How combinations of TRIZ tools are used in companies – results of a cluster analysis

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Many engineers and natural scientists in companies are using tools directly or indirectly related to the theory of inventive problem solving (abbreviation derived from the Russian title: TRIZ) by Altshuller (1984, 1996). Some of the TRIZ tools are based on the application of condensed technical knowledge, others are special techniques for directed creativity. The usage of TRIZ and its tools should lead to improvement of efficiency within the innovation process as well as to more and smarter problem solutions.

More than 40 reported applications of TRIZ in companies show that usually not the whole set of TRIZ tools is used. This is surprising, because in the original TRIZ literature all the tools are recommended for usage in a classified order named ARIS (Russian acronym for 'algorithm for inventive problem solving'). A cluster analysis of the applications reveals that there are three subsets: (i) basic TRIZ, (ii) resource and ideality-based TRIZ, and (iii) substance-field based TRIZ. This leads to important consequences: TRIZ training and TRIZ implementation should be structured according to the three subsets.

1. Introduction

The theory of inventive problem solving (abbreviation derived from the Russian title: TRIZ) was developed to provide access for engineers and natural scientists to the knowledge of former inventors. It consists of a bundle of tools which can be used either separately or in combination with others (see Knott, 2001, Mann, 2001 as well as Stratton and Mann, 2003). Within the concept of problem-driven inventing (Moehrle and Pannenbäcker, 1997), the various tools are structured into a framework consisting of the five fields 'current state', 'resources', 'goals', 'intended state', and 'transformation'. Some of the TRIZ tools are based on the application of condensed technical knowledge, others are special techniques for directed creativity. TRIZ and its tools were developed in the former Soviet Union, but meanwhile a lot of TRIZ applications have been reported in European and American companies as well (see the examples in Savransky, 2000; Rantanen and Domb, 2002; Orloff, 2003). Still there is no satisfiable survey about these applications and the combinations of TRIZ tools applied within them. This paper should give a first answer, but there is still a need for further research.

In a first attempt it is interesting to find answers to four research questions:

- Which TRIZ tools were used in published cases? In other words: Does the label TRIZ imply that really the whole TRIZ toolset is included in the package?
- Are there specific configurations regarding frequently implemented tool combinations?
- Are there differences in tool application between industries?
- Based on the answers to the first questions, which advice can be given to R&D mana-

gers for an efficient implementation of TRIZ tools?

The paper aims at a better R&D management based on deeper insight into inventive tasks. It will unfold benefit for three types of readers: (i) Non-TRIZ users can reflect the use of TRIZ in general. However, it is not the aim of this paper to describe TRIZ tools in detail. Therefore, especially inexperienced readers should use an additional introductory book on TRIZ (e.g. Altshuller, 1984 or Mann, 2002). (ii) Experienced-TRIZ users might be able to take this paper as a benchmark for their own TRIZ understanding as well as a foundation to develop their further theoretic understanding. This might also help in interaction with consultants and top-level management. (iii) Furthermore, academics may find this paper inspiring. The hypothesis that TRIZ tools are subject to a wide variety of combinations to generate technical solutions can provide a basis for further research.

2. Survey of TRIZ tools in theory

TRIZ is an empirically based theory with several tools. These tools can be structured into a framework with five fields, all of which have to be addressed during the process of solving a problem and thus during the process of inventing:

- *Current state*: What does the current situation look like?
- *Resources*: Which resources are available?
- *Goals*: Which goals shall be fulfilled?
- *Intended state*: How is the future situation supposed to look like?
- *Transformation*: In which way can the current state be transferred into the intended state?

The following sections give a brief description of the tools for a better understanding of section 3. For a comprehensive view see the original literature by Altshuller (1984, 1996), or Mann (2002) as well as Terninko et al. (1998) with a more tool-oriented view.

2.1. Current state

Five tools help to analyse the current state: systems analysis with its two variants (i) *function* and (ii) *object analysis*, (iii) *thinking in contradictions*, (iv) *substance-field analysis,* and (v) *evolution analysis*.

