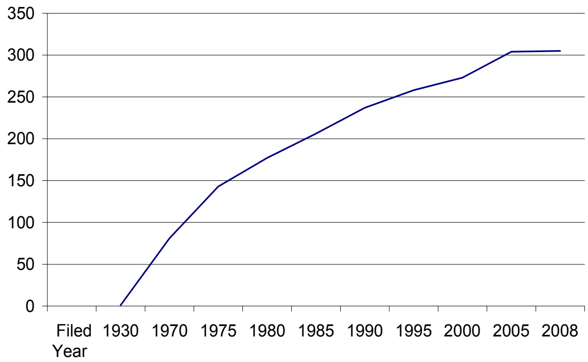


Figure 6: Total count of classes per year

The statistical-bibliometric analysis is performed to obtain the data needed to calculate the Intellectual Property Density (IPD) number as the ratio between the cumulative number of patents and the classes involved (i.e. the ratio among the figures plotted in Figure 5 and Figure 6). The curve describing IPD behaviour over time is shown in Figure 7.

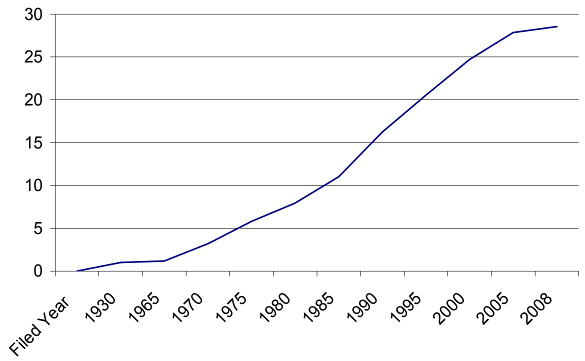


Figure 7: Intellectual Property Density IPD

Step 3: logistic curves fitting

This step is the most important as it provides the empirical evidence that IPD trend is a logistic trend. By using Loglet Lab software we found out that the distribution of Figure 7 is actually fitting with minimal residuals (3% maximum) to a set of three S-curves. Figure 8-10 show respectively the S-shaped curves, the bell curves and the Fisher-Pry transform curves.

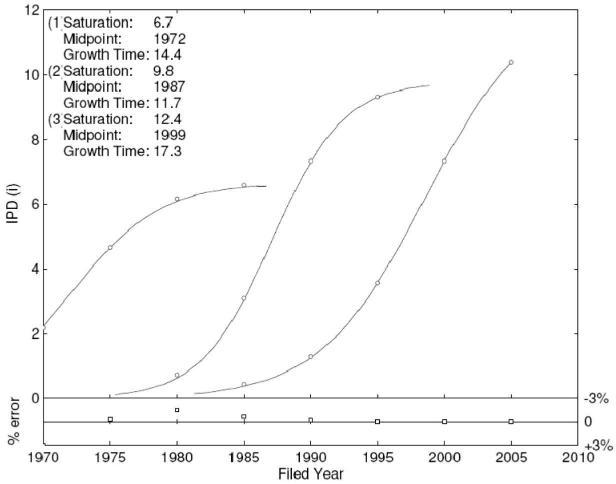


Figure 8: S-shaped curves fitting IPD data

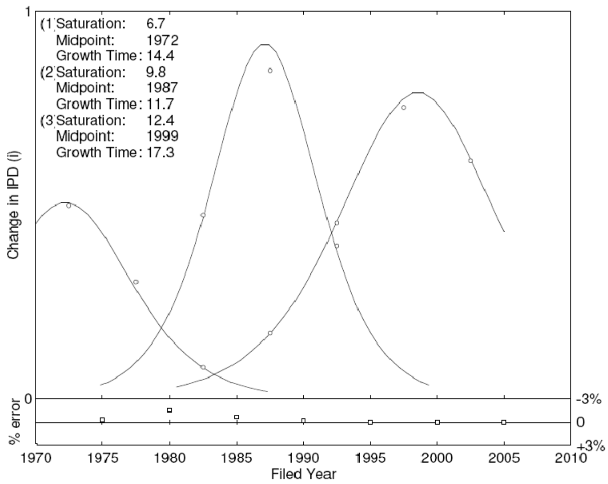


Figure 9: Bell-shaped curves fitting IPD data

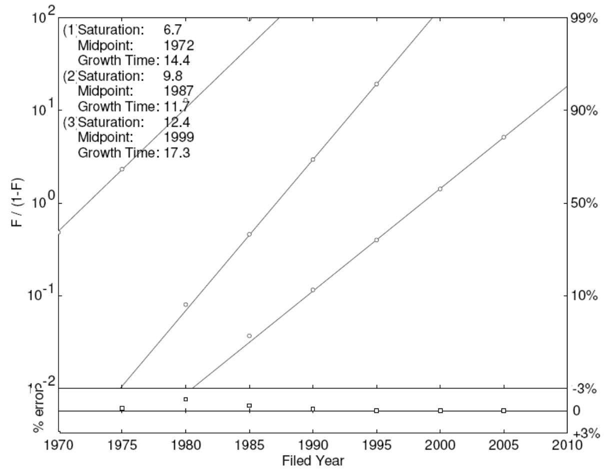


Figure 10: Fisher-Pry transform curves fitting IPD data

From the fitting of the curves three main technologies concerning *"filamentary manipulation (gripping)"* emerged. Each curve is characterized by the following data:

- Technology I: midpoint = 1972; growth time = 14.4; saturation = 6.7;
- Technology II: midpoint = 1987; growth time = 11.7; saturation = 9.8;
- Technology III: midpoint = 1999; growth time = 17.3; saturation = 12.4.

The technologies defined in this way have to be interpreted according to breakthrough technological changes regarding, for examples, new materials, new chemical-physical discoveries/principles or due to socio-political events, new standards.

On the next paragraph a clustering algorithm is applied to applications and patents of said saturation points:

(((d03d OR b65h) <in> IC) AND ((gripp) <in> (TITLE,ABSTRACT,CLAIMS)))* (2)

Filed Year	Items	%	Bar Chart
1999	305	3.5 %	
1987	320	3.7 %	
1972	112	1.3 %	

Table 2: number of patents

Step 4: new IPC classes of interest

In the next paragraphs 3.4.1, 3.4.2 and 3.4.3 a clustering algorithm is applied to patents and applications of specific saturation points: 1972, 1987 and 1999. Analyzing the text of patents and applications, terms are grouped in order to obtain the minimum number of cluster having almost no cross connections. The result can be automatically shown by a graph. Each cluster is composed by a number of terms, describing both devices and actions quite homogeneous for meaning and field. A quick scan of the terms is enough to associate TRIZ Inventive Principles to each cluster. By the way there no need to go through all the clusters if in the working context a specific goal is defined.

3.2.1 technology I: midpoint = 1972; growth time = 14.4; saturation = 6.7

A clustering overview of patents and applications filed on 1972 considers specific devices and actions constituting the Boolean algorithm (4):

Cluster Overview 5 Clusters
For work file: 1972 (112 items)

Cluster Descriptive words

1 comprise, loom, roller, provide, apparatus, mean, move, device, control, include

2 sheet, mechanism, gripper, mount, press, transfer, conveyor, include, movement, printing

3 form, engage, surface, end, material, drive, provide, apparatus, lower, length

4 mean, member, parallel, relative, grip, pair, include, release, pass, **groove**

5 **release**, side, **arrange**, adjacent, **movement**, locate, operation, hold, first, time

Table 3: clustering overview of collection 1972

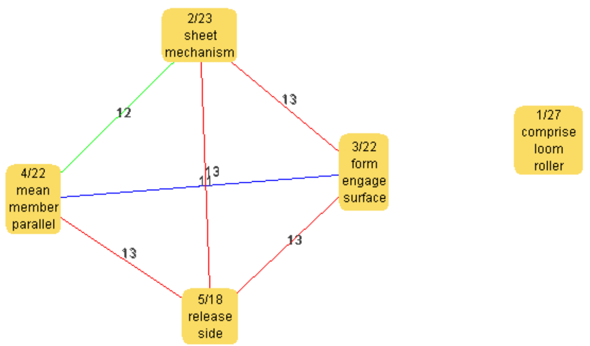


Figure 11: 5 clusters graph of collection 1972

((release AND groove AND arrange AND movement) <in> (TITLE,ABSTRACT,CLAIMS)) (4)

Collections searched: **European (Applications - Full text), European (Granted - Full text), US (Granted - Full text), WIPO PCT Publications (Full text), US (Applications - Full text)**

6,400 matches found of 11,374,720 patents searched

The Boolean algorithm (4) produces a collection of about 6.400 documents, the IPC resource being the technological branch (IPC):

- F16L 37/00 Couplings of the quick-acting type



;

- A61M 5/00 Devices for bringing media into the body in a subcutaneous, intra-vascular or intramuscular way; Accessories therefor, e.g. filling or cleaning devices, arm rests .

3.2.2 technology II: midpoint = 1987; growth time = 11.7; saturation = 9.8

A clustering overview of patents and applications filed on 1987 considers specific devices and actions constituting the Boolean algorithm (5):

Cluster Overview 10 Clusters
For work file: 1987 (320 items)

Cluster Descriptive words

1 mount, support, include, horizontal, comprise, use, adjacent, rotation, engage, recess

2 apply, stack, apparatus, grip, relate, say, method, improve, feeding, position

3 roll, web, direction, material, contact, winding, device, determine, include, part

4 sheet, apart, grip, spread, example, transport, location, first, move, apparatus

5 arrange, fold, gripper, printed product, apparatus, advance, first, extend, needle, invention

6 clamp, weft, thread, side, element, move, shed, weft thread, loom, end

7 mount, provide, shaft, include, cam, position, drive, dispose, introduce, end

8 **support**, surface, **rotation**, point, outer, **tube**, **extend**, end, form, **press**

9 move, object, stack, conveyor, deliver, include, grip, release, vacuum, carry

10 process, transfer, arm, transport, perform, mean, position, control, path, sheet

Table 4: clustering overview of collection 1987

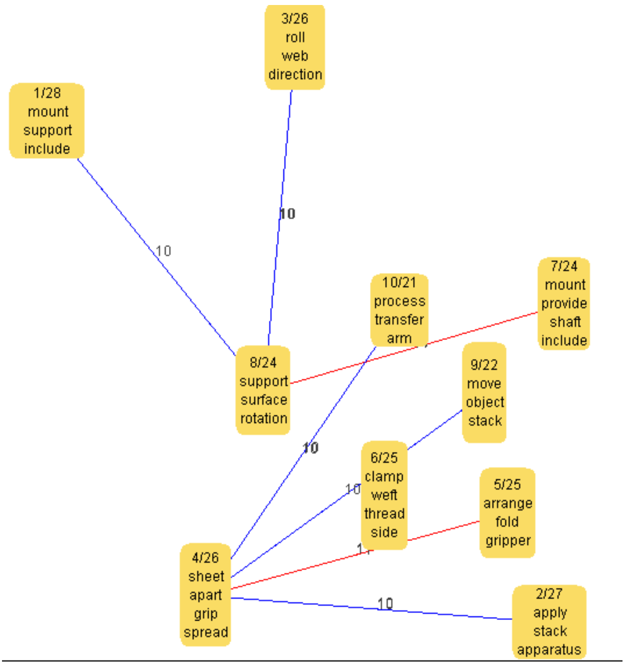


Figure 12: 5 clusters graph of collection 1987

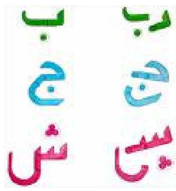
((support AND rotation AND tube AND extend AND press) <in> (TITLE,ABSTRACT,CLAIMS)) (5)

Collections searched: **European (Applications - Full text), European (Granted - Full text), US (Granted - Full text), WIPO PCT Publications (Full text), US (Applications - Full text)**

1,210 matches found of 11,374,720 patents searched

The Boolean algorithm (5) produces a collection of about 1.200 documents, the IPC resource being the technological branch (IPC):

- B29C SHAPING OR JOINING OF PLASTICS; SHAPING OF SUBSTANCES IN A PLASTIC STATE, IN GENERAL; AFTER- TREATMENT OF THE SHAPED PRODUCTS, e.g. REPAIRING.



3.2.3 technology III: midpoint = 1999; growth time = 17.3; saturation = 12.4

A clustering overview of patents and applications filed on 1999 considers specific devices and actions constituting the Boolean algorithm (6):

Cluster Overview 5 Clusters
For work file: 1999 (305 items)

Cluster Descriptive words

1 sheet, device, form, grip, machine, method, station, gripper, position, comprise

2 invention, relate, say, gripper, comprise, define, provide, include, section, guide

3 mean, apparatus, control, arrange, transfer, provide, convey, product, form, first

4 **include**, **move**, **position**, first, grip, stack, **engage**, apparatus, **rotation**, **hold**

5 end, support, portion, reel, rotatably, comprise, mount, shaft, arrange, provide

Table 5: clustering overview of collection 1999

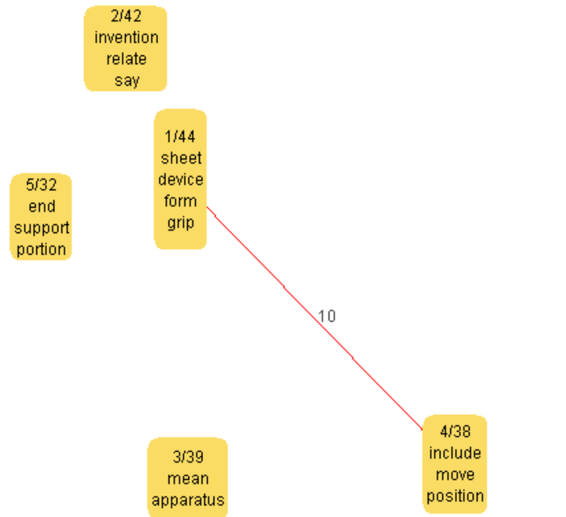


Figure 13: 5 clusters graph of collection 1999

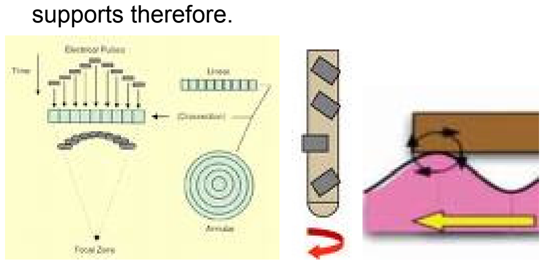
((include AND move AND position AND engage AND rotation AND hold) <in> (TITLE,ABSTRACT,CLAIMS)) (6)

Collections searched: **European (Applications - Full text), European (Granted - Full text), US (Granted - Full text), WIPO PCT Publications (Full text), US (Applications - Full text)**

21,483 matches found of 11,374,720 patents searched

The Boolean algorithm (6) produces a collection of about 21000 documents, the IPC resource being the technological branch (IPC):

- G11B 17/00 Guiding record carriers not specifically of filamentary or web form, or of supports therefore.



4 CONCLUSIONS

This paper shows an experience-based way to perform a patent search capable of gathering not only the static state of the art of a specific technological domain, but providing quantitative data to rely on to perform problem solving as well as technological forecasting. The methodology is rooted in a simple but unconventional use of patent search engine and of a software package for logistic curve analysis available for free. The most relevant result achieved within the experience behind this paper is that the ratio among number of patents and their distribution on IPC classes, called Intellectual Property Density, behaves in a logistic way. This assumption is based on a number of case studies differing for field of applications and maturity of technology in which the IPD trend has always shown such characteristic.

After the evolution steps of a device or a technology have been defined and each of them is associated to a quantitative S-shaped curve, both problem solving and technological forecasting can be performed with relevant benefits. Actually the maturity level of present state of the art systems is assessed and even maturity and decay period can be foreseen and taken into account to search for solutions exploiting resources that won't run out in the near future or already thought to overcome problems that still have to appear.

Concerning the specific application reported in this paper the emerging technological collections defines new resources that are practically unknown from prior art analysis by Boolean algorithm (2), as shown on table 6:

- F16L 37/00 Couplings of the quick-acting type;
- A61M 5/00 Devices for bringing media into the body in a subcutaneous, intra-vascular or intramuscular way; Accessories therefor, e.g. filling or cleaning devices, arm rests ;
- B29C SHAPING OR JOINING OF PLASTICS; SHAPING OF SUBSTANCES IN A PLASTIC STATE, IN GENERAL; AFTER- TREATMENT OF THE SHAPED PRODUCTS, e.g. REPAIRING;
- G11B 17/00 Guiding record carriers not specifically of filamentary or web form, or of supports therefore.

IPC-R Code- 4 digit	Items	%	Bar Chart
B65H B — Performing Operations; Transporting; Conveying	6375	45.0 %	
D03D D — Textiles; Paper; Weaving; Woven	1140	8.0 %	
B41F B — Performing Operations; Transporting; Printing	853	6.0 %	
…..	…..	….	…..
B29C B — Performing Operations; Transporting; Working of PLA	184	1.3 %	
….	….	….	…
G11B G — Physics; Information Storage; Information Storage B	63	0.4 %	
….	…..	….	…
F16L F — Mechanical Engineering; Lighting; Heating	21	0.1 %	
…	….	….	….
A61M A — Human Necessities; Medical or Veterinary Science; H	8	0.0 %	

Table 6: confront of collocation of new IPC resources respect to main IPC classes of prior art Boolean algorithm (2)

REFERENCES

[1] Gibson N., (1999) The Determination of the Technological Maturity of Ultrasonic Welding, The TRIZ Journal, http://www.triz-journal.com/archives/1999/07/a/index.htm

[2] N. Leon, J. Martinez, C. Castillo, (2005) Methodology for the Evaluation of the Innovation Level of Products and Processes, proceedings of TRIZCON05, Brighton MI USA, April 2005

[3] Cascini G., Neri F., "Natural Language Processing for patents analysis and classification", Proceedings of the TRIZ Future 4th World Conference, Florence, 3-5 November 2004, published by Firenze University Press, ISBN 88-8453-221-3.

