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Compilation of heuristics for inventive problem solving

Rodolfo K. Tessari[*], Marco A. De Carvalho[a]

[a]*Federal University of Technology – Paraná (UTFPR), Av. Sete de Setembro 3165, CEP 80230-901, Curitiba, Brasil*

Abstract

Heuristics are widely accepted and used as tools for inventive problem solving. A problem when using heuristics is that their number is relatively high (469 heuristics were found in this research) and keeps increasing. This amount of heuristics makes it necessary for problem solvers to spend a significant amount of time in understanding them, finding the most applicable ones to their specific situation and using them. This article presents a first step towards decreasing this complexity. We synthesized the available inventive problem solving heuristics in a single list. The development of this list involved the identification of the inventive problem solving heuristics in literature, followed by analysis and comparison, resulting in a final list of 263 heuristics. The authors hope that this list can save problem solvers' time and become a basis for a future, essential set of inventive problem solving heuristics.

Keywords: Heuristics; Inventive Problem Solving; TRIZ; Systematic Innovation.

1. Inventive Problem Solving and Heuristics

Problem solving can be defined as the process of gathering people and resources to analyze a situation, determine the real problem, propose and evaluate solutions, and choose the best one that fulfills their needs (Knippen & Green, 1997).

Nomenclature

TRIZ	Theory of Inventive Problem Solving
S.S.	Standard Solutions
121H	Polovinkin's 121 Heuristics

Problem solving processes can be divided in two classes: inventive and non-inventive. As Newell et al. (1962) define, although the boundary between these two classes is practically impossible to distinguish, inventive problem solving (or creative problem solving) is characterized by novelty, unconventionality, persistence, and difficulty in problem formulation.

Although inventive problem solving seems to be the harder way to pursue, there are good reasons to remain in this path. According to Proctor (1998), today new and better ways to solve problems are necessary, since an ever growing number of problems have few or no precedents.

Furthermore, inventive problem solving and the use of creative knowledge are believed to be the best and fastest way to the enhancement of an organization's productivity (Knippen & Green, 1997), the only way of gaining a sustainable competitive advantage (McFadzean, 2002), leading to the development of new products or services, generation of new strategies and opportunities, and solution of complex personal or organizational problems (Proctor, 1998; Mann, 2002; Sheu, 2009).

Because of this, many problem solving techniques arose to assist the inventive process, as the heuristic ideation technique (McFadzean, 1999b). The techniques can be classified according to different criteria. VanGundy apud McFadzean (1999a) proposed, for example, the division of individual techniques from group techniques, and the ones that use related stimuli from those that use unrelated stimuli. Several articles refer to group techniques especially applied to workplace (McFadzean, 2002; Fenwick, 2003; LoBue, 2002; McFadzean, 1998a), and others demonstrate some related stimuli techniques based on computer software (Proctor, 1998; Hollingum, 1998).

Other possibility proposed by Newell et al. (1962) is to differentiate processes for finding possible solutions (known as "solution-generating processes") from those for determining whether a solution proposal is in fact a solution (so-called "verifying processes"). By this classification, heuristic definition can be framed as a solution-generating process.

According to de Carvalho et al. (2003) heuristics are rules, strategies, principles or methods for increasing the effectiveness of a problem resolution, not providing, however, direct and definitive answers, nor guaranteeing a solution for a problem.

Heuristics can be better classified as a paradigm stretching technique (McFadzean, 1998b), since their main task is not to work simply as solution generators (unlike the methods of trial and error and brainstorming). Actually, they work as devices that contribute to the reduction in the average number of solutions to be searched (Newell et al., 1962), aid in finding an easy path to the answer in complex problems (Chu et al., 2010), and focus attention on the most relevant aspects (Renkl et al., 2008).