Through systems analysis the inventor chooses and specifies the relevant part of the technical system for his subsequent work in terms of its structure, its function and its focus (Schweizer, 1989, pp. 44–50). The structural and functional specification defines the system borders in space and in process, i.e. a higher or subordinate system. The focus indicates which aspect of the technical system is relevant, e.g. the efficiency, the reliability or the safety of control (see also Phan, 1995, pp. 21–22). Within TRIZ two variants of systems analysis are suggested: function analysis and object analysis. Both use graphs for the representation of the system (see Wenzke, 2003, pp. 147–155).

In a function analysis, the nodes of the graph represent positive and negative functions of a system. The nodes are connected with arcs that show relationships between the functions.

In an object analysis, the nodes of the graphs represent components and products of a system, as well as outlying elements. The arcs show functions between the nodes.

Thinking in contradictions is very unique for TRIZ and helps the inventor to carry the problem to extremes. A contradiction exists when (i) there is a desired function in a system, (ii) there is a conventional means to realise this function, and (iii) the realisation is opposed by harmful factors (see Moehrle, 2005).

An alternative to contradiction thinking as well as to the application of the two variants of systems analysis mentioned above is the substance-field analysis. With this tool, the inventor focuses on the critical zone of a problem and there identifies systems of substance-field relationships, which can be changed by the so-called standard operators (see Section 2.5).

Evolution analysis is based on laws of evolution of technical systems which have been introduced by Altshuller (1984, pp. 124–128). It appears to be helpful to derive various more expressive lines of evolution out of the rather abstract laws of evolution (Invention Machine, 2003, module 'prediction'). The inventor can assess the previous development of the analysed system as well as former inventions for this system (see Section 2.5 for transformation use of this tool) through consideration of these laws and trends of technical system evolution.

2.2. Resources

The consideration of the resources complements the previously described analysis of the current state. By means of resource analysis, possible design options can be unfolded. Consequently, the problem solver should make himself aware of all resources currently used and those additionally available and list them exactly. In TRIZ resource analysis, six types of resources should be analysed: substances, fields, space, time, informational, and functional resources. The problem solver should especially think of the resources normally taken for granted, e.g. the atmosphere, sunlight and time. Resources that are allowed for the invention have to be selected out of the list in the end.

2.3. Goals

Two tools serve for goal selection: 'ideality thinking' and 'fitting'.

Ideality thinking is based on an 'ideal machine'. Construction of an 'ideal machine' means to provide the desired function of a system without using any substantial parts. In other words, the ideal machine is a machine that is not a machine. Analogous goals are the ideal substance and the ideal field. Together they describe the ideal ending result (IER) for the problem approach. The inventor systematically limits his search area and leaves aside many of the other possible but ultimately weak solutions through orientation towards the ideal result (Altshuller, 1984, pp. 52–53).

Besides thinking in ideality, the inventor has to take economic, technological, and social restrictions into account, e.g. customer demands and legal requirements. *Fitting* means to adjust an invention to those restrictions, i.e. – similarly to a construction element in a casing – to make it fit (Heister, 1996, pp. 22–24).

2.4. Intended state

The goals described above are directly related to the intended state of a problem. The intended state is interpreted as a strong solution. A strong solution results from the area of conflict between the ideal machine and the fitting: it draws itself as close as possible to the ideal machine and at the same time achieves a high degree of fitting the restrictions.

2.5. Transformation

A whole bundle of tools is available in the field of transformation. It encompasses (i) the application of scientific effects and phenomena, the 40 inventive principles (ii) either independently or (iii) together with the contradiction matrix, (iv) the separation principles in space, time, structure, and state, (v) the substance-field modulation, (vi) the evolution prediction, and (vii) the resource variations.

Inventions are often a direct result of the application of scientific effects and phenomena. However, a single inventor is usually only well versed in a single discipline and has only limited additionally knowledge and experience in others. Therefore, he needs a comprehensive catalogue of effects and phenomena of different disciplines including their explanation (Altshuller, 1984, pp. 107–111). A self-explanatory catalogue – as available in different software solutions nowadays – on the one hand offers well-devised search facilities; on the other hand, it allows grouping and filtering of the effects and phenomena according to their functions and field of application.

The 40 inventive principles are the second transformation tool to be explained. This tool is extraordinarily substantiated and can be applied both in its original form according to Altshuller and in various modified versions. A very comprehensive patent analysis of far more than 40,000 protective rights publications backed the thesis that large numbers of superior inventions are based on a comparatively small number of inventive principles. Thereupon Altshuller (1984, p. 86) formulated the 40 inventive principles.