[4] Kucharavi, D., De Guio R., Technological Forecasting Assessment of Barriers of Emerging Technology IAMOT 2008, p.20, Dubai, UAE, 2008

[5] M. S. Slocum, C. O. Lundberg, (2007) Case Study: Using TRIZ to Forecast Technology, The Triz Journal, http://www.triz-journal.com/content/c070507a.asp

[6] Han Tong Loh, Cong He and Lixiang Shen, (2006) Automatic classification of patent documents for TRIZ users World Patent Information, Vol. 28, Issue 1, March 2006, Pages 6-13

[7] Han Tong Loh, Cong He (2008) Grouping of TRIZ Inventive Principles to facilitate automatic patent classification Source, Expert Systems with Applications: An International Journal, Volume 34 , Issue 1 (January 2008), ISSN:0957-4174

[8] V. Souchkov (2007) Differentiating Among the Five Levels of Solutions, The Triz Journal, http://www.triz-journal.com/archives/2007/07/02/

[9] www.delphion.com

CONTACT

Roberto Nani

Scinte s.n.c.

24020, Ranica (BG), Italy

E-mail: info@scinte.com

Phone: +39 (035) 513683

FAX: +39 (035) 513683

Daniele Regazzoni

University of Bergamo,

24044, Dalmine (BG), Italy

E-mail: daniele.regazzoni@unibg.it

Phone: +39 (035) 2052353

FAX: +39 (035) 2052077

A Taxonomy of Inventive Principles for Robust Design Concepts

Philip Samuel[1], Rajesh Jugulum[2]
[1]Breakthrough Management Group International, USA
[2]Massachussetts Institute of Technology, USA

Abstract
This paper describes the evolution toward a taxonomy of inventive principles for achieving robustness during concept design phase. Robust design is a set of scientific principles used to design products and services so that they perform the intended functions with minimum amount of variation under broadest range of usage conditions possible and for longest period of time possible. The proposed taxonomy of inventive principles for generating robust design concepts are derived by using a research methodology similar to that employed by Altshuller in developing the “Theory of Inventive Problem Solving”. The taxonomy is based on the concept of P-diagram or parameter diagram. Based on P-diagram elements, nineteen strategies were identified based on the analysis of about two hundred inventions.

Keywords
Robustness Inventions, Design Concepts, Inventive Principles, Conceptual Robustness, Taguchi Methods

1 INTRODUCTION

Robust design is a set of scientific principles applied during design in such a way that performance goals are met with minimum amount of variation under broadest range of usage conditions possible for longest period of time possible. Typically designs are developed and optimized through three phases – concept design, parameter design and tolerance design. The key activities during concept design are to create concepts that provide the desired function, make the concept provide the function in a robust manner and select the best concept. The key activities during parameter design include search the design space to establish the relationship between outputs and inputs (both controlled and uncontrolled inputs), and identify the best location for inputs to minimize the impact of variation on the outputs. Similarly, major tasks during tolerance design are to reduce the impact of variation by tightening tolerances and using trivial many inputs to reduce cost by increasing allowable variation of these inputs (wider tolerances).

Traditionally, significant contribution from robust design approaches have benefited mainly during parameter design and tolerance design [1, 2, 3]. It is well known that the earlier phases of design, such as concept design, have significant influence on the final design outcome including cost, time to market and quality of the solution. However, very little research is carried out in identifying approaches to create design concepts that are robust and reliable.

2 METHODOLOGY

Since most robust design methods are employed at the detailed design stage, benefits derived would be significantly larger if robustness can be achieved during concept design phase. To achieve this objective, research was carried out through a collaboration between Ford Motor Company and Massachusetts Institute of Technology by studying a large number of US patents that claimed robustness as a key advantage over prior art.

Altshuller showed that inventions can be classified on the basis of how they overcame contradictions in previously existing systems [4]. We found that Altshuller’s research approach of great value. The present research approach comprised of the following steps:

1. Collect a large body of inventions related to robustness. We have principally drawn patents from searchable full text databases such as the U. S. Patent and Trademark Office on-line database.
2. Analyze the inventions in detail to understand how they achieved improved robustness. We produced engineering models or simulations of the inventions whenever needed to identify the basic working principles involved.
3. Seek useful classification principles for the inventions. We grouped the patents studied on the basis of general strategies they employed. We found that the strategies can be usefully organized via the P-diagram.
4. Develop a database organized around the classification principles. The database should have a “front end” that queries the engineer about some of the features of the problem he/she faces. Then inventions will be automatically drawn from the database that have resolved similar robustness problems and therefore may stimulate the engineer’s creativity.

Although the U. S. Patent and Trademark Office (USPTO) have issued a large body of innovations in the form of nearly 7 million patents, most of these are not robustness inventions. We queried the searchable patent database from USPTO for terms related to robustness (e.g., “less sensitive”, “repeatable”, “regardless of change”, and “not affected by variation”) in the abstract and body of the patents. Less than half of the patents we have retrieved have been confirmed to be related to robustness inventions according to the definition of this paper. Nevertheless, we estimate that there are over 100,000 U.S. patents that meet our definition of “robustness invention”.

3 TAXONOMY FOR ROBUST DESIGN CONCEPTS

Based on a small sample of patents analyzed so far, we have developed a preliminary scheme for classifying robustness inventions. This scheme should be regarded as a rough draft since we have studied less than 1% of the available patents. The scheme may change on the basis of what we learn as the project progresses.

The first layer of our taxonomy for classifying robustness inventions is based on the concept of a P-diagram or parameter diagram. The strategies are organized into four major classes based on a P-diagram as depicted in Figure 1. A P-diagram is a block diagram used to represent a system depicting its input signal, control factors, noise factors, and response [1].

One may sort any robustness patent according to whether the gain in robustness was achieved by acting upon the signal, the response, the noise, or the control factors. Some examples of each of these major classes of robustness inventions are provided. Based on P-diagram elements, 19 groups were identified based on the analysis of about 200 inventions as shown in Figure 2.

3.1 Signal Based Robustness inventions

One class of robustness inventions works principally by acting upon the signal. One example is provided below.

Selective Signal Amplification

In this class of patents, the system is reconfigured to amplify effects of the signal factor while not appreciably amplifying the effects of the noise. Thus one may make substantial improvements in the signal to noise ratio.

An example of this class of inventions is patent #5,024,105 (Figure 3 – "Viscosity-Insensitive Variable-Area Flowmeter"). In the rotameter of the prior art, flow rate is measured by forcing fluid to flow through a variable area duct, which causes a pressure change proportional to flow rate. But changes in the viscosity of the fluid (the noise) cause drag which adversely affects the measurement. In the new design, the pressure change is magnified by allowing it to act on a large surface. Viscous forces are not amplified by this design since the flow is mostly parallel to the surface. Thus ratio of pressure force to viscous force (signal to noise ratio) is improved substantially.

3.2 Noise Based Robustness Inventions

One class of robustness inventions works principally by acting upon the noise. Some obvious approaches include insulating the system from noise or filtering noise out. The less obvious approach of inoculating a system against noise is described below.

Inoculate against Noise

In this class of patents, a dose of the noise factor applied to the system renders the system less sensitive to the very same noise factor. One example of this category is Patent #4,432,606 (Figure 4. Optical Fiber Insensitive to Temperature Variations). Optical fibers have been found to evidence a substantial decrease in optical transmission as a function of increased temperature. In this patent, annealing a metal-coated optical fiber at 500 centigrade is found to render the fibers insensitive to temperature variations between about -200 and 560 degrees C.

3.3 Control Based Robustness Inventions

The control factors in the P-diagram represent physical parameters whose nominal values can be selected by the designer. In robust parameter design methods such as approaches pioneered by Taguchi, the designer systematically explores control factor settings while simultaneously inducing noise factor variations in an effort to make the system response relatively insensitive to noise factors. In concept design, there are strategies by which actions upon the control factors can either make the system inherently more robust or which can make later parameter design steps more effective. We describe one of the four strategies identified in which changes in control factors are the primary means of improving robustness.

Relax a constraint limit

An example of in this class of inventions is "Axial Flow Fans and Blades Therefore (Patent # 4,345,877)". This invention is related to re-design of the fan, which is an important part of modern commercial jet engines. Fan increases the total mass flow, thereby enhancing propulsion efficiency. One of the failure modes associated with the fans is flutter vibration due to length of blades and their exposure to inlet flow distortions. It has been known that increase in length of blades will stiffen the blades thereby reducing the incidences of flutter vibration. But, increase in length will cause increase the weight (and cost), which is undesirable. In this invention, as shown in Figure 5, blades are made hallow by providing neck at its inner end which is attached to hub. This will enable to increase the length of blade which will reduce flutter. The strategy used in this invention is "relax a constraint limit".

3.4 Response Based Robustness Inventions

This major class of robustness inventions works principally by acting upon the response directly to reduce sensitivity without eliminating the cause. One example is provided below.

Correlate and take a difference

In this class of patents, the system is reconfigured to create two responses to the signal. The two responses must both be affected by the noise so that the two effects are strongly correlated, equal in magnitude, and opposite in sign. By taking a difference between the two responses (either electronically or mechanically) one creates a response that is substantially insensitive to the noise.

An example of this category is Patent #5,483,840 "System for Measuring Flow" (Figure 6). Here the velocity of a fluid at the core of a pipe is to be measured by means of the drag induced on a body on the flow. However, the fluid is highly non-Newtonian so its viscosity varies with shear rate as well as temperature and fluid composition. The signal is the fluid velocity at the core of the pipe. The noise is the viscosity which changes with shear rate. The invention resolves the problem by placing a disc in the flow with one edge near the core of the pipe and the other edge near the wall of the pipe. The disk will rotate at exactly the rate that makes the shear on both sides balanced. That condition will occur when the relative velocities of the disk and the flow are equal regardless of the viscosity of the fluid. In effect, the disk takes a difference between two quantities (shear forces) and equates that difference to zero. Both sides of the disk are affected to the same degree by the noise factor. Hence the rate of rotation of the wheel is a function of only the velocity of the fluid and is unaffected by viscosity of the fluid.

4 RELATIONSHIP TO TRIZ

In general, TRIZ body of knowledge can be grouped into TRIZ analysis techniques and TRIZ database techniques. TRIZ analysis techniques include Ideal Final Result, Functional Analysis, Resource Optimization and Nine Windows. TRIZ database techniques were created as empirical principles derived from analysis of millions of inventions, including patents. The major database techniques include contradiction matrix, separation principles, effects database, solution tree principles, and compilation of technological and business trends. We believe that robustness principles discussed in this paper can complement the TRIZ data base techniques. We propose this in Figure 7.

5 SUMMARY

A robustness invention is a technical or design invention whose primary purpose is to make performance more consistent despite the influence of noise factors. The patent summary and prior art sections in patent or invention description usually provide clues to find robustness invention.

Identification of strategies based on elements of a P-diagram has been found to be very useful because most engineers working in robust engineering or Design for Lean Six Sigma are familiar with use of a P-diagram to represent the system. Moreover, use of these strategies will allow engineers to visualize concepts in terms of a various-element P-diagram. After selecting a robust concept, other methods can be applied to improve robustness further. Thus, this research effort helps engineers more quickly develop robust products by starting with a robust concept. In other words, these strategies will help reduce time of product development and can be applied in Robust Engineering and Design for Lean Six Sigma activities.

ACKNOWLEDGMENTS

This project was funded through Ford-MIT collaboration. We extend our sincere thanks to Dan Frey, Don Clausing, Chris Magee, and Tim Davis for their contribution to this research.

REFERENCES

[1] Phadke, M.S., *Quality Engineering Using Robust Design*, 1989 (Prentice Hall: Englewood Cliffs, NJ).

[2] Fowlkes, W.Y. and Creveling, C.M., *Engineering Methods for Robust Product Design*, 1995 (Addison-Wesley: NewYork).

[3] Michael, W. and Siddall, J.N., The Optimization Problem with Optimal Tolerance Assignment and Full acceptance. *ASME J. Mech. Design*, 1981, 103, 842–848.

[4] Altschuller, G.S., Creativity as an Exact Science: The Theory of the Solution of Inventive Problem Solving, 1984 (Gordon & Breach Science Publishers: NewYork).

[5] Tentler, M.L. and Wheeler, G.L. *Viscosity-Insensitive Variable-Area Flowmeter*. US Patent No. 5,024,105, 1991.

[6] Blair, R., Optical Fiber Insensitive to Temperature Variations. US Patent No. 4,432,606, 1984.

[7] Monroe, R.C., *Axial Flow Fans and Blades Therefore*. US Patent No. 4,345,877, 1982.

[8] Chang, V., Chang, O. and Campo, M., *System for Measuring Flow*. US Patent No. 5,483,840, 1996.

CONTACT

Dr. Philip Samuel

Breakthrough Management Group International

1921 Corporate Center Circle

Longmont, Colorado 80501

USA

E-mail: Phil.Samuel@bmgi.com

Phone: +1 (303) 827-0010

FAX: +1 (303) 827-0011

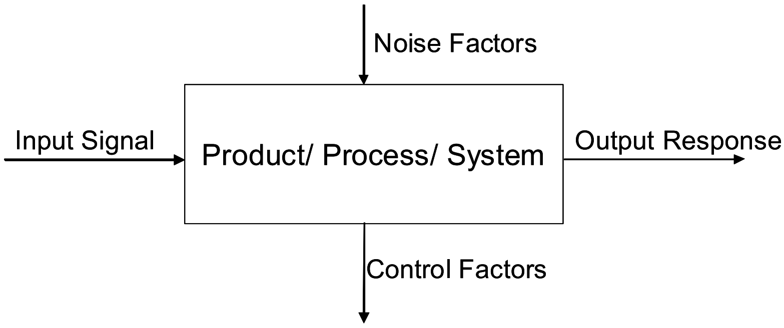


Figure 1: A Parameter Diagram

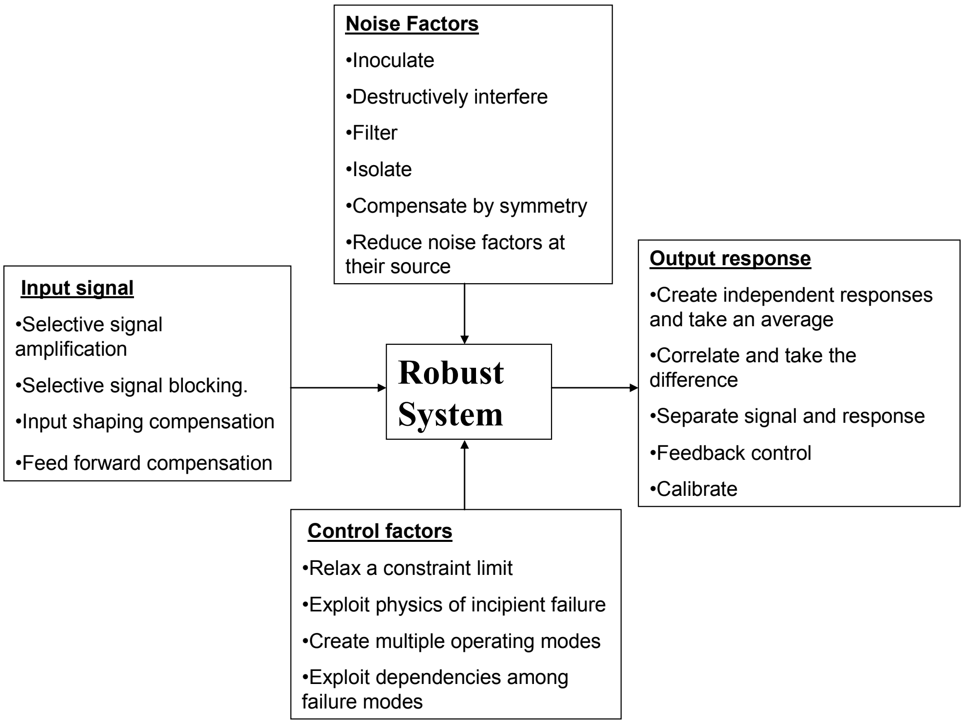


Figure 2: Representation of Robustness Strategies Using a P-Diagram

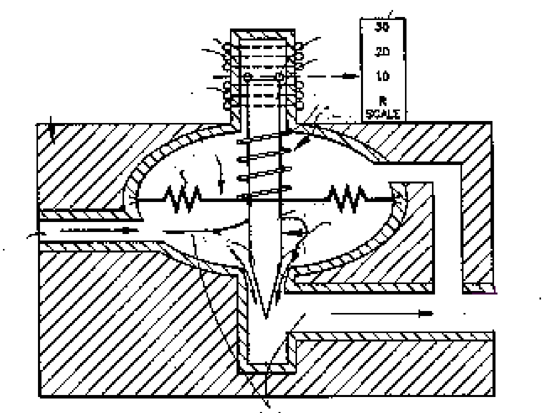


Figure 3: Viscosity-Insensitive Variable-Area Flowmeter (adopted from [5])