With such qualities, heuristics techniques are popular, playing a major role in TRIZ (Theory of Inventive Problem Solving). In this work, we use the name heuristics for generalizing “principles”, “standards”, “patterns”, “operators”, and “templates”. TRIZ heuristics were abstracted from the most inventive patents into a generic problem-solving framework, enabling the solution of the most varied specific problems (Mann, 2002; MCB UP Ltd., 2003). Common examples are “Do it in Reverse”, a heuristic that suggests that the user do the opposite action or explore an opposite configuration or property to the one in the original situation, going toward a counter intuitive directionality (Sickafus, 2009), and “Consolidation”, which proposes making one object perform more functions, something that can be seen in cell phones and multi-purpose tools.

In TRIZ, there are almost five hundred heuristics involving the most varied fields, with special attention to engineering fields. This large number is an obvious obstacle to newcomers to TRIZ and Systematic Innovation. Moreover, this number grows with new publications. TRIZ heuristics also have different abstraction levels (sometimes specific, sometimes vague), which hinders their adoption and use.

The main objective of this research is to compile a single list that represents the main heuristics of TRIZ and Systematic Innovation. Specific objectives encompass collecting available TRIZ heuristics, looking for overlaps, and seeking to eliminate them.

This paper does not cover a way to apply the resulting heuristics to problem solving. This is an objective for further research.

2. Background

Some studies have addressed the problem of the large number of heuristics in TRIZ, especially focusing on the Inventive Principles. They all have the same goal of trying to extract the real essence of TRIZ and condense it into an easy-to-use method, so that it can be more widely adopted.

The first attempt occurred in Israel in the beginning of 1980s and gave rise to the Systematic Inventive Thinking method (SIT), which comprised Altshuller's forty principles into only four in SIT (Horowitz & Maimon, 1997). Later, in 1995, Ford Motor Company adapted SIT and improved it into a Unified Structured Inventive Thinking methodology (USIT) (Sickafus, 1997) that replaced the notion of overcoming conflicts with the application of the sufficient conditions, i.e., a minimal set of heuristics that leads to creative conceptual solutions to industrial problems. (Nakagawa, 2000).

Likewise, Horowitz (2001) proposed the reduction of the Inventive Principles into only five heuristics called "five idea provoking techniques", giving rise to the ASIT method (Advanced Systematic Inventive Thinking). The main changes of this method are the elimination of engineering-specific heuristics, reduction to a lower number of rules and tools, and replacement of knowledge by pure thinking (Horowitz, 2001). Actually, the main difference from SIT and USIT is that ASIT methodology is centered on the ideation of new products instead of problem-solving itself.

Another important approach to simplify TRIZ was developed by Rantanen & Domb (2008). They attempted to simplify TRIZ by focusing on what they call "five + one patterns". Such patterns include the use of the five most useful patterns of evolution of TRIZ – uneven evolution of technology, transition to the macro level, transition to the micro-level, increase of interactions, and expansion/convolution of systems – in conjunction with the criterion of the ideal final result. They also presented a new version of the list of Altshuller's Inventive Principles, in which two features in particular stand out: the simplification of the principles under their central form without expansion in sub-principles; and new ways to interpret the label of the classical principles to expand their use.

Mao et al. (2007) followed a different approach, aiming at the generalization of the 76 Standard Solutions (Altshuller et al., 1989). The study promoted a careful evaluation of the standards, substantially reducing their number to just seven "Generalized Solutions" and preventing excessive redundancy and details. In addition, they suggested replacement of some of the standard solutions in other TRIZ tools where they were believed them to be more suitable. According to the authors, this effort contributed to the improvement of TRIZ logic and facilitated the implementation of Su-Field Analysis.

All above-mentioned publications relate to cases where TRIZ heuristics were taken to a higher abstraction level. However, other works have been done in order to satisfy users looking for specific problem solutions.

With the intention to create software for problem solving, Zlotin and Zusman (1998) tried to develop the essence of ARIZ (Algorithm of Inventive Problem Solving) into an algorithm that could run on computers. They worked in association with other TRIZ experts and created ARIZ-SMV 91 (E) (Zlotin & Zusman, 1991). They continued their research seeking to unify most of TRIZ knowledge-base tools under what they called a system of operators. This integrated operational knowledge base was then presented in the form of the Innovation Workbench System Software (Zlotin & Zusman, 1992).