The 40 inventive principles may be applied independently or together with the contradiction matrix of 39 rows and columns. The contradiction matrix is also connected to the contradiction-thinking tool. The rows of the matrix determine the desired function of an invention, whereas the columns state the harmful factor when the invention is realised by conventional means. A contradiction can be isolated through selection of rows and columns. In the related cross-fields of the matrix up to four of the 40 inventive principles are stated whose application appears to be particularly promising for overcoming this contradiction (Altshuller, 1984, pp. 96–97).

The separation principles may be interpreted as a generalisation of the inventive principles. The inventor mentally varies some of the properties of a technical system or its elements in a purposeful manner through fundamental separations. Four types are especially advisable (Altshuller, 1984, p. 57): separations in space, in time, in structure, and in state.

Based on the results of the substance-field analysis (see Section 2.1), the substance-field modulation can be applied. With the help of 76 standard operators the inventor can modify different types of substance-field systems until he reaches an acceptable solution (see Pannenbäcker, 2001, pp. 103–107 for an advanced tool).

The evolution prediction complements the evolution analysis introduced in Section 2.1. Supported through the laws and trends of evolution of technical systems the inventor gets a notion of the further development – including prospective problems – of the technical system and of promising new inventions for the system.

Resource variations can be defined as conscious considerations about the use of resources, i.e. substances, fields, space, time, informational and functional resources. These resources may be minimized, rationalized or maximized (Pannenbäcker, 2001, pp. 110–112).

3. TRIZ tools in company applications

The TRIZ tools were introduced in the previous section. Now the question arises if all of these tools are always used or if subsets are identifiable.

3.1. Data

To answer this question, 43 case studies of European or American companies TRIZ applications were examined (see Table 1). These case studies were selected according to three criteria: (i) they should be directly related to TRIZ, (ii) they should originate from companies to show the economic relevance, and (iii) they should be accessible by the public. To receive such cases the author examined three online sources: the American TRIZ journal, the German TRIZ journal, and a TRIZ consultancy publication site. The cases cover the time period from 1997 to Spring 2003. All cases in the online sources matching the first two criteria were considered. The applications comprise different types of problem areas, stretching from the construction of an integrated steering shaft lock (case No. 2) to problem solving for airline airport management (case No. 4). The universe consists mainly of engineering companies, enriched by some cases from other industries. The main application industries were automotive, aerospace, and machinery.

The TRIZ tools were extracted from the cases in two steps. In the first step a team member and the author identified the TRIZ tools in all cases. During this step some discussion was carried out, for instance about the question, when to assign the TRIZ tool 'resource variation' to a case. For some critical assignments a set of rules was established to secure intracoderreliability. In the second step another research associate was provided with the set of rules from the first step. He evaluated 10 randomised selected cases independently. There were only minor differences between the first and the second evaluation, so this shows acceptable intercoderreliability.

Besides simply answering the research question it is worthwhile to take data quality into consideration. The ideal data set would be a collection of representative cases from industry, reported and documented by independent researchers. This goal is hardly to achieve, because of two reasons: (i) As opposed to less comprehensive approaches TRIZ is not well standardized. There are different terms, different problem solving process models. This listing could easily be carried on. (ii) TRIZ is used in the centre of R&D – high level of confidence is needed there. The author himself has experience from several TRIZ industry-university cooperations, none of them may be publicly discussed.

Second best solutions seem to rely on publicly available case studies, which one can find mainly in internet sources. If referring to the internet as source there are three aspects to discuss: (i) Normally, most people like to publish success more than failure stories. This may be the source of a first bias. (ii) As these case studies mostly are published by consultants, who want to promote TRIZ, they may not reflect the 'true' problem solving process in total. (iii) As the source of the case studies is the internet, there are normally no quality checks in sense of independent referees before publication. These three aspects are important, but nevertheless there seem to be reasons to take the second best way: (i) As one aim of this paper is to suggest some hypotheses for further research it seems that it is more appreciable to learn from successes. Case studies pointing out failure would perhaps show ways not to move into. However, these are not published. (ii) This bias has to be accepted. Therefore, the results may change, when the suggested hypotheses are tested with a more valid data basis. (iii) Internet sources have been checked in plausibility with trustworthy TRIZ journal editors.