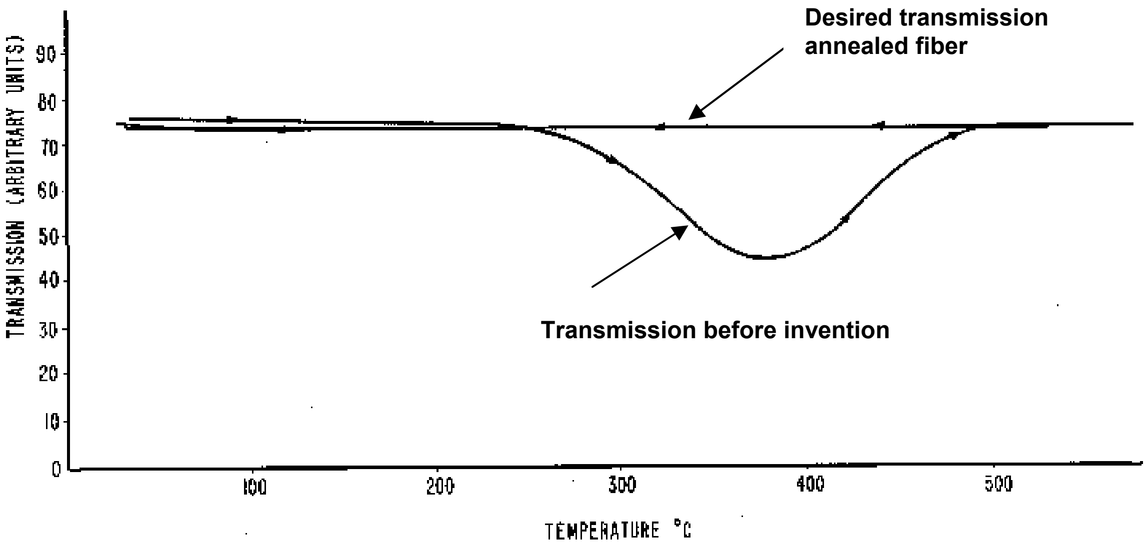


Figure 4. Optical Fiber Insensitive to Temperature Variation (adopted from [6])

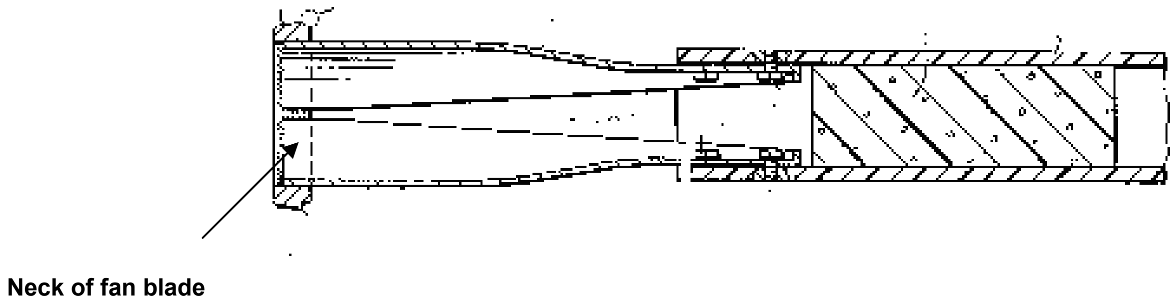


Figure 5: Axial Flow Fans and Blades Therefore (adopted from [7])

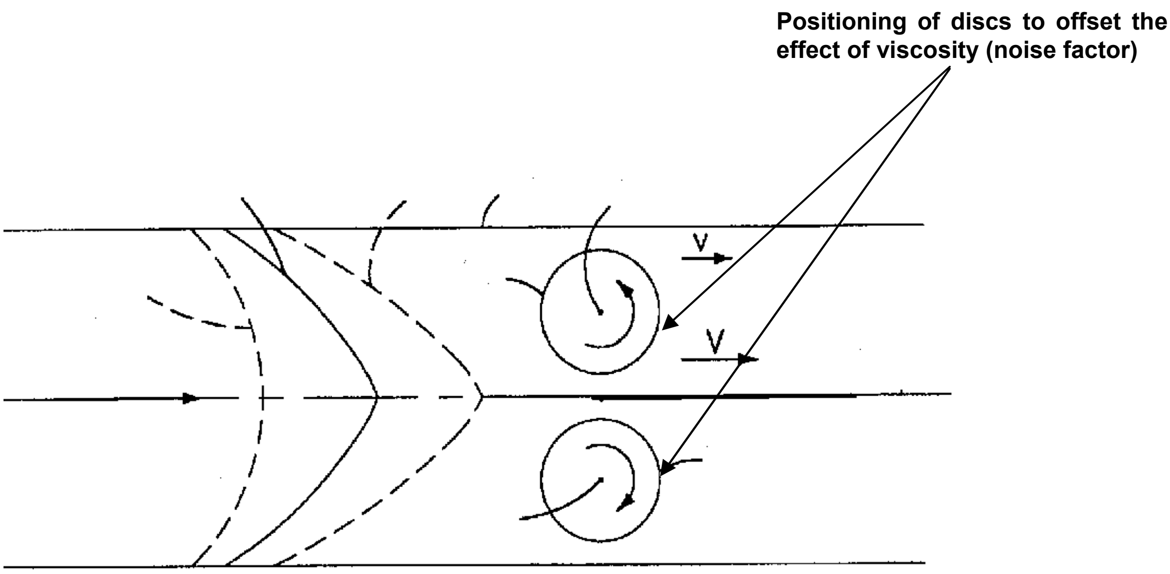


Figure 6: System for Measuring Flow (adopted from [8])

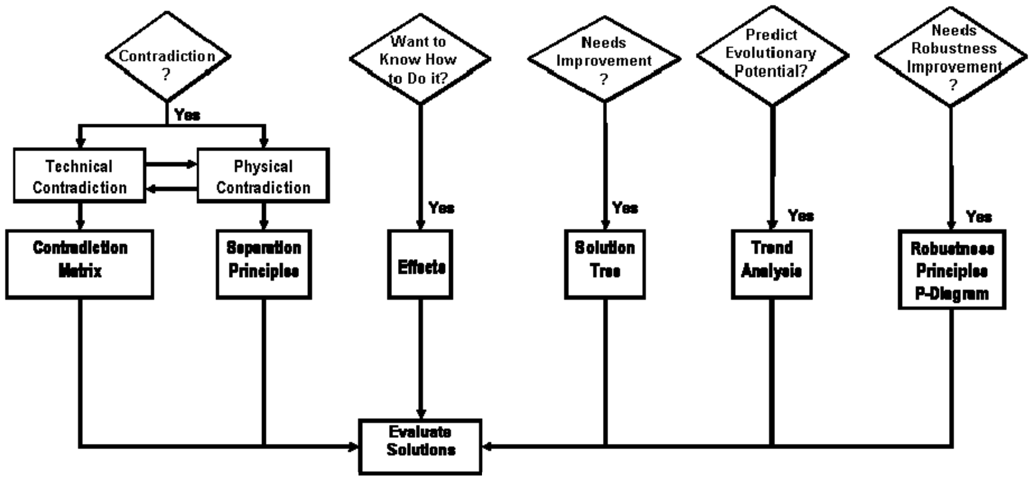


Figure 7: Addition of Robustness Principles to TRIZ Database Techniques

Value-Conflict Mapping (VCM) To Structure Innovation Strategy

Valeri Souchkov
ICG Training & Consulting, The Netherlands

Abstract

The paper presents an overview of key concepts of Value-Conflict Mapping (VCM), developed to help with collecting and structuring information about existing and potential problems in various types of man-made systems in a systematic way. These problems are represented in terms of contradictions between market and/or business demands caused by current system properties or parameters which often must have opposite values or be in opposite states to satisfy two or more different demands. A procedure of value inversion is introduced to extract more information about demands and contradictions. The paper also shows a general process of Value-Conflict Mapping and is illustrated by several examples.

Keywords

Contradictions, Conflict Analysis, Value-Conflict Mapping, TRIZ, OTSM-TRIZ, Innovation Management

1 INTRODUCTION

Evolution of any design or business product is driven by three large groups of impacting factors:

- **Voice of market**: each demand and requirement which are comprised by existing and emerging demands, new trends, new developments, changes in a product's supersystem.
- **Voice of business**: each business organization is interested in growth as well as in the most effective and efficient production and delivery of its products and services.
- **Voice of technology**: internal drivers of technology evolution, new technological developments, emerging technologies, scientific discoveries, technology diversification.

Today virtually every organization, no matter what type of material, products or immaterial services it delivers, relies heavily on underlying technologies to create new value: it can be either a new manufacturing technology for producing steel pipes or new telecommunication and data processing technologies used by an insurance company.

The dialectic approach to evolution states that each time, soon after a balance between these groups of factors is achieved, some factor will change and the only adequate response by a business system would be to innovate: either on a product or a business side (e.g. a new business model). It is well known in TRIZ that in order to create a breakthrough innovation, we need to eliminate a contradiction which blocks further evolution of a current system, which can be either a technical product, or a business service. However, emergence of contradictions is not limited to technical demands and parameters only. There is always a large group of cross-disciplinary contradictions between these three voices. For example, a mass market demands ordinary lightweight bicycles for comfort and easier riding – but a company producing these bicycles is interested in reducing material costs which would be not possible to achieve if the bicycles would use lightweight composite materials which are still too expensive today. Thus a good known technical solution can not be used due to a limiting business constraint.

To correctly define future innovation strategy related to the customer's business, one needs to design a map which would establish and structure relationships between all types of contradictions to be able to identify those contradictions which should be resolved within short and long terms. To create such maps, we developed and introduced a technique called "Value-Conflict Mapping™" which we discuss below.

Due to a limited scope of this paper, which does not allow us making a comprehensive coverage of our method, we limit ourselves to presenting a general overview and the key concepts and ideas of the Value-Conflict Mapping.

2 CURRENT SITUATION

In classical TRIZ, main research focus was traditionally placed on solving a specific inventive problem [1], and that is why major attention was paid by G. Altshuller and his associates to developing and enhancing ARIZ [2] and a system of Inventive Standards [3].

However in many cases, a starting point for an innovative project is to explore how our product or service can be improved and evolved on a broader scale before solving any specific problem. Even if we would like to focus on solving a specific but complex problem, we need a method that would assist us with managing the problem complexity and provide us with sufficient information to make the right decisions on what and how to change.

One of the first techniques for complex analysis of technical systems which was included within TRIZ was Function-Cost Analysis [4] (today also known as Function-Attribute Analysis). Another approach is a direct application of the TRIZ Trends of Technology (or Business) Evolution to a selected product or service to breed new ideas of future generations of products and services [5,6]. All known modifications of these approaches have their advantages and disadvantages: they either deal with contradictions in implicit way, or do not provide linking between the three groups of impacting factors ("voices") mentioned above. For instance, while Function Analysis can be used to comprehensively map functional interactions in a system, it is limited to representing non-functional attributes (such as, for instance, aesthetic, emotional or business parameters) of the system, and as a consequence they are not included to the analysis. On the other hand, a disadvantage of the direct application of the TRIZ Trends of Evolution is that we might miss crucial information about existing and potential contradictions and thus we can only rely on our intuition to make a conclusion about the degree of future success of ideas proposed. In addition, evolution of a system can be blocked by many smaller, often "invisible" contradictions which we do not properly recognize. For that reason we need a tool which will help us to recognize, visualize, and map blocking contradictions thus we would

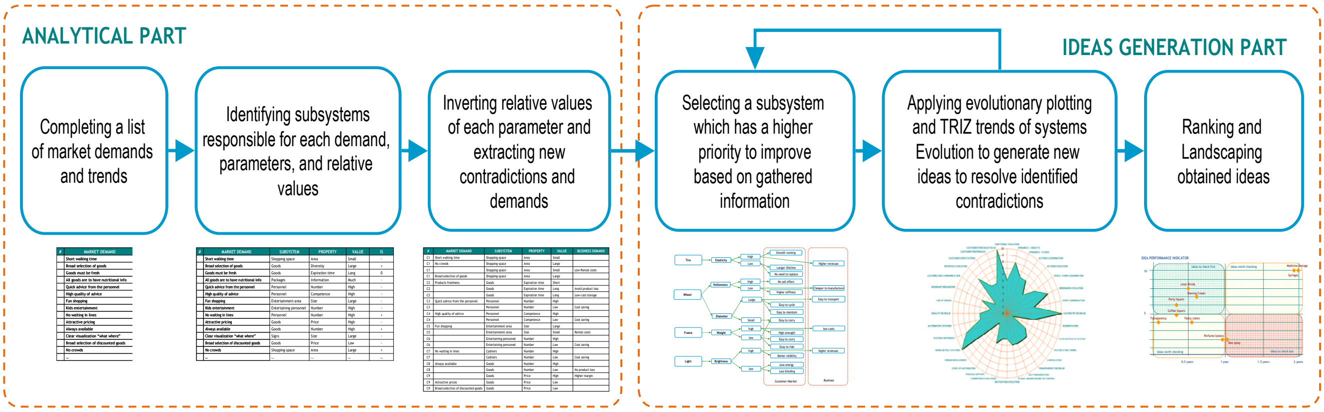


Figure 1: A general process of Value-Conflict Mapping

clearly see what we have to do and use this information to define our innovation strategy.

The concept of contradiction is a core element of TRIZ and should not be neglected during innovative projects. Today there is a range of existing and emerging techniques which help with identification and definition of contradictions for solving specific problems such as Problem Formulator [7], RCA+ [8]. Proper recognizing of driving and even minor contradictions ensures the success of new innovative ideas since we get a better understanding why we need to introduce one or another change. Another important issue is to be capable of foreseeing new contradictions.

Modern technological and business systems are quite complex and involve large numbers of interrelated contradictions. Some research and developed techniques already deal with this issue within OTSM-TRIZ, which is extension to Classical TRIZ being developed by N. Khomenko and his colleagues [9,10].

Value-Conflict Mapping has been developed in parallel and incorporates some basic ideas of OTSM-TRIZ and is based on a similar idea to networking contradictions. On the other side, it introduces an approach to mapping market demands to contradictions as well as mapping the contradictions to new demands.

3 VALUE-CONFLICT MAPPING

In general, Value-Conflict Mapping (VCM) is designed to help with extracting and linking technological, business and market contradictions [11]. VCM proposes a process of direct mapping of existing demands and market trends to relative values of properties or parameters of existing products or services, and then identifying the existing contradictions and revealing potential ("hidden") contradictions by a procedure of value inversion. Thus a central idea of VCM is to define how the existing technological or business products and systems contradict to business and market demands, trends, and requirements.

There might be three groups of contradictions:

1. Between two specific market demands put on the same system's part. For instance, an automotive light should have both high intensity of light (to better lit a road in the dark) and low intensity (to avoid blinding of other drivers). Most of contradictions in technical systems and products arise at the level of market demands or can be translated to them.
2. Between a market and a business demands. For example, a plane must be checked very thoroughly during airport parking to ensure safety of a flight. However it requires increasing the number of technicians and parking time which would negatively influence revenues of the airline.
3. Between two business demands. For example, a supermarket management considers bringing more employees to the supermarket floor to help customers with better product choice. However it requires increasing the number of sales assistants which would negatively impact profit margin of the supermarket.

VCM is performed by completing the table which consists of the following columns (Table 1):

1. A market demand or a market trend.
2. A part of a system responsible for fulfilling the demand or the trend.

#	MARKET DEMAND	SUBSYSTEM	PROPERTY (PARAMETER)	RELATIVE VALUE	INDEX OF SATISFACTION	BUSINESS DEMAND
	A customer /market demand or a market trend which is becoming a demand	*A part of a system (subsystem) responsible for meeting the demand. Can be a whole system as well.*	*A property (parameter) which is responsible for meeting the demand. It is associated with a subsystem defined in the left column.*	*A desired relative value of a property/ parameter to fulfill the demand (e.g hard, soft, high, low, etc.)*	*Index of current market demand satisfaction:* *+: good* *0: can be improved* *-: not satisfactory*	*A business demand which contradicts a market or another business demand demand (if any)*

Table 1: A typical string in a VCM Table

3. A parameter (property, attribute, feature) which is responsible for fulfilling the demand or the trend.
4. A desired relative value of a parameter.
5. Index of Satisfaction of each demand.
6. Business demand which is associated with the parameter.

4 VALUE-CONFLICT MAPPING PROCESS

Although the key ideas and techniques which belong to VCM can be used in various contexts, below we show a process of using VCM in combination with the TRIZ trends of Technology (Business) Evolution (depending on which system is analyzed: technical or business). The entire process consists of two parts: *Analytical Part* and *Ideas Generation and Landscaping* part (Figure 1).

To start VCM, we should first select a system which we are going to analyze. It can be a technical object, or a "soft" service, or a business organization. In other words, it can be any man-made system.