This software allegedly redesigned completely all existing TRIZ Operators (Principles, Standard Solutions, Utilizations of Resources, and other ones), making them more detailed and specific in order to fit the particular need of each single user. Examples are provided for each solution, gathered from a list of approximately 300 illustrations at the software's initial development stage. The problem of the abstraction level was thus believed to be solved, at least for pre-determined specific areas (Zlotin & Zusman, 1992).

However, problem solvers are not believed to fit their problem on a menu with limited possibilities. TRIZ should give an answer to current and future problems, focusing its power on the universality of the theory. As Zlotin and Zusman (1992, pg. 3) refer in their article, Altshuller, the father of TRIZ, withdrew from specific forms of the Principles, for the sake of the universality and convenience.

As could be seen, many previous works condensed somehow the essence of TRIZ. The majority of these researches, however, stayed restricted to the heuristics proposed by Altshuller. This is where we sought to innovate. We focus not only on the Classical TRIZ heuristics, but also on more recently proposed ones.

On the other hand, Savransky (2000, p. 220) stated that "Continuous search for new Inventive Principles and sub-Principles is one of the current activities of TRIZ experts". Indeed, many heuristics have been discovered throughout the years.

We sought to cover the vastest number of inventive problem solving heuristics, but not all of them are available in open sources. Thus, information available only in proprietary software such as Innovation Workbench could not be considered. The analysis was limited to the heuristics suggested by Altshuller (1998, idem et al., 1989), Polovinkin (apud De Carvalho et al., 2003), Savransky (2000), Mann (Mann et al., 2003), and Yezersky (2006).

The number of heuristics belonging to each of these groups is detailed on the section bellow together with their order of conception, as their characteristics will be further analyzed on section 4.

3. Methodology

In order to accomplish the goal of this study, i.e., the compilation of a single list of heuristics able to facilitate idea generation, we started with a literature review.

A historical timeline was used to clarify the process of evolution of TRIZ and Systematic Innovation theories. This perspective was used in order to make evident which of the selected groups of heuristics was conceived first and evaluate all the others as "improvements" of that one. Such improvements can range from original heuristics discovered through patents databases researches, personal observations and practical experimentations, to the filling of gaps left by previous inventive methods or merely grammatical changes in the way of formulating heuristic sentences.

Following this perspective, the originality of all heuristics could be evaluated, ending up with the elimination of those with a lack of novelty and originality.

This research was focused on six main groups of heuristics, arranged chronologically according to their order of conception. The first group is composed by the Inventive Principles, developed between 1956 and 1971, and the second is composed by the 76 Standard Solutions, whose development started in 1975 and ended in 1985 (Souchkov, 2008). The former totals 90 heuristics, and the latter, 84.

The third set of heuristics includes the work of another researcher from the former USSR, Polovinkin (1985, 1988, 1991). He suggested a number of heuristics for design and problem solving, which was later reduced to 121 by De Carvalho et al. (2003), by elimination of the heuristics that do not contribute for conceptual problem solving.

The last three groups include more recent work: the fourth group, authored by Savransky (2000), includes six heuristics published as new principles and sub-principles added to the Inventive Principles; the fifth, 37 Most Important Combined and Special Principles was developed by Mann et al. (2003), and contains 105 heuristics; and finally, the sixth group of heuristics, from the General Theory of Innovation (GTI), includes seven Templates proposed by Yezersky (2006), totaling 63 heuristics.

After gathering these 469 heuristics, the research proceeded with the confrontation of the heuristics developed by each of the authors and elimination of those with the same meaning, adding to the final list only the original ones.

Before starting the confrontation process, every heuristic was rewritten in order to facilitate the comparison. They were rephrased according to pattern: “to <verb> <object> in order to <complement>”. By doing this, the central idea of each heuristic was put in evidence right away. This made the comparison process easier.