3.2. Method

Cluster analysis is a widely accepted method to identify homogeneous accumulations inside data

Table 1. Sample of cases of industrial TRIZ applications

No	Subject	Industry	Source	Year
Basic TRIZ				
1	Slag problems of steering knuckle	Automotive	Cordova Lopez, E.; Lacoste, G.; Le Lann, J.-M. (2002): Use of Altshuller's Matrix for Solving Slag Problems Related to Steering Knuckle (Part I of II), in: triz-journal 2002/03, pp. 1–12.	2002
2	Integrated steering shaft lock	Automotive	Nähler, H.; Gundlach, C.; Montua, S. (2002): Beispiel integriertes Lenkerschloβ für Motorroller, in: triz-online 02/01, pp.1–8.	2002
3	Containment ring problem	Aerospace	O.V. (2002): Containment Ring Problem–Inventive Problem Solving Case Study, in: http://www.ideationtriz.com/Containment_Ring_Case_Study.asp, pp. 1–7.	2002
4	Airlines airport management	Aerospace	Takemura, M. (2002): TRIZ Introduction in Airlines Airport Management Division, in: triz-journal 2002/07, pp. 1–13.	2002
5	Aircraft cabin design	Aerospace	Carter, S. (2001): Case Study: The Application of TRIZ to Economy Class Aircraft Cabin Design, in: triz-journal 2001/12, pp. 1–15.	2001
6	Textile kiss-coat	Textile	Grace, F.; Slocum; Clapp (2001): A New TRIZ Practitioner's Experience for Solving an Industrial Problem Using ARIZ 85C: Increasing a Textile Kiss-Coat Operation Speed, in: triz-journal 2001/01, pp. 1–18.	2001
7	Flash photography	Photography	Mann, D. (2001): Case Studies in TRIZ: Anti Red-Eye Flash Photography, in: triz-journal 2001/07, pp. 1–10.	2001
8	Yarn spinning technology	Textile	Gahide, S. (2000): Application of TRIZ to Technology Forecasting–Case Study: Yarn Spinning Technology, in: triz-journal 2000/07, pp. 1–11.	2000
9	Better wrench	Machinery	Mann, D. (2000): Case Studies in TRIZ: A better Wrench, in: triz-journal 2000/07, pp. 1–7.	2000
10	Jet engine nose cone	Aerospace	Mann, D.; Baillie, C.; Dewulf, S. (2000): Case Studies in TRIZ: A Novel Jet Engine Nose Cone, in: triz-journal 2000/09, pp. 1–6.	2000
11	Fast clasping mechanism	Machinery	Runhua, T. (2000): The Conceptual Design of a Fast Clasping Mechanism–Based on Function Means Tree and TRIZ, in: http://www.triz-journal.com/archives/2000/10/f/2000}{–}{10f.pdf, pp.1–7.	2000
12	Public transport agency	Public Transport	Skrupskis, M.; Ungvari, S. (2000): Management Response to Inventive Thinking (TRIZ) in a Public Transport Agency, in: triz-journal 2000/05, pp. 1–12.	2000
13	Method for opening envelopes	Machinery	Chen, J.-L.; Tseng, C.-H. (1999): Case Studies in TRIZ: A Quickly and Reliable Method for Opening Envelopes, in: triz-journal 1999/08, pp. 1–5.	1999
14	Brake shoes of a bicycle	Bicycles	Chiang, C.-P.; Tseng, C.-H. (1999): Development of Conceptual Design for Brake Shoes of a Bicycle by Using TRIZ, in: triz-journal 1999/10, pp. 1–5.	1999
15	Mouse trap	Manufacturing	Kohnhauser, V. (1999): Use of TRIZ in the Development Process - Zero-Defect-Development for Customer Centred Innovative Products -, in: triz-journal 1999/06, pp. 1–10.	1999
16	Patient–doctor relationship	Medicine	Domb, E.; Corbin, D. (1998): QFD, TRIZ, and Entrepreneurial Intuition–The DelCor Interactives International Case Study, in: triz-journal 1998/09, pp. 1–7.	1998
17	Management problem	Consulting	Hipple, J. (1998): The Use of TRIZ Separation Principles to Resolve the Contradictions of Innovation Practices in Organisations, in: triz-journal 1999/08, pp. 1–6.	1998
18	Bolts around a flange joint	Machinery	Mann, D. (1998a): Case Studies in TRIZ: Halving the Number of Bolts around a Flange Joint, in: triz-journal 1998/11, pp. 1–4.	1998a
19	Bicycle seat	Bicycles	Mann, D. (1998b): Case Studies in TRIZ: A Comfortable Bicycle Seat, in: triz-journal 1998/12, pp. 1–3.	1998b
20	Windshield/backlight molding	Automotive	Lynch, M.; Saltsmann, B.; Young, C. (1997): Windshield/Backlight Molding–Squeak and 'Buzz' Project, in: triz-journal 1997/12, pp. 1–20.	1997