There are nine basic steps in the analytical part of the process:

1. Gathering information on market demands and market trends. Often such information is readily available after thorough customer and market research independently of TRIZ and other innovation activities. Usually the list includes both functional and non-functional requirements and demands.
2. Each market demand or a trend is linked to a certain part (subsystem) of a system under consideration which is responsible for meeting that particular demand. Often, general demands can be divided to more specific demands. If there are several subsystems connected with the same demand, all of them are included to the analysis. In some cases, the entire system can be related to a particular demand (for instance, the overall weight of a system), although in this case it is recommended to extract most contributing subsystems.
3. A parameter (property, feature, attribute) which is responsible for fulfilling a selected demand is identified. It can be weight, size, transparency, amount of information, number of sales people, amount of transactions, and so forth. It should not necessarily be a physical parameter, especially when we work with business or organizational systems. In case of non-functional parameters which are often addressed to consumer products and cannot be directly translated to quantitative parameters (e.g. "a product must look sexy") it is allowed to define such product attributes which correspond to common features which are known in general to achieve the desired effect (e.g. a parameter can be "artistic design"). It is important to note that there is no need to translate each demand to engineering or a technical parameter since the VCM philosophy does not limit types of parameters used as long as they can be represented by any meaningful values.
4. A relative value of a parameter is identified: here with a "relative value" we mean a desired qualitative measure of the parameter with respect to fulfilling a corresponding demand. For instance, the weight can be high or low, a number of employees can be small or large, and so on. At this stage we do not pay attention to any specific numeric values, only to their qualitative states. With respect to non-functional parameters, we can operate with such values as a type of artistic design of a system or a product (e.g. a value of artistic design can be "Danish Design").
5. After each parameter has been identified with its relative value, its index of satisfaction is estimated. There are three possible values: "satisfactory", "non-satisfactory", and "satisfactory but can be improved". The latter is used to indicate that there is a potential for improvement and this parameter should not be neglected.
6. A relative value of each parameter is inverted to explore if we can discover missed or new market or business demands which can be added to the table.
7. If a desired relative value contradicts a certain business demand, this business demand is added to the column of business demands.
8. All contradictions in the resulting VCM table are grouped and graphically represented as a VCM tree.
9. Based on the analysis of VCM tree and priorities of market demands, the contradictions are ranked and those subsystems are selected which have the highest importance to be changed.

#	MARKET DEMAND	SUBSYSTEM	PROPERTY	VALUE	IS
	Short walking time	Shopping space	Area	Small	-
	Broad selection of goods	Goods	Diversity	Large	+
	Goods must be fresh	Goods	Expiration time	Long	0
	All goods are to have nutritional info	Packages	Information	Much	-
	Quick advice from the personnel	Personnel	Number	High	-
	High quality of advice	Personnel	Competence	High	-
	Fun shopping	Entertainment area	Size	Large	-
	Kids entertainment	Entertaining personnel	Number	High	-
	No waiting in lines	Personnel	Number	High	+
	Attractive pricing	Goods	Price	High	-
	Always available	Goods	Number	High	+
	Clear visualization "what where"	Signs	Size	Large	-
	Broad selection of discounted goods	Goods	Price	Low	-
	No crowds	Shopping space	Area	Large	+
	...	...	...	...	...

Table 2: Completing the first 5 steps of VCM Analytical parts

The output of the Analytical Part of VCM is a set of ranked trees of contradictions related to system's parts. These contradictions, in turn, can be further resolved with relevant TRIZ techniques. In the case when a system's part experiences the largest number of contradictions, it is usually selected as a primary candidate for improvement. The required improvement is reached by increasing the overall degree of ideality of the system's part with the TRIZ trends of technology or business evolution.

An example of completing the first 5 steps of the VCM process is shown in Table 2. Only a fragment of the actual table is shown to simplify presentation. A case was to explore how a supermarket's product department could be improved.

As we can see, the table already gives us information about several contradictions: for instance, the area of a shopping space should be large to avoid overcrowding, and at the same time the area should be small to reduce walking distance, and as a consequence, shopping time. Next, this table should be added with new contradictions and new demands.

5 INVERSION IN VCM

Value inversion plays an important role in the VCM philosophy to discover new opportunities. We often take things for granted and do not think about "what if….". It is one of numerous effects of our psychological inertia: we used to accept things which surround us as they are; and we rarely think about what would happen if we consider the same things within the opposite context. For instance, we used to think that roads must be as wide as possible to accommodate more traffic. But what would happen if the roads would become extremely narrow? In such case we will obtain many positive effects: less noise, no large damage to the existing infrastructure, less building and maintenance costs, and so forth. But narrow roads will demand a complete rethinking of a concept of transportation. Still, making such statement explicit is important: inversion will force us to register contradictions and eventually come up with new breakthrough ideas to resolve either small-scale or long-standing contradictions.

The process of inversion is performed in the following way. A string in a VCM table looks as follows (Index of Satisfaction is omitted):

Demand -> Subsystem -> Parameter -> Relative Value

Now we should replace the relative value with its "anti"-relative value and reconstruct the chain backwards:

Anti-Relative Value -> Parameter -> Subsystem –> New Demand

This new demand can be a market demand or a business demand. Let us consider the following example with a bicycle. A wheel should have a large diameter to provide easy riding. Thus the string should look as:

Easy Riding -> Wheel -> Diameter -> Large

Now we should invert the relative value "large" to the relative value "small" and ask the question: will there be any positive effects for a customer or business of a bicycle manufacturer? Certainly: the bicycle will become smaller and less bulky, thus the customers will be able to carry it with less efforts. A small bicycle means lower material and delivery costs for the bicycle manufacturer as well. Thus we can add the following lines:

Easy Riding -> Wheel -> Diameter -> Large

Easy Carrying -> Wheel -> Diameter -> Small

Easy Transportation -> Wheel -> Diameter -> Small

Easy Maintenance -> Wheel -> Diameter -> Small

#	MARKET DEMAND	SUBSYSTEM	PROPERTY	VALUE	BUSINESS DEMAND
C1	Short walking time	Shopping space	Area	Small	
C1	No crowds	Shopping space	Area	Large	
C1		Shopping space	Area	Small	Low Rental costs
C1	Broad selection of goods	Shopping space	Area	Large	
C2	Products freshness	Goods	Expiration time	Short	
C2		Goods	Expiration time	Long	Avoid product loss
C2		Goods	Expiration time	Long	Low-cost storage
C3	Quick advice from the personnel	Personnel	Number	High	
C3		Personnel	Number	Low	Cost saving
C4	High quality of advice	Personnel	Competence	High	
C4		Personnel	Competence	Low	Cost saving
C5	Fun shopping	Entertainment area	Size	Large	
C5		Entertainment area	Size	Small	Rental costs
C6		Entertaining personnel	Number	High	
C6		Entertaining personnel	Number	Low	Cost saving
C7	No waiting in lines	Cashiers	Number	High	
C7		Cashiers	Number	Low	Cost saving
C8	Always available	Goods	Number	High	
C8		Goods	Number	Low	No product loss
C9		Goods	Price	High	Higher margin
C9	Attractive prices	Goods	Price	Low	
C9	Broad selection of discounted goods	Goods	Price	Low	

Table 3: Adding new customer and business demands to VCM (Supermarket case)

As one can see, we can add new demands after inversion which makes a picture of contradictions more complete.

Apart from helping to identify other market and business demands, inversion helps to make many contradictions explicit which block further evolution of the same subsystem. It is important since in many cases the same subsystem might cause numerous contradictions and thus we should have as most complete picture of involved contradictions as possible to define the right priorities and areas where to concentrate most of our future innovative efforts.

The resulting fragments of the VCM tables for the supermarket and bicycle cases are shown in Tables 3 and 4 respectively.

For instance, by inverting the relative value for "the number of personnel is high" (Table 3) to "low" would provide us with considerably lower labour costs which was added as a business demand. Similarly, a new market demand was added to the table illustrating the bicycle case (Table 4): by inverting the relative value of light intensity we added a new demand: low intensity of the light will help to avoid blinding of other riders. In the actual table on the bicycle case, more than 50 new market demands were added.

6 VCM TREES

To provide a better visualization of results, so-called "VCM trees" are built after completion of the VCM process. Fragments of such trees are show in Figures 2 and 3. As we can see, on top of each tree we place subsystems which were included to the corresponding VCM tables.

The VCM trees can be useful to visually present the results of the VCM to a larger group of people, whose input might directly lead to new insights.

Often the question arises, "Why can not we start doing VCM directly with building the VCM trees?" A goal of VCM is to systematically map market demands to relative values of system properties and not vice versa. A process will be more systematic and results will be more complete and consistent after we first complete the VCM tables and then visualize them in form of the VCM trees.

7 WORKING WITH VCM RESULTS

After the VCM Analytical Part is complete, there might be several ways of working with its results. For instance, most important contradictions can be identified with the ranking procedure and then resolved with classical TRIZ problem solving techniques, for instance, ARIZ.

However, in many cases the same subsystem is related to a multitude of contradictions, and solving one or another contradiction will only satisfy a part of demands, or it will generate new problems depending on a particular solution. As follows from our experience, a more effective strategy will be to use the TRIZ Trends of Evolution by applying them to a subsystem which causes most of contradictions. This procedure is known and thus we omit is presentation in this paper.

After the ideas generation session is finished, ideas and concepts obtained are ranked and landscaped to identify:

- most promising candidates for a short-term implementation and
- most promising candidates which would require more efforts for a long-term implementation.

Since a completed VCM process provides sufficient information and a broad overview of current and potential contradictions which can be used to formulate many different tasks, these results can be re-used in different projects.

#	MARKET DEMAND	SUBSYSTEM	PROPERTY	VALUE	BUSINESS DEMAND
C1	Smooth running	Tire	Elasticity	High	
C1		Tire	Elasticity	High	Higher revenues
C1	Longer lifetime	Tire	Elasticity	Low	
C1	No need to replace	Tire	Elasticity	Low	
C2	No sail effect	Wheel	Hollowness	High	
C2	Higher stiffness	Wheel	Hollowness	Low	
C2		Wheel	Hollowness	Low	Cheaper to manufacture
C3	Easy to carry	Wheel	Diameter	Small	
C3	Easy to cycle	Wheel	Diameter	Large	
C3		Wheel	Diameter	Large	Easier transportation
C3	Easy maintenance	Wheel	Diameter	Large	
…	…	…	…	…	…
C54	Better visibility in the dark	Lamp	Light Intensity	High	
C54		Lamp	Light intensity	High	Better revenues
C54	Less blinding	Lamp	Light intensity	Low	
C54	Less energy spent	Lamp	Light intensity	Low	

Table 4: Adding new customer and business demands to VCM (Bicycle case)

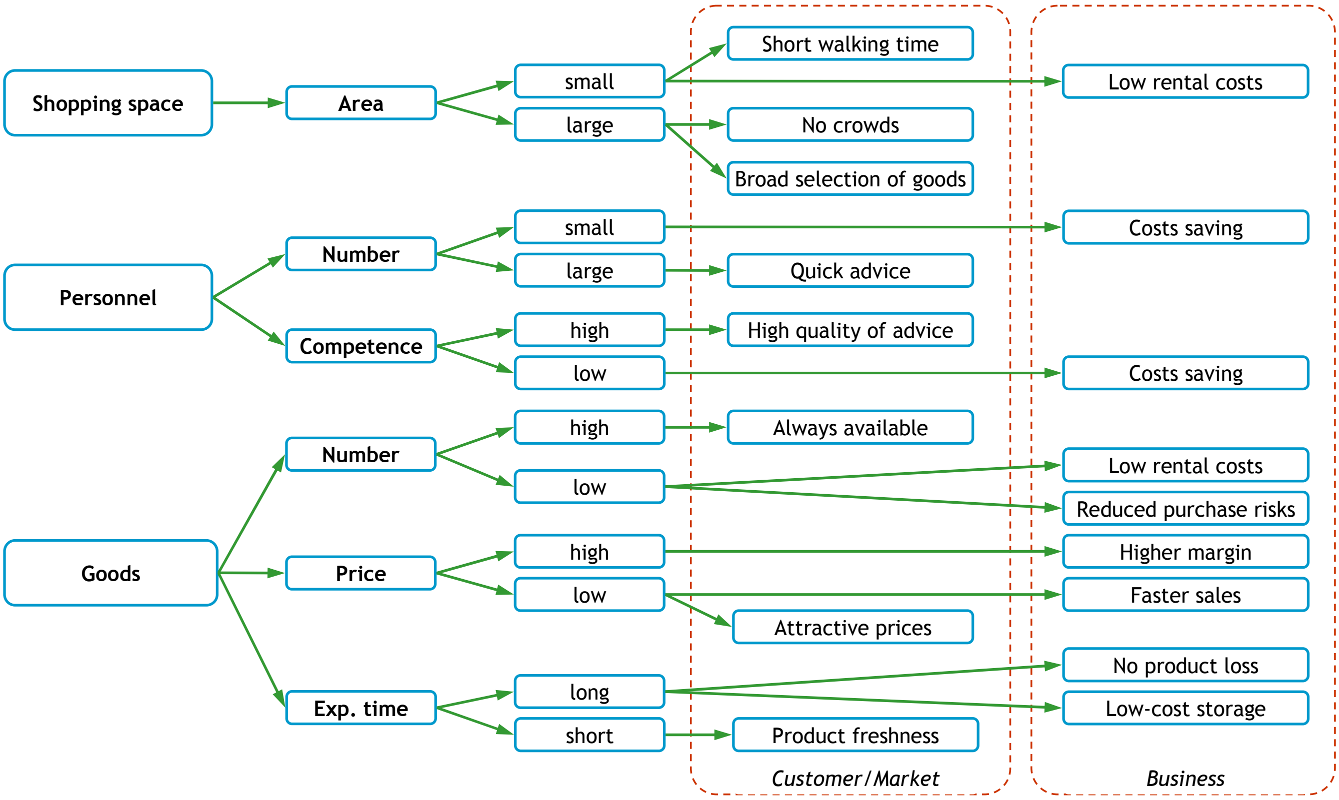


Figure 2: A fragment of a VCM tree (Supermarket case)

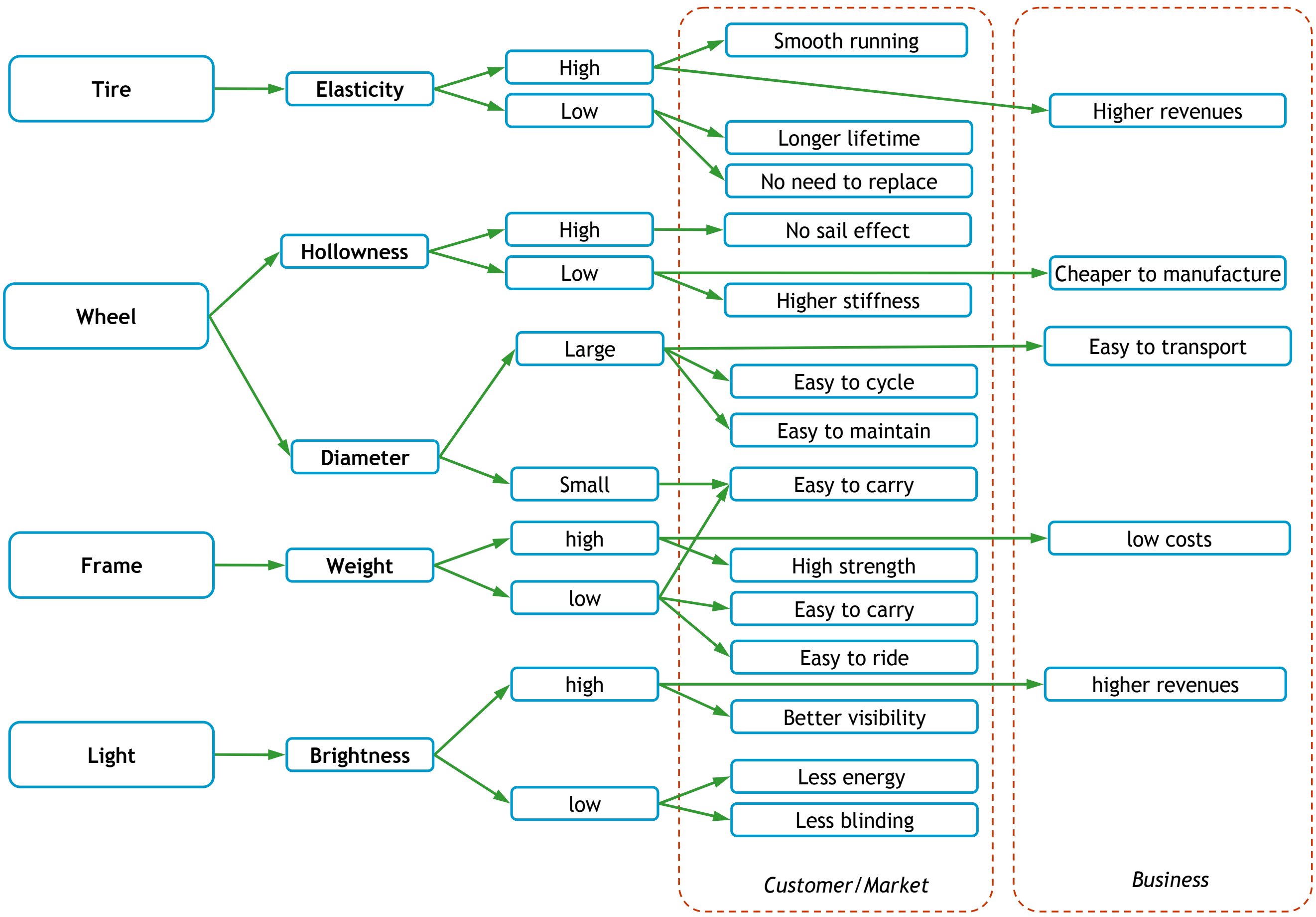


Figure 3: A fragment of a VCM tree (Bicycle case)

8 APPLICATION AREAS

By now, a number of projects on basis of VCM were successfully performed for technological and business applications. VCM was applied to B2B and B2C products and services with high market potential, as well as to business and organizational systems. A question arises if VCM can be applied to products and services which have a low market potential. This question requires additional studies. However our experience demonstrates that even in case of a product or a service with a low market potential VCM might help to reveal resources to innovatively redesign a product or a service (or a business system built around) and achieve benefits on the basis of costs reduction.

9 SUMMARY

Summarizing, application of VCM provides the following:

- Mapping market demands to contradictions caused by a current system.
- A comprehensive overview of system parts (subsystems) causing contradictions.
- Identification of new or "hidden" contradictions and demands via the procedure of value inversion.
- Input for a multitude of projects on further system innovation.
- Information for defining and structuring innovation strategy with respect to a selected technological, business, or organizational system.

VCM can be used in various contexts and for analysing various types of systems. For instance, VCM can be used to analyze technical systems and products without adding business demands: to collect information about contradictions at the level of market and technical demands only.

Shortly after introduction in 2006, VCM was successfully used by ICG Training & Consulting and its customers in a number of educational and consulting projects for both technology and business innovations. Its application helped to structure information about current and potential problems, recognize new, previously "hidden" demands and contradictions, and make strategic decisions what parts of system should be improved first, why, and how.

ACKNOWLEDGMENTS

I would like to express my sincere thanks to Nikolai Khomenko for useful discussions which were taken to account when developing VCM.

REFERENCES

[1] Souchkov V., A Brief History of TRIZ, White Paper, ICG T&C, 2008, www.xtriz.com/BriefHistoryOfTRIZ.pdf

[2] Altshuller G., Algorithm for Solving Inventive Problems ARIZ-85B, Sverdlovsk, 1985 (In Russian)

[3] Altshuller G., "System of 76 Inventive Standards", In "Methods of Solving Technical and Scientific Problems", St. Petersburg (Leningrad), 1985 (in Russian)

[4] Gerasimov V. & Litvin S., FCA (Function-Cost Analysis) and Methods of Technical Creativity, St. Petersburg, 1988 (in Russian)

[5] Mann D. Hands-on Systematic Innovation for Technology and Engineering, CREAX Press, 2002

[6] Zlotin B. and Zusman A., Directed Evolution: Philosophy, Theory and Practice, Ideation International Inc., 2001

[7] Zlotin B., Bushuev D., Haimov E., Malkin S., Zusman A., Tikhonov & A, Pevnev, "Automated Problem Formulator and Solver", US Patent 5581663, 1996.

[8] Souchkov V., "Root Conflict Analysis (RCA+): Structuring and Visualization of Contradictions," in Proc. ETRIA TRIZ Future 2005 Conference, Graz, November 16-18, Leykam Buchverlag, 2005.

[9] Kucharavy D., De Guio R., Gautier L. & Marrony M., "Problem Mapping for the Assessment of Technological Barriers in the Framework of Innovative Design", in Proc. Int. Conference of Engineering Design (ICED'07), Paris, France, 2007

[10] Khomenko N., Guio R.D., Lelait L. & Kaikov I. "A Framework for OTSM-TRIZ Based Computer Support to be used in Complex Problem Management", International Journal of Computer Applications in Technology (IJCAT), 2007

[11] Souchkov V., "Value-Conflict Mapping", in xTRIZ: Materials of Advanced Training in TRIZ and Systematic Innovation, ICG Training & Consulting, 2006-2008.

CONTACT

Valeri Souchkov
ICG Training & Consulting
Willem-Alexanderstraat 6
7511 KH, Enschede, The Netherlands
E-mail: valeri@xtriz.com
Phone: +31 (53) 4342884
FAX: +31 (53) 2011174

TRIZ Incorporating the BRIGHT Process in Design

Shuo-Kai Tsai, Peter R.N. Childs
University of Sussex, Department of Engineering and Design, United Kingdom

Abstract

The theory of inventive problem solving (TRIZ) is widely acclaimed by adoptees and in the academic literature. However, an apparent disparity exists between the low reported industrial take-up of TRIZ and perceptions in the TRIZ community which indicate more widespread use. A review of TRIZ, design processes and creative problem solving processes are reported, showing differences in the emphasis on creative thinking and the use of iteration. The advantages of a procedure related to the aspects of usability, creative thinking and iteration within the TRIZ environment has been recognised and addressed by the development of a new process named BRIGHT.

Keywords

Brainstorming, Creative Problem Solving Process (CPS), Design, Design Process, TRIZ

1 INTRODUCTION

The numbers of training events on the use of the Theory of Inventive Problem Solving (TRIZ) over the last year provide evidence of an increasing interest in TRIZ and its effects. In order to find out how useful TRIZ could be to the design industry, a survey was sent out to 194 design consultancies and companies in the UK. However, the outcome of these results did not show a high percentage of TRIZ use. In order to explore further how TRIZ is used, arrangements were made to discuss its use with TRIZ experts in the UK. Results highlighted that some people may not want to reveal that they are using TRIZ for confidentiality and commercial reasons, and also that unclear procedures on how to use TRIZ tools in a design project could be another issue.

Because of difficulties in finding out how TRIZ has been used so far by its end-users in industry, these three TRIZ experts in the UK were consulted. Methods were subsequently explored in order to improve the use of TRIZ in design. To develop a process, this research started to focus on studying these designers' habits and knowing how they normally solve their design problems. At this study, six product designers who are based in the UK were interviewed in order to find out those methods they use to solve their design problems and what their expectations are of a technique that is able to assist the design project. Results of the interviews are summarised below:

- Designers often start to generate solutions to the problem straightaway without spending time to clarify the design problem.
- Designers often do not like to use any method, process or technique unless it is a structured and easy technique such as Brainstorming.
- Designers do not like changing or learning a new technique. Some designers indicated that they had their own methods and ways of thinking for design and that there is no need to change it.
- If a process to assist in design is identified as desirable, designers expect it to be easy to understand and use in a design project. In addition, designers would also like to clearly know what to do with the results step by step after using those tools.
- Many designers even were not aware of the wide range of creative and design process techniques as well as TRIZ when interviewed.

From this information a number of 'invisible' questions were developed which could be incorporated in TRIZ in order to help designers develop problem solutions. Generally speaking, designers start by exploring the needs and then carry on to the stage of idea generation. However, some designers might have ignored the importance of refining the problem to find out the core issue. Several TRIZ tools such as functional analysis, Su-field analysis or trends of evolution have been demonstrated to be of value in helping to refine the problem. In addition, other TRIZ tools are also useful in evaluation and testing ideas. However, a clear process to guide designers to incorporate TRIZ tools in their process is required if its wider acceptance and implementation is to be achieved. In addition, as part of this research study the traditional design process was reviewed along with existing schemes for the implementation of TRIZ in order to compare them and identify reasons why people have found it difficult to integrate TRIZ into their design projects.

2 THE GENERATIVE PROCESS

In order to identify a more effective process for the implementation of TRIZ, the traditional design process, the creative problem process and a number of existing schemes for the implementation of TRIZ were reviewed and compared.

2.1 The design process

Chaturvedi and Rajan [6] indicated that successful products are dependent on the use of a well organised design process and management. In a design process, the designer often starts with initial sketches to describe possible solutions to the design problem. This may typically be followed by detailed design, evaluation and testing. An inappropriate design process could not only affect the product life-cycle but also increase the possibility of failure in generating a viable design. This indicates that the selection and use a good design process is as important as looking at a suitable creative technique to use.

Will creative techniques be easily integrated within the design process? How and when to use these techniques during the design? Stoll [24] highlighted that an effective product development process which is given in Figure 1 must have characteristics of "well defined and understood customer needs", "in a timely manner", "product transitions easily and smoothly into process with minimal engineering change" and "a reasonable profit over its life cycle". In addition, Braha and Maimon [2] illustrated that almost all the design process flowcharts generated as attempts to describe the design process have identified it as comprising sequential phases that are revisited in an iterative manner. This process emphasises the importance of having feedback and iteration in a process as these actions play important factors in a design process and allows users to review and rethink issues in order to produce the best solutions.

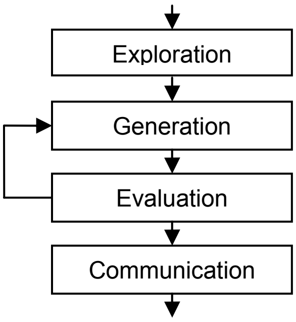


Figure 1: A simple four-stage model of the design process (adapted from [14])

It is generally agreed that design process models can take many forms depending upon the designers' purpose and origin in a product design, but they always includes certain activities [21]. However, so far there is no universally agreed format for the design process. If a design process is so important and useful in defining a successful design, does or has the TRIZ process fulfilled these requirements? A comparison between the use of the traditional design process and existing TRIZ implementation processes is discussed in section 2.4.

2.2 Creative problem solving processes

Creative Problem Solving (CPS) is a broadly applicable process that also provides a structured framework to help to design and generate new and useful outcomes [14]. Sefertzi [22] state that the main objectives of a creative thinking process are to think beyond existing boundaries, to awake curiosity, to break away from rational, conventional ideas and formalised procedures, to rely on the imagination, the divergent, the random and to consider multiple solutions and alternatives. Overall, the process of creative problem solving involves a framework that provides a systematic procedure to guide designers to effectively use techniques and methods in each stage of the process. Isaksen and Treffinger [13] explained some reasons for the importance of using CPS:

- The use of CPS helps designers to think about the goals they would like to meet or achieve.
- The process helps people think about their wishes, hopes, dreams and aspirations.
- The CPS process makes people think about the problems and challenges in their lives.

In this research study Osborn-Parnes' CPS model [19] and de Bono's "TO LO PO SO GO" process [7] were taken as references to discuss creative problem solving processes. The reasons were:

- Alex Osborn [18] described a seven-stage version of Creative Problem Solving (CPS) process and this has been widely identified as the first comprehensive description of the CPS process.
- This CPS includes the steps which guide a creative process and informs designers on what to do at each step in order to eventually produce one or more creative, workable solutions. A unique feature was that each step first involves a divergent thinking phase in which one generates lots of ideas (facts, problem definitions, ideas, evaluation criteria, implementation strategies), and then a convergent phase in which only the most promising ideas are selected for further exploration.
- The "TO LO PO SO GO" process described by de Bono can be recognised not only as a kind of thinking but also as a process to solve problems more creatively and a technique for boosting creativity.

When considering creative problem solving processes, divergent and convergent thinking are often identified as significant. A schematic, given in Figure 2, characterises these following research on the personality, profession, needs and psychological issues, Hudson [12]. For scientific or technical purposes, people tend to use a convergent thinking style while for artistic and humanities based activities, the more prevalent thinking style is divergent thinking.

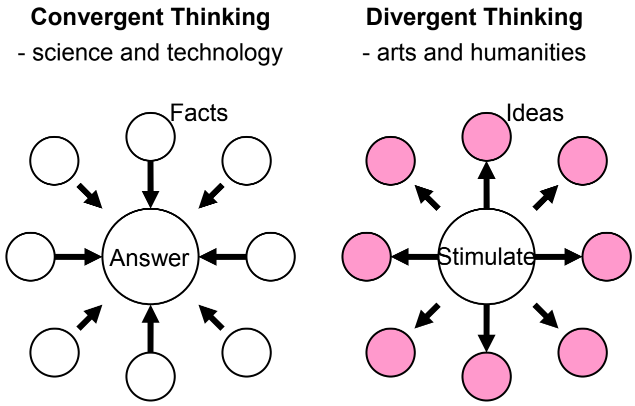


Figure 2: Characteristic thinking modes of convergent and divergent thinking (adapted from [12])

The advantage of emphasising creative thinking in the process is aimed to think problems and generate solutions in more creative way.

2.3 TRIZ implementation processes

Figure 3 shows a typical model illustrating how to implement TRIZ in practice to a problem and generate solutions for this.

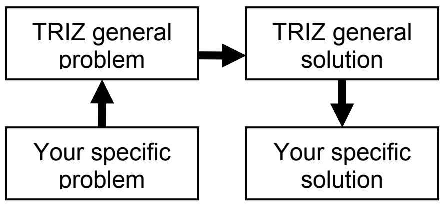


Figure 3: The general model for TRIZ problem solving

This process looks easy, but, in fact, it just provides a thinking mode rather than a clear guide with the instructions on how to use each of the TRIZ tools in the process. Through the limited research survey undertaken as part of this study and personal facilitation experience, many people find that TRIZ is too complicated such that they give up and use other approaches. In addition sometimes they also do not know how, when and which tools to use at each stage.

There have been many different types of processes developed for TRIZ including [1, 4, 5, 6, 8, 9, 15, 17, 20, 23, and 25]. Overall, these TRIZ processes have covered and stressed many different stages in a design project. Some processes give users many selections on which TRIZ tools to use but some do not. In addition, some just provide users the indication that TRIZ can be applied but there are no details about the methods.

2.4 Process comparison

The design process and two creative problem solving processes are compared in Table 1 in order to identify any substantive differences. The comparison shows that the creative problem solving process is very similar to the traditional design process, with the principal difference being the focus on the use of divergent and convergent thinking in creative problem solving.

Table 2 shows a comparison between the traditional design process and existing schemes for the implementation of TRIZ. This shows substantial similarities between these, with most covering the stages of exploration, idea generation and evaluation. However, as a result of this comparison, the following findings are highlighted.

- None of these TRIZ processes explicitly mention that the process is sequential and iterative. It is important to allow users to review the developments they have achieved so far and return to any stage of their design projects design if it is necessary and not just review the outcome at the final stage of the process [2].
- The existing schemes for the implementation of TRIZ do not give clear instruction or connection between each stage of the process and TRIZ tools. For example: if users follow Mazur's process to help in the use TRIZ, will they have to run through each of these TRIZ tools until the end of the project or just pick up one or two tools at each stage. In addition, once users obtain results through the use of certain TRIZ tools at a particular stage, it may not be obvious how they should deal with this result and take the design forward.

The examination of the literature on existing processes for the implementation of TRIZ identified that almost none of these processes involved the use of divergent and convergent thinking at each stage of the process. Mainly the processes just indicate tools or methods to be used but does not explicitly encourage practitioners to think broadly at first and then try to narrow down afterwards to generate the most suitable outcomes.

Some people, especially in the design profession, may argue that the use of a step- by-step process could not work in producing competitive and creative outcomes. However, some evidence has shown that a structured process is very useful to help generate creative ideas such as the use of Morphological Analysis [11]. In addition, the idea of using a structured process is also recommended by its effects. For example, a method of providing structured guideline was introduced by Zaltman and Higie [26]. This process, called the Zaltman Metaphor Elicitation Technique (ZMET), employs a personal interview to elicit the metaphors, constructs, and mental models that drive customers' thinking and behaviour.

In addition, a review of the literature shows that the use of creative problem solving process is generally agreed to be useful in helping generate solutions to design problems. The comparison, shown in Table 1, indicates that the CPS process has similarities with the design process which is performed phase by phase, but also explicitly involves the use of divergent and convergent thinking at each stage.

Furthermore, this research study examined existing TRIZ processes to see whether these processes have the same user advantages as the design process and the creative problem solving process or not. The findings are:

- Being able to sequence and iterate plays an important characteristic in the traditional design process. However, most TRIZ processes do not show the ability to allow users to adjust and return to the previous design stage whilst using them.
- Research has found that the use of divergent and convergent thinking can help users to solve design problems more creatively. However, convergent and divergent thinking are not currently emphasised explicitly in TRIZ processes and tools.
- Some TRIZ processes have been able to provide requirements at the stage of exploring design problems; defining design problems; concept design; evaluating ideas; and implementing. However, in these processes, they do not clarify the use of each of the TRIZ tools and its connection with what to do afterwards at the next stage. In addition, although, the use of ARIZ has provided a structured process of the use of TRIZ, many users founds it is difficult to apply for and is mainly used for solving complex problems.

Basing on these findings, it was decided to develop a process which is able to provide most of the advantages found so far through the literature reviews and comparisons.

3 THE BRIGHT PROCESS

The construction of a process incorporating TRIZ was based on helping designers better understand their design problems and more effectively solve these problems by the use of TRIZ. To provide designers guidance on which TRIZ tools could be used at each stage of the design process of their projects, a process has been developed called the BRIGHT process. BRIGHT is an acronym for Build the needs, Refine the problems, Identify the type of problem, Generate ideas, Handle and modify ideas, and Test and evaluate.

The structure of the BRIGHT process is built in six stages. The process, which is shown in Figure 4, covers the stages of building the needs; refining the problems; identifying types of problems; generating ideas; handling and modifying ideas; and, finally, testing and evaluating.

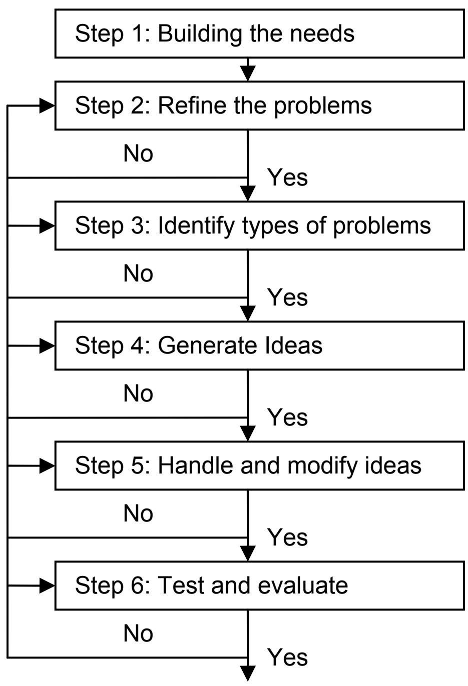


Figure 4: The BRIGHT process and associated iterative steps

The BRIGHT process is a sequential and iterative process which enables designers to assess problems and solutions at any stage of the process. Table 3 shows the structure and characteristics of the BRIGHT process which includes the design intentions, design methods and the use of TRIZ tools in order to more systematically and effectively help to solve problems and generate ideas. Significantly BRIGHT involves three additional steps in the design process. Normally designers know the traditional design process involves the stages of exploration (marketing), idea generation (creating) and evaluation (testing). However, the BRIGHT process not only includes these stages but also uses and emphasises "*Refining the problem*", "*Identifying the type of problem*" and "*Handling and modifying ideas*" into the process.