Table 1. (Contd.)

No	Subject	Industry	Source	Year
Resource and ideality based TRIZ				
21	Endoscopic instrument	Medicine	Zusman, A.; Zlotin, B.; Zainiev, G. (2003): An Application of Directed Evolution, in: http://www.ideationtriz.com/Endoscopic_Case_Study.asp, pp. 1–11.	2003
22	Integrated circuit	IT/computer science	Montua, S.; Gundlach, C.; Nähler, H. (2002): Fallstudie 'integrierter Schaltkreis', in: triz-online 02/03, pp. 1–18.	2002
23	Integrated circuit	IT/computer science	O.V. (2002): Yield/Reliability Problem–Analog Integrated Circuit–Inventive Problem Solving Case Study, in: http://www.ideationtriz.com/Yield_Reliability_Case_Study.asp, pp. 1–17.	2002
24	Portable toilet	Machinery	Sawaguchi, M. (2002): Development of the Next Generation Portable Toilet Through New Product Development Approach Based on the Combined Effects of Three Methods: TRIZ, VE and Marketing–Consulting Case of Company S -, in: triz-journal 2002/07, pp. 1–13.	2002
25	Space mirror	Aerospace	Shpakovsky, N. (2002): Space Mirror, in: triz-journal 2002/06, pp. 1–8.	2002
26	Solving technological problems	Media Techology	Shpakovsky, N.; Lenjashin, V.; Hyo June Kim (2002): Structural Scheme For Solving a Problem Using TRIZ, in: triz-journal 2002/01, pp.1–8.	2002
27	Composite flywheel	Aerospace	Keeley, S.; Clarke, D.W. (2001): Innovative Problem Solving: Composite Flywheel Structural Improvement, in: http://www.ideationtriz.com/paper_Composite_Flywheel.htm, pp. 1–6.	2001
28	Automatic boarding machine	Textile	Kunst, B.; Clapp, T. (2000): Automatic Boarding Machine Design Employing Quality Function Deployment, Theory of Inventive Problem Solving, and Solid Modeling, in: triz-journal 2000/01, pp. 1–16.	2000
29	Monitoring seat seam characteristics	Textile	Clapp, T.; Dickinson, B. (1999): Design and Analysis of a Method for Monitoring Felled Seat Seam Characteristics Utilizing TRIZ Methods, in: triz-journal 1999/12, pp. 1–7.	1999
30	Rapid prototyping equipment	Machinery	Clarke, D.W. (1999): Case Study: Application of Ideation/TRIZ to a Technological Problem with Rapid Prototyping Equipment, in: triz-journal 1999/11, pp. 1–18.	1999
31	Self-locking nut	Automotive	Mann, D. (1999a): Case Studies in TRIZ: A Re-Usable, Self-Locking Nut, in: triz-journal 1999/04, pp. 1–6.	1999a
32	Hard drive problem	IT/computer science	Royzen, Z. (1998): Case Study: TRIZ Solves a Hard Drive Reliability Problem, in: triz-journal 1998/11, pp. 1–5.	1998
33	Air bag fatalities problem	Automotive	Kowalick, J. (1997): 'No-Compromise' Design Solutions to the Air Bag Fatalities Problem–Problem-Analysis with TRIZ Using Invention Software, in: triz-journal 1997/04, pp. 1–21.	1997

Table 1. (Contd.)