3.1 Rationale for the BRIGHT process

The reasons for emphasising the use of these three additional steps in the BRIGHT process to the traditional design process are listed below.

- Dorst and Cross [10] adapted other research results that had mentioned the defining and framing of a design problem is a key aspect of creativity in design.
- Normally, designers know that they have to find out the needs or problems which they are expected to solve. But analysis of the needs/problems and refining the problem and its core causes should render more effective problem solving.
- To understand the types of problems being faced would enable one to speed up and concentrate on finding a solution. For example, does the problem belong to the type of problem which is missing something in a Su-field diagram? Or it is a contradiction appeared and needed to be solved?
- The reason to handle and modify ideas before testing is because sometimes designers just stick with one or two ideas which they think are the most possible solutions without considering others. Using this additional step, designers would be able to modify and handle several ideas which are included in the most possible solutions by the use of 'Trends of Evolution' and its radar plot to mix the advantages into a final solution. Of course, this is not a new method but is just used to remind designers to consider the combination if there are more advantages from other ideas.
- Furthermore, as well as using ranking and discussion for selecting a solution, the BRIGHT process suggests testing and evaluation of the solution by asking whether the proposed final solution has overcome the 'Yes, but…' problems which were listed earlier at the stage of the ideal final result phase or not. In addition, designers are encouraged to ask that whether or not the final solution has caused another problem or contradiction to appear in the system.
- Finally, it is important to mention the principle to emphasise the use of divergent and convergent thinking at each stage of the BRIGHT process. Designers are encouraged to expand on the problem producing a multipliciticity of potential solutions and related ideas, possibility through the use of brainstorming [3] to generate more possibilities, and then to converge ideas to better solutions by using the TRIZ tools.

In addition, through the use of these three additional steps, this research makes the BRIGHT process become a more helpful, acceptable and systematic process to be used in conjunction with TRIZ. Furthermore, the use of symbols at each stage of the BRIGHT process also helps designers or process users to more easily understand and remember what they should do and direction they should focus on.

3.2 Implementation of BRIGHT

In the BRIGHT process, designers are encouraged to think broadly (divergent thinking) at first and then narrow down the possibilities (convergent thinking) at each stage and incorporate the use of TRIZ tools and other creative techniques such as Brainstorming and ask why five times.

In addition, there are three methods of using the BRIGHT process. These are shown in Figure 5. In a design project, designers can start by using one of these three methods to guide them and use TRIZ tools. However, it is important to emphasise that there is no strict rule to indicate which TRIZ tools have to be used at each stage of the process and how as this will all depend on an individual's preferences and experiences.

The following are the descriptions of these three methods of the implementation.

- **Method 1**: This is a straight forward method to use the whole of this six-stage BRIGHT process, step by step in order to generate solutions.
- **Method 2**: This method encourages designers to ask themselves questions such as shown in below in order to clarify which stage of the BRIGHT process to begin with. According to the situation the designers are facing, there is no specific question which must ask. The questions could be modified and adapted by designers and as suggestions these could be:
  - ❖ Do you understand the design problem(s)?
  - ❖ Have you clearly understood the core problem in the design project?
  - ❖ Do you know the type of problems you are facing? Are they contradictions? Are they the type of problems in the incomplete Su-Field Analysis?
- **Method 3**: This method is similar to the first but it is used at the end of each stage of the BRIGHT process to find out whether ideas to the design problem have been generated or not. If the answer is "Yes", designers can start to develop ideas further with some proper TRIZ tools such as Trends of Evolution or Ideal Final Result; otherwise, designers will have to continue the following stage of the BRIGHT process in order to clarify and narrow down their design focus and generate solutions to solve the problem.

3.3 The benefits of using the BRIGHT process

It is important to state that using TRIZ incorporating the BRIGHT process is not going to replace anything which people usually do in their design projects. The principle of TRIZ is to help designers quickly focus on the right direction for solutions. In addition, the use of the BRIGHT process is to help designers understand when to use TRIZ and which tools to use. There is no point in designers giving up what they have learnt, known, and have used at the moment.

During the use of the BRIGHT process, designers can still use other techniques to accompany the project. For example, people might still use a survey or even personally try out the product to help them explore any design problems. It is suggested that based on these methods, designers can still quickly use TRIZ tools to compare the results they have already have to see either they have missed any important design points, or even add more values into their ideas.

The advantage of emphasising the use of the iterative process within the BRIGHT process, which is shown in

Figure 4, is that designers can easily go back to any stage of the process in which they have identified a problem. By having this function in the process, designers do not have to run through the whole process but instead can just focus on the problem area.

From a psychological point of view, the creation of the BRIGHT process uses a simple step by step policy to encourage interest in TRIZ. By giving them small tips and guidelines, TRIZ could become a more acceptable and easy way to apply TRIZ to a design project. There is no doubt that the way to introduce TRIZ through a process would cut down on its original power. However, the search for a method to get more people pay attention to using TRIZ has been an on-going issue discussed over the last few decades.

The three methods given for the implementation of the BRIGHT process are examples of how it can be integrated in a design project. As this process is flexible and adaptable, designers can easily adapted it or even extend the ways of the use in their design projects. Designers do not really have to follow this process step by step if they have some ideas about what to do in their design projects, or they have got some ideas after running one or two steps of the BRIGHT process, they could always jump through other steps into the last one or two in order to test and evaluate their ideas. There is no strict policy that designers have to run each of the TRIZ tools which are suggested at each stage of the process. Designers can always choose and use any of the TRIZ tools which they are familiar or confident with. Sometimes designers may find that they could use just one or two TRIZ tools to help them build the needs, refine the design problems and also indentify the types of problems; therefore, the use of TRIZ tools is totally up to designers favourite and knowledge of TRIZ.

Furthermore, looking at those TRIZ tools at each stage of the BRIGHT process, people might start to question the criteria of choosing them. The criteria to choose each of these TRIZ tools was based on the understanding of these tools and personal experience; therefore, this can be a further work on researching whether these tools befit the occasion of each stage or not. Moreover, the use of these tools does not strictly mean that is the only way to use them. In fact, some tools even have the characteristics of supporting the use needs cross different stages of the process. Once designers are more familiar with these tools, they might choose to use one or two tools to run through the whole process with their knowledge and design skills.

Some TRIZ experts, however, might argue the use of this kind of process to be incorporated in associated with TRIZ will just reduce the power of its use. It is totally agreed that TRIZ is a powerful toolkit because that it contains many different types of tools which are used to solve different design problems. Designers or engineers can look at the kind of problems they are facing and then choose a suitable TRIZ tool to use. In theory, this is an ideal situation of using TRIZ; but many beginners could struggle with such a huge amount of information and then lose confidence when using it. Therefore, it is necessary to have a simple and clear guideline or process to help them know and understand when, which and where to start using TRIZ in their particular design project.

4 SUMMARY

The theory of inventive problem solving (TRIZ) is widely acclaimed by adoptees and in the academic literature. However, an apparent disparity exists between the low reported industrial take-up of TRIZ and perceptions in the TRIZ community which indicate more widespread use. It is thought that one of the main reasons for this is because of the perception that TRIZ is complicated and hard to use. For this reason, a procedure to be incorporated in association with TRIZ has been developed with the hope of making TRIZ easier to understand and use.

A review of TRIZ, design process and creative problem solving processes have been reported, showing differences in the emphasis on creative thinking and the use of iteration. The advantages of a procedure related to the aspects of usability, creative thinking and iteration within the TRIZ environment has been recognised and addressed by the development of a new process named BRIGHT. The new process addresses building the needs, refining the problem, identification of the type of problem, generation of ideas, handling and modification of the resulting ideas and testing and evaluation. In order to identify whether the BRIGHT process has significant benefits in design on-going research is underway.

REFERENCES

[1] Ahmed, S. S., 2005, "Analysis Management: TRIZ and Systematic Innovation - An Overview", The TRIZ Journal [E-Journal].

[2] Braha, D., and Maimon, O., 1998, "Design as Scientific Problem-Solving." A Mathematical Theory of Design: Foundations, Algorithms, and Applications, Springer.

[3] Campbell, B., 2003, "Brainstorming and TRIZ", The TRIZ Journal [E-Journal].

[4] Carvalho, M. A. D. and Back, N., 1999, “TRIZ Methodology and Its Use in Systematic Engineering Design”, Proceeding of XV Congresso Brasileiro de Engenharia Mecânica, Aguas de Lindoia.

[5] Changqing, G., Kezheng, H. and Fei, M., 2005, "Comparison of Innovation Methodologies and TRIZ", The TRIZ Journal [E-Journal].

[6] Chaturvedi, K. J., and Rajan, Y. S., 2000, "New Product Development: Challenges of Globalisation", International Journal of Technology Management, 19(7/8), 788-805.

[7] de Bono, E., 1996, “Teach yourself to think”, Penguin Books, London, UK, ISBN 0-14-023077-7.

[8] Domb, E., 1998, “QFD and TIPS/TRIZ”, The TRIZ Journal [E-Journal].

[9] Domb, E., and Miller, J., 2007, "The complete technical system generates problem definitions", Proceedings of TRIZ-Future Conference 2007, Frankfurt, Germany.

[10] Dorst, K., and Cross, N., 2001, “Creativity in the design process: co-evolution of problem–solution”, Design Studies, 22(5), 425-437.

[11] Goldenberg, J., and Mazursky, D., 2002, “Creativity in Product Innovation”, Cambridge University Press, Cambridge, UK, ISBN 0-521-80089-7.

[12] Hudson, L., 1967, “Contrary Imaginations; a psychological study of the English Schoolboy”, Penguin, Harmondsworth.

[13] Isaksen, S. G. and Treffinger, D. J., 1985, “Creative Problem Solving: The Basic Course”, Bearly Limited, Buffalo, New York, ISBN 0-943456-05-3.

[14] Isaksen, S. G., Dorval, K. B., and Treffinger, D. J., 1993, “Creative Approaches to Problem Solving”, Third Test Edition, Buffalo, New York.

[15] Mann, D., 2002, “Hands-On Systematic innovation”, CREAX Press, Belgium, ISBN 90-77071-02-4.

[16] Mann, D., 2007, "Systematic Innovation." Beginner Level Workshop, IFR Press, Clevedon, UK.

[17] Mazur, G., 1996, "Theory of Inventive Problem Solving (TRIZ)", http://www.mazur.net/triz/ accessed on November 2005.

[18] Osborn, A.F, 1953, "Applied Imagination", Scribner's, New York.

[19] Parnes, S. J., Noller, R. B., and Biondi, A. M., 1977, "Guide to creative action", Scribner's, New York.

[20] Rantanen, K. and Domb, E., 2002, "Simplified TRIZ: New Problem-Solving Applications for Engineers and Manufacturing Professionals", St. Lucie Press, Boca Roton, ISBN 1-57444-323-2.

[21] Roonzenburg, N. F. M., and Eekels, J., 1995, "Product Design: Fundamentals and Methods", John Wiley & Sons Inc. ISBN 0-4719-5465-9.

[22] Sefertzi, E., 2000, "Creativity", Report produced for the EC funded project called "INNOREGIO: dissemination of innovation and knowledge management techniques", Stockholm School of Economics in Riga.

[23] Soderlin, P., 2002, "TRIZ the Simple Way." The TRIZ Journal [E-Journal].

[24] Stoll, H. W., 1999, "Product design methods and practices", Marcel Dekker, New York, ISBN 0-8247-7565-1.

[25] Straker D. and Rawlinson G., 2002, "*How to Invent (Almost) Anything*", Spiro Press, London, ISBN 1-904298-87-7.

[26] Zaltman, G., and Higie, R. A., 1993, "Seeing the Voice of the Customer: The Zaltman Metaphor Elicitation Technique." Marketing Secience Institute.

CONTACT

Shuo-Kai Tsai
University of Sussex, Brighton
East Sussex, BN1 9QT, United Kingdom
E-mail: s.k.tsai@sussex.ac.uk
Phone: +44 (1273) 876708
FAX: +44 (1273) 678486

Peter R.N. Childs
University of Sussex, Brighton
East Sussex, BN1 9QT, United Kingdom
E-mail: p.r.n.childs@sussex.ac.uk
Phone: +44 (1273) 678793
FAX: +44 (1273) 678486

Design Process / CPS Process	Establish the Needs	Analyse the Problems	Generate Ideas		Evaluate the Solutions	Implementation
			Conceptual Design	Detailed Design		
Osborn-Parnes' CPS Model	Objective Finding and Fact Finding	Problem Finding	Idea Finding		Solution Finding	Acceptance Finding
de Bono's "TO LO PO SO GO"	TO	LO	PO		SO	GO

Table 1: Comparison of the traditional design process and the creative problem solving process

Design Process / TRIZ Process	Establish the Needs	Analyse the Problems	Generate Ideas		Evaluate the Solutions	Implementation
			Conceptual Design	Detailed Design		
Mazur (1996) [17]	*Problem's engineering system *Its operating environment *Resource requirements *Primary useful function *Harmful effects *Ideal result	Restate the problem in terms of physical contradictions	Through 39 parameters decide which parameter has to be changed	* Search the contradiction matrix * Find a solution through 40 inventive principles	-	-
Domb (1998) [8]	*Functional Analysis *Ideal Final Result *Resources *Locate the zone of conflict		*Principles *Predictions *Effects		Yes, but no details on how to do it	-
Carvalho and Back (1999) [4]	* Correctly formulate problems	* List all system requirements * Analyse	* Engineering parameters * Inventive principles		-	-

	* Verify the system according to the laws of evolution * Find available resources Find contradictions	paired requirements			
Mann (2002) [15]	*Problem Explorer *Function Analysis *S-Curve Analysis *IFR		*Contradictions *Trends *Su-Field Analysis *Trimming *Psychological Inertia (PI) tools *IFR *ARIZ	*System Operator *PI Tools *Multi-criteria decision analysis *Pugh concept selection *Axiomatic Design	-
Rantanen and Domb (2002) [20]	*Tool-Object	*Contradictions *Resources *IFR	*Inventive Principles *Patterns of Evolution	-	-
Soderlin (2002) [23]	Situation Analysis: How to find the problems (to solve with TRIZ)? What is the problem? (Getting acquainted). Function Analysis. Setting the target: Mini or Maxi? The Approach or which route to choose?		Different routes and uses of TRIZ tools	IDEATE > SCREEN > IMPLEMENT > VERIFY ("Tricks", STC, MMD, Trimming, etc available in subsequent "Route")	
Straker and Rawlinson (2002) [25]	*Resources *Parameters *Benefits		*Ideality *Evolution *Trends *Contra-dictions	-	Resources
Ahmed (2005) [1]	→System→Sub system→Component→Function→ Parameter→		40 principles or 76 solutions	**Transform**: Solutions→ Usable form	**Convert**: Usable form→ Product/ Process/ Invention
Changqing et al. (2005) [5]	-	* 39 Parameters *Altshuller's Matrix * Su-field Analysis * ARIZ * 76 Standard Solutions * Patterns of Evolution	* 40 Inventive Principles * Altshuller's Matrix * 76 Standard Solutions * Effects and Examples * ARIZ	* 39 Parameters * Altshuller's Matrix * Su-field Analysis * ARIZ * 76 Standard Solutions * Patterns of Evolution	-
Domb and Miller (2007) [9]	-	*Complete Technical System	*System Operator -	-	-
Mann (2007) [16]	*Self-asking questions *IFR		*Contradictions *Function Analysis *Trends *Trimming *Knowledge (patent)	-	-
In this table, the use of "-" means that this aspect might not have been considered or specified.					