No	Subject	Industry	Source	Year
	Substance-field based TRIZ			
34	Fbc boiler's tube erosion	Electrical engineering	Lee, J-G.; Lee, S-B.; Oh, J. (2002): Case Studies in TRIZ: FBC (Fluidized Bed Combustion) Boiler's Tube Erosion, in: triz-journal 2002/07, pp. 1–7.	2002
35	Integrated dryer	Automotive	Ofenböck, K.; Kohnhauser, V. (2002): TRIZ-Anwendungsbeispiel für integrierte Trockner, in: triz-online 02/02, pp. 1–9.	2002
36	Harvesting potatoes	Machinery	Vicente-Gomila, J.M. (2001): Applying some TRIZ Concepts to the Problem of Harvesting and Selection of Potatoes, in: triz-journal 2001/10, pp. 1–5.	2001
37	Particle filled fibers	Machinery	Batchelor, S. (1999): Solving the Problems of Particle Filled Fibers TRIZ Methodology, in: triz-journal 1999/10, pp. 1–7.	1999
38	Heat exchanger	Machinery	Busov, B.; Mann, D.; Jirman, P. (1999): Case Studies in TRIZ: A Novel Heat Exchanger (Use of Function Analysis Modelling to Find and Eliminate Contradictions), in: triz-journal 1999/12, pp. 1–13.	1999
39	Speed of yarn spinning	Textile	Khona, V. (1999): Increasing Speed of Yarn Spinning, in: triz-journal 1999/08, pp. 1–14.	1999
40	Process of flourination	Machinery	Monplaisir, L.; Jugulum, R.; Mian, M. (1999): Application of TRIZ and Taguchi Methods: Two Case Examples, in: triz-journal 1999/01, pp.1–10.	1999
41	CMM support problem	Machinery	Monplaisir, L.; Jugulum, R.; Mian, M. (1999): Application of TRIZ and Taguchi Methods: Two Case Examples, in: triz-journal 1999/01, pp.1–10.	1999
42	Wine barrels	Winery	Quartly-Watson, T. (1999): TRIZ and Taguchi Methods at a World-Class Winery and Vineyard, in: triz-journal 1999/02, pp. 1–7.	1999
43	Trellising system	Winery	Quartly-Watson, T. (1999): TRIZ and Taguchi Methods at a World-Class Winery and Vineyard, in: triz-journal 1999/02, pp. 1–7.	1999
44	Child safety stairgate	Machinery	Mann, D. (1999b): Case Studies in TRIZ: Child Safety Stairgate, in: triz-journal 1999/10, pp. 1–5.	1999
45	Product development	Automotive	Smith, L.R.; Zlotin, B.; Zusman, A. (1999): The Dilemma of Improving Quality in New Product Development, in: triz-journal 1999/05, pp. 1–4, Attachment I pp.1–26, Attachment II pp.1–16.	1999

The case studies are grouped according to the results of a cluster analysis and listed chronologically.

Table 2. Application of TRIZ tools

No	Function analysis	Object analysis	Contradicions	Substance-field analysis	Evolution analysis	Resource analysis	Ideality	Fitting	Strong solution	Effects and phenomena	Inventive principles (IP) in independent form	IP with contradicion matrix	Separation principles	Substance-field modulation	Evolution predicion	Resource variation
Basic TRIZ																
1			X										X			
2			X				X					X				
3			X									X			X	
4			X									X			X	
5			X									X				
6			X					X				X				
7			X				X					X				
8			X					X				X			X	
9	X		X									X	X			
10			X				X					X			X	
11			X									X				
12	X		X						X			X				
13			X	X								X		X		
14			X												X	
15	X		X	X									X	X		
16			X				X					X				
17			X				X					X				
18			X									X				
19			X									X				
20			X									X			X	
	0.15	0	1	0.1	0	0	0.25	0.1	0.05	0	0	0.85	0.15	0.1	0.3	0

Table 2. (Contd.)