Table 2: Comparison between the traditional design process and existing schemes for the implementation of TRIZ

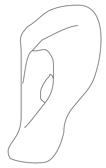
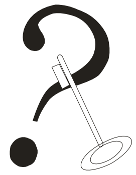
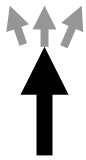
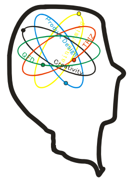
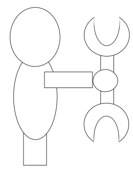
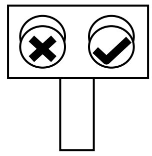
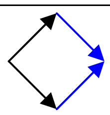
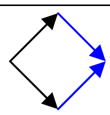
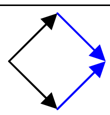
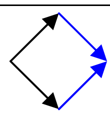
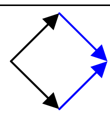
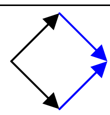
Stage	**B**uilding the needs	**R**efine the problems	**I**dentify types of problem	**G**enerate ideas	**H**andle and Modify Ideas	**T**est and Evaluate
Iterative Process		No	No	No	No	Yes
Symbol						
Intentions	• Build user needs. • Understand users' habits, life style, etc.	• Translate needs into desig specifications • Discover design problems	• Find out the types of contradictions • Decide which to focus on would be more suitable	•Generate alternative solutions	• Modify ideas • Combine different components into a better solution	• Evaluate • Try out Prototyping • Implement • User-friendly
Suggested TRIZ tools	• Ideal Final Result (IFR) • System Operator	• Su-field Analysis • Function Analysis • Trends of Evolution	• Problems on the incomplete Su-field • Physical Contradictions • Technical Contradictions	•Contradiction matrix • 40 Inventive Principles • 76 standard solutions • Resources	• Resources • Trimming • Trends of Evolution	• Ideal Final Result • System Operator • Has it been solved "yes, but" questions?
Design Thinking						
	: Divergent thinking phase : Convergent thinking phase					

Table 3: The BRIGHT process

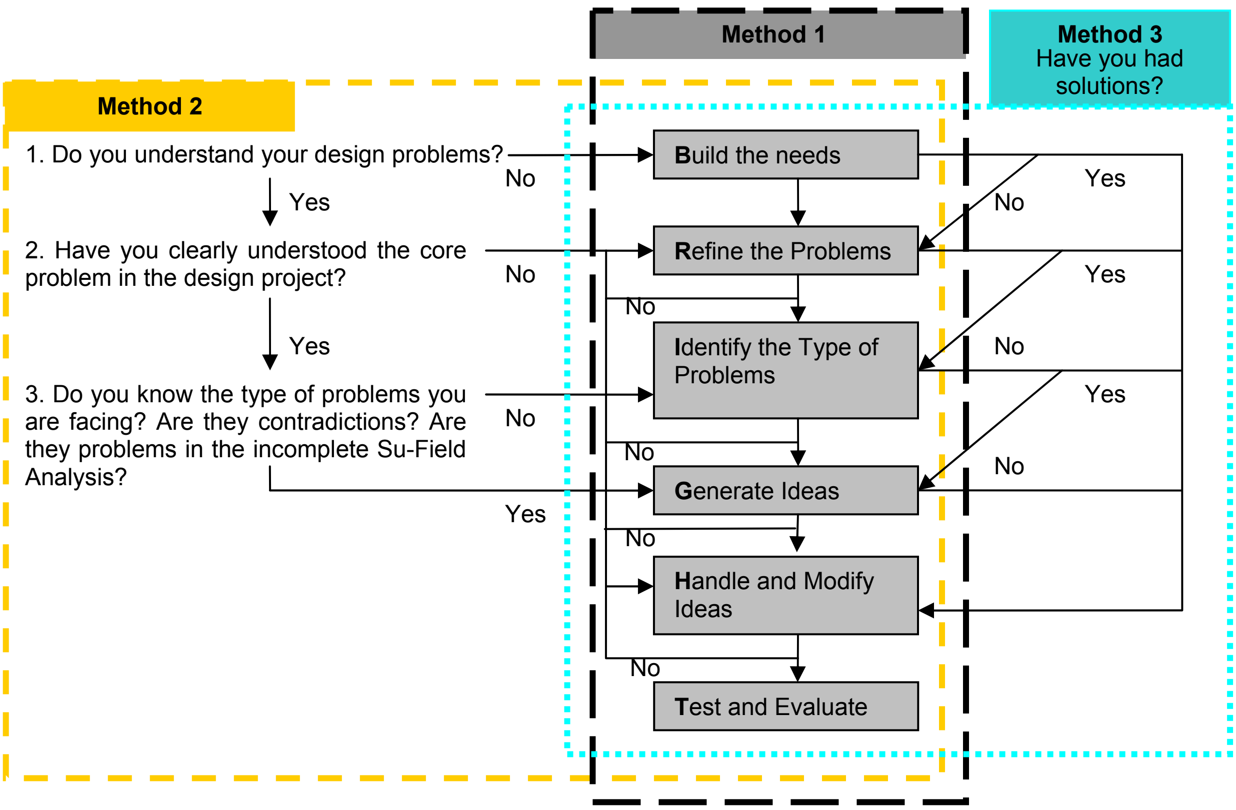


Figure 5: Three example methods of using the BRIGHT process in a design project

A Study on Pointers to Effects for Non-technical Problem Solving

Hongyul Yoon
TRIZ Center, South Korea

Abstract

Most of TRIZ thinking tools can help us to solve non-technical problems. However, the efficiency and effectiveness of TRIZ for solving those problems seem much lower than used for technical problem solving. Absence of pointers to effects for non-technical problem solving should be one of the main causes of that. Non-technical problem solving requires some effects that are different from those based on physical science and engineering technology. In order to develop some pointers to effects for non-technical problem solving, the structures and meaning of ‘function model’ and ‘effect’ were discussed. Based on the discussion, some pointers to effects were proposed for non-technical problem solving.

Keywords

TRIZ, Pointers to Effects, Non-Technical Problem, OTSM, Function Model, ENV

1 INTRODUCTION

Recently, not only technical problem solving but also non-technical problem solving has been successfully achieved with the thinking tools of TRIZ. In this paper, ‘non-technical problem’ means some problems which cannot be solved through application of physical, chemical, geometrical, and biological knowledge or technological knowledge based on physical science. The author has been running some on-site training courses to generate new market ideas or new technology ideas through TRIZ tools based on OTSM[1]. The participants told the thinking ways of TRIZ and OTSM helped themselves to systematize their own thinking processes beyond their expectation. That favorable response seemed to come mainly from the use of abstract problem models and solution idea models of TRIZ and OTSM. OTSM leads us effectively to transform a complex and non-typical problem situation into a set of simple and typical problem models. Almost all of the abstract models for thinking offered by TRIZ and OTSM guide us very well to solve non-technical problems as they do for technical problem solving.

However, the author found the efficiency and effectiveness of TRIZ tools are much lower in non-technical problem solving than in technical problem solving. Some people showed difficulty in coming up with ideas after getting the clear understanding of the solution models offered by TRIZ. Others took more time to get effective ideas compared to those who tried to solve technical problems.

The causes of those points required deeper examination. One of the causes was checked through the following discussion.

Based on OTSM viewpoint, the process of inventive problem solving could boil down to two main stages [2];

1. problem model transformation from a complex and non-typical situation into a set of simple and typical problem models
2. application of typical abstract solution models of the human being including those of TRIZ

In technical problem solving, to get solution ideas from typical solution models of TRIZ, we need knowledge of materials, several types of energy, and influences of energy transmission. Even if we get the simple and typical problem and solution models in OTSM viewpoint, we cannot get a solution idea without scientific knowledge related to the model. It could be a good explanation of the fact to examine the application of inventive standards to idea generation for technical problem solving.

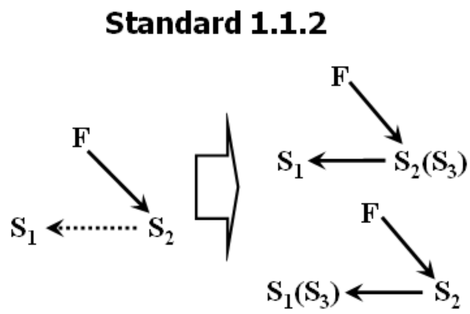


Figure 1: a simple and typical model case

In Figure 1, the solution model recommends us introduction of a new substance into the tool or the object. We can imagine what will happen if a certain additive is introduced ‘according to our scientific knowledge’. If someone has no knowledge even a bit on the physical nature of the world, he or she would be hardly able to propose a solution idea with some confidence. As the methodology helping with problem solving, TRIZ offers the way to overcome the shortage of scientific and engineering knowledge. The scientific knowledge itself doesn’t belong to the realm of TRIZ. TRIZ gives us the efficient way to adopt the scientific knowledge. The way is called as ‘pointers to effects’ [3]. An effect is a ‘TRIZ-version’ equivalent of a certain scientific law, principle, or engineering knowledge.

The pointers to effects help solvers in technical problem field. Even though the solver has little scientific knowledge, the pointers to effects of TRIZ give him or her helpful clues and directions on the required knowledge. The pointers to effects of TRIZ activate the abstract solution models like inventive standards in a solver’s mind. Main ideas of pointers to effects often lead solvers more comprehensive understanding of familiar scientific knowledge.

Likewise, those who try to apply TRIZ to non-technical problem solving need some kind of pointers to effects. They might not have enough knowledge required to activate the abstract solution models provided by TRIZ. Sometimes, they depend on very wrong subjective thoughts against objective knowledge to result in some irritating ideas against their wishes. For those reasons, many TRIZ learners for non-technical problem solving have required ‘Pointers to Effects’ for them. This paper was prepared to fulfil the request.

2 PRAGMATIC REQUIREMENTS OF POINTERS TO EFFECTS IN NON-TECHNICAL PROBLEM SOLVING

The pointers to effects in classical TRIZ are formulated as the matching of a certain technical function and some physical, chemical and geometrical effects adopted to deliver the function in which an effect could be translated into a pair of 'input action' and 'output action' (or the resultant change) of an object (a resource) [4][5]. That is depicted as shown in Figure 2.

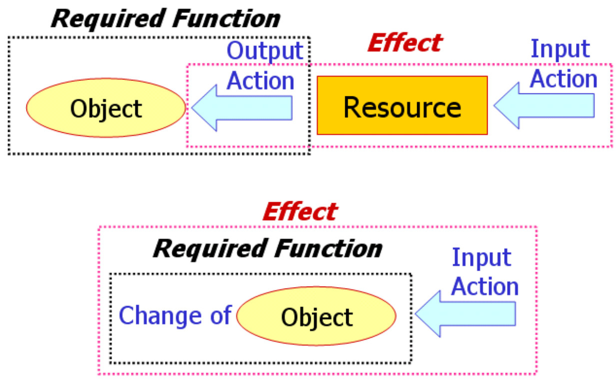


Figure 2: General structure of 'a pointer to effects'

The similar structure could be kept for the pointers to effects for non-technical problem solving.
Before developing those kinds of pointers for non-technical fields, a question seems to lie in front of us;
What are the requirements for the pointers to effects to provide efficient use?
This question looks too big to be answered completely in this first stage paper. The author will try to discuss it in only two aspects.
First, we will examine how to formulate 'function model' for efficient use of the pointers to effects.
Second, we will discuss what kinds of effects are needed for non-technical problem solving.

2.1 'Function model' as a problem model

The pointers to effects are not always helpful to problem solving.
Actually, 'A function' as a problem model must be formulated correctly in order to use the points of effects efficiently. The usefulness of the pointers to effects is from the matching of a function and some effects but depends on the correct formulation of the problem.
Generally, 'a problem' could be defined as 'a situation in which the current state of the target object is different from its' state of what I want'. In this case, 'a solution' is defined as 'how to eliminate the difference between two states of the target object' or 'to change the current state of the target object to the desired state of it'.
The above descriptions can be translated into ENV modelling of OTSM.
'A problem' ; there is a difference between the current value and the required value of a certain property of the target object. 'A solution' : the way to change the value of a certain property of the target object from the current to the desired.
After identifying the problem situation according to the above descriptions, we can search the knowledge required to change the target object. In order to do so, if we use the pointers of effects offered by classical TRIZ, 'function model' is adopted as a guide to search the proper knowledge.
'Function' is defined as 'Action + Object in which the action must change the state of the object'[5]. OTSM defined it more precisely as 'Change (increase, decrease, …) + Value of a Property of an Object'.
According to the above discussion, we can draw two descriptions of function modelling;

1. 'Function' is formulated as 'Action + Object'
2. 'Function' is formulated as 'Change (increase, decrease, …) + Value of a Property of an Object'

where 'Object' corresponds to 'the target object' in the general definition of a problem and a solution. If we hope to avoid any confusion with the meanings of words, the second formulation could be better for us to get the clarified meaning than the first.
Figure 3 presents schematically the above discussion. Through abstraction of a real problem situation, we get a function model as a general problem model. The pointers to effects lead us to map the function model to some effects as a solution model.

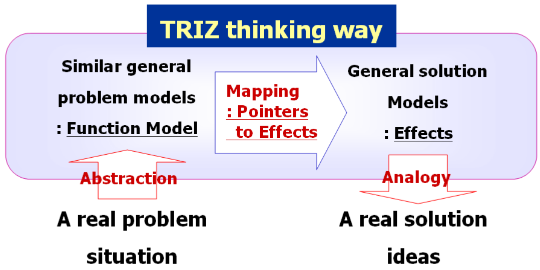


Figure 3: Relationship between 'function model', 'pointers to effects' and 'effects' in TRIZ thinking way

Therefore, in order to use the pointers of effects efficiently, the property of the target object in the function model must be one of physical, chemical or scientific parameters. The author's experiences have shown that not a few TRIZ beginners formulate functions as ones including performance parameters. Performance parameters like productivity, efficiency, device complexity, etc are not suitable for the property described in a function model for use of pointers to effects. The performance parameters are determined not directly by some scientific laws but by how a certain technical system operates with scientific laws. For example, if we want to increase the productivity of our chemical process, the function model, 'to increase productivity' is not matched with certain scientific effects as solution models. Before checking the pointers to effects, we have to examine how the required functions are performed and what kinds of losses are happening in our specific process. The working way of a certain technical system belongs to a certain particular case. The productivity of a certain process depends on the way that our certain process as a particular case performs with physical, chemical effects. If you want to improve performance parameters of an object, you should analyze the object first, and then formulate function models to map them to physical, chemical, geometrical parameters through the pointers to effects.
When beginners treat non-technical problems with TRIZ, they often make the same mistakes as in technical problem solving. They formulate a problem as a function which has performance parameters like 'to reduce total cost', 'to increase revenue', 'to increase productivity', etc. Those performance parameters are caused by a specific situation. Before searching abstract and general solution models, above all, they must be dealt with analytic tools like multi-screen thinking, function analysis, and root conflict analysis, etc.

Only if a solver formulates function models according to the above explanation, the pointers to effects serve helpfully. From the above discussion, the author derived necessary conditions of function modeling for effective use of the pointers to effects for non-technical problem solving.

1. The function model should be formulated as 'Change (increase, decrease, etc) + Value of a Certain Property of an Object' or 'Action + Object' in which the action must change the state of the object.
2. The property mentioned in the function model of a pointer to effects should not be a kind of performance parameter which mainly depends on a specific condition and then needs deeper analysis of the condition.

2.2 'Effect' as a solution model

The definition of 'effect' in classical TRIZ terminology could be put like below.
An effect is a relationship of input action(input influence) and output action(the resultant change) of an object(a resource), which is governed by a certain principle of physical, chemical or geometrical viewpoint.
An effect as a tool of classical TRIZ shows the change of an object when we give a certain influence on it. It says about the change of a certain object governed by an objective principle like scientific ones. In order to extend the concept of 'an effect' in classical TRIZ up to non-technical problem solving, the governing principles in it must be replaced by principles in non-technical solution fields.
Therefore, more generalized definition of 'effect' could be like below.
An effect is a 'relationship of input influence and resultant change of an object, which is governed by a certain objective principle.
When examining the principles in non-technical fields, the author has taken the following points as criteria for selection as effects for TRIZ application.

1. The principle must be as objective as possible.
   For example, the principles as advice given by so-called gurus in economics and management were excluded. Some people say, "The smarter employees you have, the more effectively you run your own company". Is that proven through objective experiments and analyses of them? If not, that must not be included in the pointers to effects for non-technical problem solving.
2. The principle must say something about the input influence and resultant change of a certain object.

In non-technical problems, if objective principles about animals and plants are considered to belong to biological knowledge, the author has not yet found any other kind of non-technical principles except the ones in which the target object is a person or people. If we examine the non-technical principles precisely, we can realize that they say about the change of a certain feature of a person or people through non-technical influence. For example, 'the law of demand' as one of economic principles could be discussed. That states that quantity demanded is inversely proportional to price, that is, 'the higher the price of the product, the less the customers will demand'. That is not about the change of a single object caused by an input influence on it. Figure 4 shows more detail steps of it as a process. There are at least three objects mentioned in that principle. First, the sellers change price of goods. Second, any kind of signs like price tags are renewed to inform persons. Finally, buyers are changed with awareness of negative incentive, or 'higher price'. They get lower demands about the goods. According to this analysis, 'the law of demand' could be a non-technical effect to solve the problem of 'how to decrease the value of the demand of people'. That means it is for human-targeted problem solving.

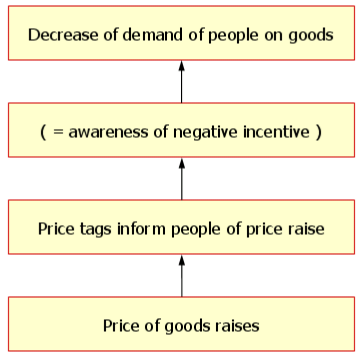


Figure 4: a deep analysis case in a non-technical field

As far as the author's 'up-to-the-present' study is concerned, non-technical principles belong to human-targeted effects if biological principles are excluded. Hence, the pointers to effects introduced in this paper will be composed of human-targeted effects.

3 POINTERS TO EFFECTS FOR SOLVING HUMAN-TARGETED PROBLEMS

Some information on psychology, economics, and marketing, etc were examined in order to pick up the non-technical principles [6][7][8][9][10][11].
Those which have no relationship of input influence and resultant change were abandoned as discussed before. After collected, the principles as effects were classified according to people's property which is changed by them. They could be explained as one sentence, 'People respond to incentives'. It must be put the accent on that the list of pointers to effects introduced in this paper is just the first one, which must be renewed if we get new non-technical principles.
In Table 1 the 'what I want' column shows only the changed properties without comments that the properties belong to a person or people.
The use of the table is the same as for the table of the pointers of effects in technical problem solving.

1. Formulate your problem as a function model.
2. Find the functions corresponding to your function model from the table.
3. Examine the effects matched to the functions.
4. Generate solution ideas according to the matched effects.