No	Function analysis	Object analysis	Contradicions	Substance-field analysis	Evolution analysis	Resource analysis	Ideality	Fitting	Strong solution	Effects and phenomena	Inventive principles (IP) in independent form	IP with contradicion matrix	Separation principles	Substance-field modulation	Evolution predicion	Resource variation
Resource and ideality based TRIZ																
21	X		X			X	X						X			X
22			X		X		X				X				X	
23					X		X								X	
24	X		X			X	X		X						X	
25			X				X				X					
26		X	X	X		X	X				X			X	X	X
27			X	X		X	X		X				X	X	X	X
28	X						X				X					
29		X	X				X				X				X	
30						X	X									X
31	X		X			X	X		X						X	
32			X									X				
33			X		X		X								X	
	0.38	0.15	0.77	0.23	0.23	0.54	1	0	0.31	0	0.38	0	0.15	0.23	0.62	0.38
Substance-field based TRIZ																
34		X	X	X								X	X	X		
35		X	X	X								X		X		
36			X	X										X		
37			X	X										X		
38		X	X	X			X					X		X		
39		X		X			X							X		
40			X	X									X	X		X
41		X		X		X	X							X	X	
42			X	X		X	X					X		X		X
43		X	X	X			X					X	X	X		
	0	0.6	0.8	1	0	0.2	0.7	0	0	0	0	0.5	0.4	1	0	0.4
44			X					X			X					X
45		X	X													

Case numbers correspond with numbers in Table 1.

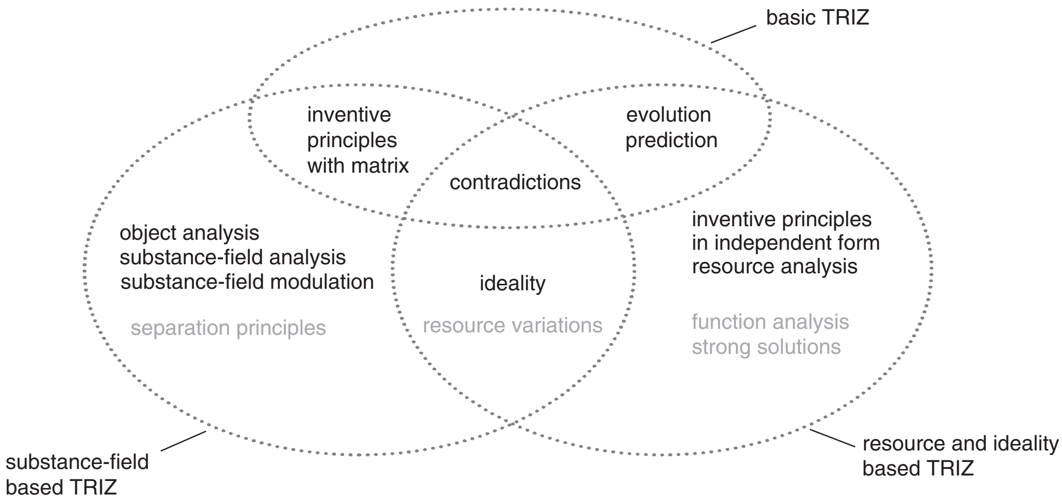

Figure 1. Assignment of TRIZ tools to three clusters. Data according to Table 2. TRIZ tools highlighted black are used in at least 50% of the cases in a cluster. TRIZ tools highlighted grey are used between 30% and 50% of the cases in a cluster.

sets. It may be classified as a method to discover formally unknown structures. The major task of the different kinds of cluster analysis such as hierarchical or K-means cluster analysis is to group objects, which are very similar inside the cluster and dissimilar to all other objects outside the cluster.

Cluster analysis was selected here as one way to determine similar cases regarding the identified TRIZ tools. The 16 TRIZ tools introduced by the author have been a basis for further examination of the database.

In a first step all 45 cases were analysed and for each case a binary profile of the identified TRIZ tools was developed. In case 2, for example, the use of the TRIZ tools (i) contradictions, (ii) ideality, and (iii) inventive principles with contradiction matrix was described to solve a specific technical problem. This leads to a data set consisting of three variables (v3, v7, and v12) that contain the binary information 1, i.e. attribute is existent, as well as 13 variables without any information.

After producing 45 data sets corresponding to the 45 cases analysed (see Table 2) a second step was performed. A hierarchical cluster analysis was used to construct homogeneous clusters of the cases (See Back et al. 2000). In order to specify an appropriate number of clusters, pretesting was conducted. An optimal number of clusters varying between three and five has therefore been determined. In a third step the hierarchical cluster analysis was conducted. The clusters were formed using the average linkage between the groups as a criterion. This means the average distances between all item couples were minimized. As a result, five clusters were generated.