These pointers could help application of inventive standards to non-technical problem solving. Instead of 'MAThChEM', these effects could be used for non-technical problem solving.

A simple example of how to use the table is as follows;
In 'Country A', a supermarket intends to sell some fruit imported from 'Country B' which people of 'Country A' hate. People dislike goods from 'Country B'. However, the manager of the supermarket wants to sell the fruit as much as possible because of the high profit. What should she do?

First of all, we try to formulate some function models. If the manager decides to sell the imported fruit, the problem can be formulated as below;
Problem Model 1; I want to decrease the value of the

negative attitude of people to the fruit imported from the hated country.
You can find the similar function model from the pointers to effects, 'to weaken the negative attitude'
The corresponding effects are as follows;

- mere-exposure effect
- ritual effect

Problem Model 2; I want to increase the value of the positive attitude of people to the fruit itself.
In this case, she should pick up a different one, 'to intensify positive attitudes'. She can try to get ideas with more than ten effects.
This problem could be attacked with inventive standards. The pointers to effects would serve ideas on 'field'.

4 SUMMARY

Based on a precise look into the pointers to effects of classical TRIZ, the guide of development of pointers to effects for non-technical problem solving was proposed. The function model as part of pointers to effects should be formulated 'Change (increase, decrease, etc) + Value of a Certain Property of an Object' or 'Action + Object' in which the action must change the state of the object. The property mentioned in the function model of a pointer to effects should not be a kind of performance parameter which mainly depends on a specific condition and then needs deeper analysis of the condition.
The generalized definition of 'effect' was suggested like below.
An effect is a relationship of the input influence and resultant change of an object, which is governed by a certain objective principle.
The author suggested that the target object in most non-technical problems be a human being. Some pointers to effects related to human-targeted principles are classified and proposed to help the idea generation for non-technical problem solving. These pointers to effects must be updated as new non-technical principles are offered.

ACKNOWLEDGMENTS

Sincere gratitude must be given to Nikolai Khomenko and Valeri Souchkov for their valuable advice while I thought about the theme of this paper. However, all faults and mistakes in this paper belong to the author.

REFERENCES

[1] Khomenko N., "OTSM training handout set", 2000, LG Electronics

[2] Yoon H., "TRIZ advanced course", 2004, POSCO

[3] Salamatov Y., "TRIZ: The Right Solution at the Right Time", 1999, published by Insytec B.V.

[4] Souchkov V., "Annotated list of TRIZ techniques", January 1998

[5] Arel E., Verbitsky M., Devoino I., Ikovenko S., "TechOptimizer Fundamentals", 2002, published by Invention Machine Corporation

[6] Mankiw N., "Principles of Economics", 1997, published by Dryden Press

[7] Cialdini R., "Influence", 2001, published by Allyn & Bacon

[8] Kotler P., Armstrong G., "Principles of Marketing", 8th ed., 2006, published by Pearson Education Inc.

[9] Zimbardo P., Weber A., Johnson R., "Psychology", 2000, published by Allyn & Bacon

[10] Park J., "유쾌한 심리학", 2006, published by 파피에

[11] Thaler R., "Behavioral Economics", from the site,
www.iies.su.se/nobel/papers/Encyclopedia%202.0.pdf

CONTACT

Hongyul Yoon
TRIZ Center,
Poonglim 2nd Apt, 102-#104, Hongeun1-dong, Seodaemun-gu, Seoul, 120-761, South Korea

www.trizcenter.co.kr/eng/ (in English)
www.trizcenter.co.kr (in Korean)

E-mail: hongyul333@empal.com

Phone: +82-19-288-2746

What I want		Effect	Input Influence
To intensify	Cognition	Effect of Moderately Incongruity	Moderately incongruous information
		State/Field-dependent learning	Signals reminding related states/fields
	Positive attitude	Bandwagon effect	Sales information on others' positive purchase
		Context effect, Primacy effect, Printing effect	First information on good points
		Demonstration effect	Informing on relatively higher classes
		Framing effect	Change of the description frame
		Halo effect	Explicit merit/attractiveness
		Hawthorne effect	Care/consideration
		Priming effect	Stimulus on a certain good experience
		Profess effect	Profession event
		Pygmalion effect	Positive encouragement/expectation
		Ritual effect	Change of usual interactions
		Romeo & Juliet effect	Cognitive dissonance
		Sunk cost effect(=Concorde effect)	Investment of money/ time/endeavor
	Liking	Expectancy-value theory	High probability of success
		Matching principle	Informing on similarity
		Mere-exposure effect	Frequent exposure/contact
		Need-complementary hypothesis	Informing on difference of need
		Priming effect	Stimulus on a certain good experience
	Tendency toward risk	Extremity shift/polarization	Circumstance change

What I want		Effect	Input Influence
To weaken	Cognition	Tunnel vision phenomena	Emotional irritating
		Stroop effect	Signals arranged for involuntary attention
	Negative attitude	Mere-exposure effect	Frequent exposure/contact
		Ritual effect	Change of usual interactions
	Positive attitude	Context effect, Primacy effect, Printing effect	First information on bad points
		Crespi effect	Reward much less than current one
		Devil effect (=Negative halo effect)	Informing on explicit demerit/ugliness
		Framing effect	Change of the description frame
		Inoculation effect	Persuasion message weaker than a threshold
		Priming effect	Informing on a certain bad experience
		Ripple effect	Blaming some other colleagues
		Snob effect	Sales information on others' positive purchase
	Tendency toward risk	Extremity shift/polarization	Circumstance change

Table 1: Table of some pointers to effects for non-technical problem solving

Poster Presentations

A Computer-based Problem-solving Assistant for Su-Field Analysis

D. Daniel Sheu and David Lee
Dept. of Industrial Engineering and Engineering Management
National Tsing Hua University, Hsinchu, Taiwan

Abstract
The substance-field analysis with inventive principles is one of the more difficult and less used TRIZ tools although it is reported as among the more likely tools which can generate breakthrough results. The difficulties primarily lie in 1) the correspondence between the initial su-field model (ISM) and the appropriate solution in inventive standards; 2) the difficulty in automating the establishment of the ISM and the Desired Su-field Model (DSM). The paper established a new coding and su-field based problem solving scheme allowing automatic generation of ISM in coded form, intelligent identification of possible corresponding standards, and allowing users to select identified standards and generate solution trigger DSM automatically.

Keywords
TRIZ, substance-field analysis, coding, inventive standards

1 CONTENT
The su-field model has been used to model the core conflict of any engineering model. At the heart of a mini-mum core conflict, its su-model can be represented by a field, two substance, and interaction(s) between the two substances. The research established a coding scheme to fully model the core conflict as (S1, S2, F, A; PC).

Where:

S1=0 or 1; S2=0 0r 1 to indicate the existence of the substance 1 and 2 respectively;

F : encodes the various type of fields including no-field situation.

A: represent the type of action between S1 and S2;

PC: encodes the various problem solving constraints, such as permissibility of adding a substance, field, etc.

By doing so, it is possible to clearly represent any core conflict and solution constraints by a set of the codes. This is the problem array in the su-field model. For each problem array, we can use know standard-searching process such as those used by Savransky, Fey, or Mann to locate its corresponding inventive standards for possible trigger solutions. Since there are finite number of problem array representations, it is possible to locate the solution standards in advance and encode them in a computer program. At the time of usage, the user only needs to select the value of the problem array and put the values into the computer program, the computer program can return the appropriate inventive standard(s) instantly. The system is an Excel-based intelligent problem-solving assistant for su-field analysis. Upon identification of solution triggers, the system will also provide ample examples to aid human generation of specific solutions given the solution triggers. It will enable a novel user to quickly generate solution triggers without detail knowledge of the su-field knowledge and laborious manual exercise.

Author profiles
Dongliang Daniel Sheu graduated from National Taiwan University with a B.S.M.E. degree in 1977. He received an M.S.M.E. degree from State University of New York at Buffalo in 1983. He received his second master-level degree from UCLA in 1987 focusing on computer science. He also received his master of management (MBA) degree from Kellogg Graduate School of Management at Northwestern University in 1994. Prior to joining National Tsing Hua University in 1996, Daniel has 9 years of industrial experience primarily in the electronic industries and with Hewlett-Packard, Motorola, and Matsuchita. His areas of interests include systematic innovation, design & manufacturing management,

semiconductor equipment management, and factory diagnostics. Daniel is the former Secretary General of Taiwan TRIZ Association and the founder and President of Society of Systematic Innovation in Taiwan.

David Lee graduate from The department of Industrial Engineering and Engineering Management at National Tsing Hua University in 2008. He is currently in the military service.

Lessons learnt in the introduction of TRiZ at IBM Corporation, aka "personal giveback to the community on my '*knowledge spiral*' pragmatic way to learn, teach and practice with busy professionals."

Pascal Sire[1, 2]

[1]IBM Software group, Global Innovation Catalyst

[2]2007 Advanced Master in Innovative Design, INSA Strasbourg [1]

Abstract

Since the beginning of 2006 when IBM Corporation launched its "Innovator's Innovator" campaign, it became obvious that the company needed to train a lot of professionals in a more structured way to help their clients to innovate, but it was also rapidly clear that these professionals were lacking in time and availability to be properly educated through a lengthy program, on top of existing methods and well-known tools, not only for project management and architecture design but also for creativity and innovation …

What should be done?

Pragmatically the author proposed to keep the ideal final result to have professionals (executives, managers, sales, or technical specialists, architects, experts in R&D labs) trained in TRiZ fundamentals with enough practice, while keeping in mind the minimal amount of time available to them, achieved through a step-by-step fully completed set of modules, from the overview of concepts and techniques to a deeper understanding of methods and tools…

This poster session will focus on this "*knowledge spiral*" acquisition way to learn, teach and practice with busy professionals, and extract some lessons learnt from these 2 years of experience, building an internal community of 600+ colleagues including awareness for 300+ and basic level for a few dozens, and advanced level for a few ones practicing in their daily jobs.

Keywords

TRIZ, Thinking Skills, Problem Solving Skills, Creativity, Model, Innovation, Teaching, Methodology, Reference, Training, Expert, Patents, Case Studies, knowledge spiral.

1 KNOWLEDGE SPIRAL & 4-PHASE PROCESS

Most colleagues were surprised not to jump directly to the solution search, mainly due to their education… Now, the "*knowledge spiral*" approach is their time-keeper!

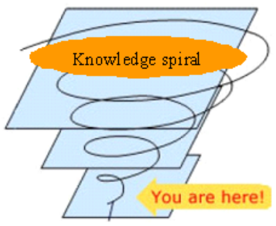


Figure 1: Knowledge spiral

Within each step of the spiral, progress & apply the standard 4-phase process.

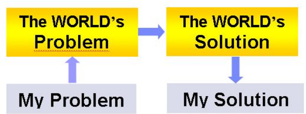


Figure 2: 4-phase process

2 TRIZ CONVERGENT PROCESS WITHIN SPIRAL

Reduce the *search area* and break the *mental inertia* to discover the *main contradictions* to solve and (re)use *available (free) resources* towards the *ideal final result*).

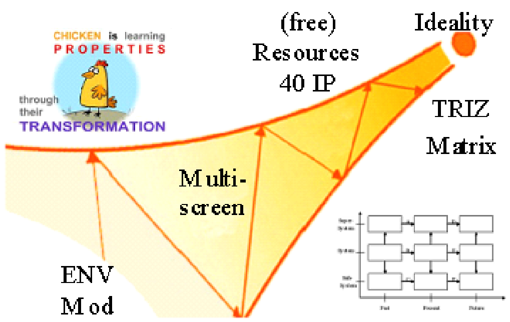


Figure 3: TRiZ convergent process, including the E-N-V model (entity-name-value) [2], Chicken learning properties [3], Multi-screen [1], and the 40 IP (Inventive Principles)

3 LESSONS LEARNT

How do you build your "innovative design community" without any official support, even if you feel it is right in the "strategic direction"?

Here is some advice from my own experience:

- Catch every opportunity of communication and support; always reply to your first fans; they truly are your best inside "sales persons" and free marketers!

- Expand the "fans network" endlessly while giving as much as you can; not only documents, links, advice, calls and e-mails, but also time, time and even more time;

- Keep confident even if the task seems really superhuman; you are not alone, other pioneers succeeded in the same "dry environment".

4 REFERENCES

[1] Master's Degree Specializing in Innovative Design (Advanced Master in Innovative design, AMiD)

[2] Jonathan Livingston Project - OTSM-TRIZ [ru]

[3] Multimedia for teaching kids - *Chicken and the Universe*

[4] TRIZ France [fr] French TRIZ Association

[5] ETRIA - European TRIZ Association

5 CONTACT

Pascal Sire - IBM Software Group, Strategic Alliances

E-mail: pascal.sire@artsindustries.com

Internet AMiD site: www.TRiZ-iD.net

"If nothing changes, nothing changes," Nick Donofrio, IBM Corp Executive VP, Innovation and Technology.

Design Adjustable Length Bus Duct Joint Kit using TRIZ

Young Joon Ahn, Yong Taek Park, Pyeong Kwan Chung, Dong Wook Kim

Abstract

Bus ducts are similar to cables in that both have conductors and isolators. The greatest advantage of bus ducts is that they can transmit a great amount of electric energy to a conductor of the same volume. Bus ducts are becoming increasingly popular since their merits in high capacity electric systems are emphasized. However, sometimes length of the bus duct is rather short or long when installing bus duct system if dimension of the building was not measured correctly. In this paper, some solution concepts which were derived by TRIZ will be presented.

Key words: Bus duct, TRIZ, Joint Kit

Young Joon Ahn
Production Engineering Center
Research Engineer
ahnyj@lscable.com

Yong Taek Park
Production Engineering Center
Research Engineer
parkyt@lscable.com

Pyeong Kwan Chung
Production Engineering Center
Principal Research Engineer
pkchung@lscable.com

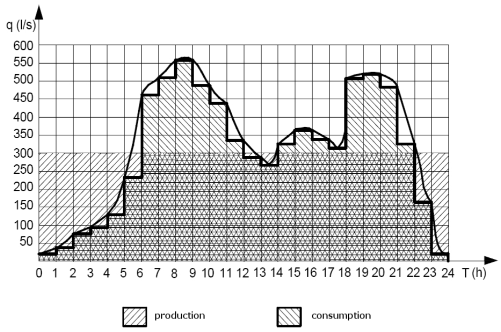
Dong Wook Kim
R&D Center
Principal Research Engineer
dwkim1@lscable.com

SZÉCHENYI ISTVÁN UNIVERSITY – GYŐR, HUNGARY
Interdisciplinary Doctoral School of Engineering, Modelling and Development of Infrastructural Systems
Baross Gábor Institute, Department of Logistics and Forwarding

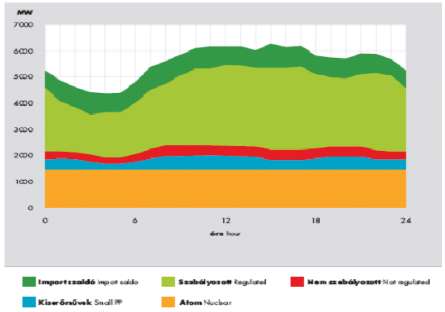
LEAN/AGILE LOGISTICS SYSTEMS IN WIRE SUPPLY

Péter Bajor (PhD-Student), Széchenyi University, Győr, Hungary
5-7 November 2008

following the fluctuation of consumer demand - "super-pull" water and electricity supply systems
the role of system operator – centralized, automated, self-driven processes
distances in time and in space – sources, networks, drains with different type of characterisitcs
oversized infrastructure - constructing for the peak demand, eliminate the possibility of shortages



Protective inventory
oversized water towers and reservoirs
(100% in reservoirs, 200% in water towers – Győr, HU)



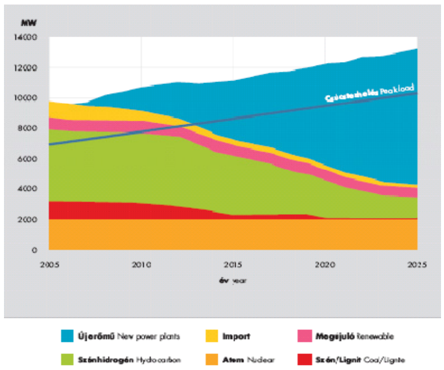
Protective capacity
generation units with different
cost-response time (inertia) characteristics
(133% in-built cap. above the peak - HU)

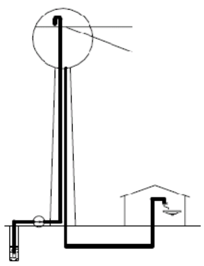
Technical breakthroughs enable the construction of hybrid lean/agile systems

1. Agile equipments in water supply
inverter-driven pumps (0-50Hz)
instead of water towers

2. Lean equipments in electricity supply
storage of electricity in accumulators,
supercapacitors and/or
hydrogen (electrolizer and fuel-cell)

- lean strategy for base-load, agile strategy for fluctuation
- dispersed generation/inventory units: efficiency, network savings





Lean supply

Agile supply

The main causes of oversizing	Protective inventory (bullwhip)	Protective capacity (puli)
Forecast	Error of the forecasted demand	Wide gap between the forecasted min-max demand
Lead time	Non-zero lead-time	Negligible lead-time
Batch (unit size)	Order batching	The size of protective capacity units
Necessity, shortage	Shortage of spare production capacity	Shortage of inventory, warehouse
Price	Price fluctuation	Price of shortage and restoration (or just the fear of)

Further information: Péter Bajor, PhD-Student tel: +36 30 63-73-270 e-mail: pbajor@sze.hu