3.3. Results

In general, four results are important. (i) There was not a single case study in which all of the TRIZ tools were used. On the contrary, using different combinations of TRIZ tools seems to lead to acceptable inventive solutions. (ii) Contradiction thinking may be defined to be the core of all TRIZ applications since it is used very often in all of the clusters. (iii) Although there is a helpful software application available, scientific effects and phenomena were not used in the TRIZ applications. A (weak) reason for this may be the potential intention of the case study authors to show ‘smart’ processes and not easily transferable solutions from a database. (iv) There seems to be no industry-specific TRIZ process because many important industries such as automotive or aerospace are represented in all three of the clusters.

In particular, three clusters may be identified: basic TRIZ, resource and ideality-based TRIZ, and substance-field based TRIZ (see the assignment of TRIZ tools to clusters in Figure 1).

The first cluster of TRIZ applications in companies may be named basic TRIZ. To this cluster 20 cases are assigned. It is quite remarkable that in this cluster only two TRIZ tools prevail in usage, (i) contradiction thinking and (ii) inventive principles in combination with the contradiction matrix. Both are easy to explain, easy to apply and very early introduced TRIZ tools. Whereas contradiction thinking is a technique for directed creativity, the inventive principles in combination with the contradiction matrix represent the application of very condensed technical knowledge. In basic TRIZ other tools are only used occasionally, e.g. the evolution prediction is applied in 30% and ideality thinking in 25% of the cases.

The second cluster of TRIZ applications can be called resource and ideality based TRIZ. In this cluster with 13 cases many more tools are applied than in the first cluster. The main tools are (i) contradiction thinking, (ii) resource analysis, (iii) inventive principles in independent form, (iv) evolution prediction, and (v) ideality thinking. Furthermore, resource variations, function analysis and strong solutions are used in more than 30% of the applications. In most of the cases resources analysis is utilized in combination with ideality thinking. This is the common ground for the denomination of this cluster.

Finally, the third cluster of TRIZ applications may be named substance-field based TRIZ. As in the cluster of resource and ideality-based TRIZ, many more TRIZ tools are used than in the cluster of basic TRIZ. The name of the cluster is derived from the fact that (i) substance-field analysis and (ii) substance-field modulation are used in all of the 10 cases of this cluster. Other main tools are (iii) contradiction thinking, (iv) object analysis, (v) inventive principles with the contradiction matrix, and (vi) ideality thinking. In addition, separation principles and resource variations are used in more than 30% of the applications of this cluster.

4. Conclusions

Based on the empirical results derived from the TRIZ applications in companies the four research questions mentioned in Section 1 can be answered. (i) Not the whole toolset of TRIZ tools is always necessary or even helpful to solve inventive problems. (ii) Certain combinations of the 16 tools introduced above are often applied; three major configurations or clusters are identifiable: basic, resource and ideality based, and substance-field based TRIZ. (iii) There seem to be no major differences in tool using between industries. (iv) Despite the fact that there is no efficiency measure of TRIZ tools or TRIZ tool configurations so far, it may be helpful to structure TRIZ training and TRIZ implementation according to the three clusters. Two cases should be considered:

- R&D managers with no experience with TRIZ that ask for efficient implementation of TRIZ may start in a first phase with the basic TRIZ subset comprising only a few tools which are easy to apply. In a second phase, they may move on to substance-field based TRIZ or resource and ideality-based TRIZ. Following this concept, the TRIZ appliers may gain some preliminary experience and feelings of success before proceeding to tools which are more powerful, but also more abstract or harder to apply.
- R&D managers, who have already gained some experience with TRIZ, may use the three configurations to compare it with their own practice. Are they using a configuration similar to one of those three? This may lead to an appraisal of how advanced the use of TRIZ is in the company. Also, strategies for further implementations of TRIZ may be derived from this comparison.

All in all, some explorative answers to the research questions have been given in this paper. These answers can be the foundation for testable hypotheses, which should be investigated in further empirical research. Furthermore, some questions should be answered by theoretical researchers. It seems to be of special interest to analyse from a conceptional point of view if there should be one or even more new procedural model(s) for working with TRIZ and its tools. Also, for receiving better acceptance, it seems to be useful to evaluate which other tools like synectics or semantic patent analysis should be applied together with TRIZ tools.

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