After this matter of syntax, the comparison and elimination process was initiated. Two conditions were considered to be exclusion criteria: the first one was that heuristics with the same meaning in their descriptions should be eliminated, i.e., those with a similar nature or based on the same physical principle; and the second one was that heuristics with common examples should be removed, i.e., those that use the same or a very similar example to demonstrate their usefulness and applicability. These are examples:

- Principle 63 – Transform An Object Micro-Structure (C) – To replace a part of the material with “void”, (…) (Mann et al., 2003) was eliminated, because it has the same meaning of Inventive Principle 31 – Porous Materials (A) – To make an object porous, or use porous elements (inserts, covers, etc.) (Altshuller, 1998);
- Template 6.1 – To change the process so that there is no need to measure anymore (Yezersky, 2006) was suppressed because it is a repetition of Standard Solution 4.1.1 – Replacing Detection or Measurement with System Change – To modify the system in a way that eliminates the need for measuring or detecting it (Altshuller et al., 1989).

In each of these cases, the original heuristic (with the role of benchmark) was maintained and added to the final list. Since the Inventive Principles were published first, they formed the basis of the final body of heuristics, and none of its heuristics were eliminated.

The research process is schematically represented in Fig. 1.

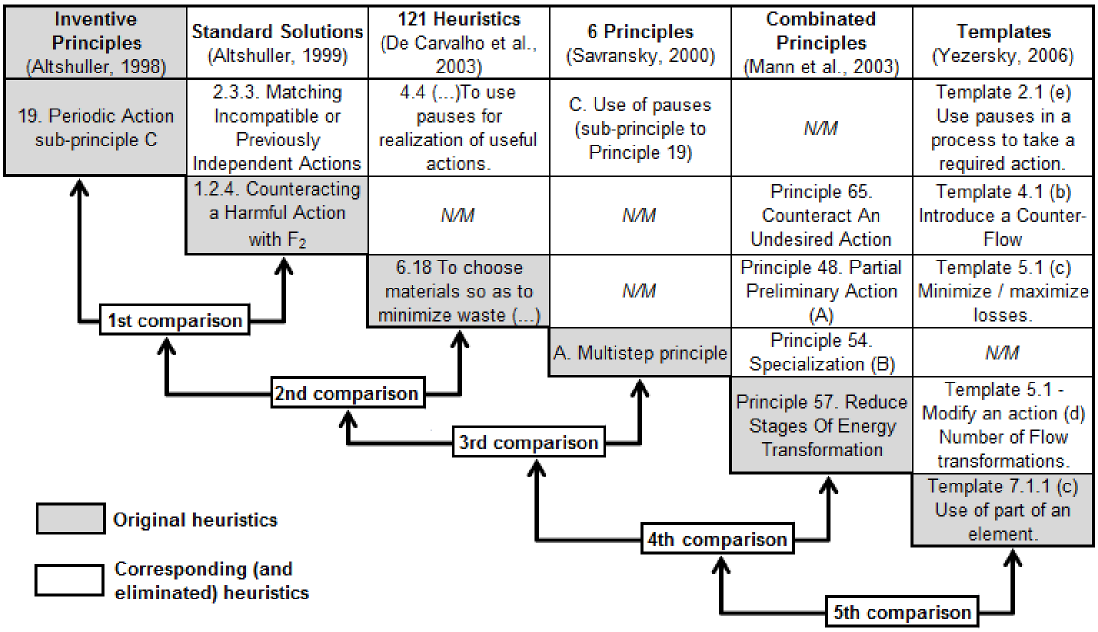

Fig. 1. The research process

In the first step, two groups were compared: the Inventive Principles and the Standard Solutions. The first group was marked with the gray color, representing original heuristics that would be added to the final list. The Inventive Principles and their sub-principles total 92 heuristics. Each one was placed on a different row. Then, the Standard Solutions began to be compared, row by row.

Every time a heuristic belonging to the Standard Solutions did not coincide with any other belonging to the gray group, it was placed at the end of its column, right after the row with the last original heuristic. The first Standard Solution maintained (1.1.1. Building a Su-Field Model), for example, was put on the row right below to the one that contained the last Inventive Principle, but under the column belonging to its group. Standard Solution 1.2.4 presented on Figure 1 demonstrates this.

Step 2 was just like the first one. Following the chronological order, in this phase the heuristics of Polovinkin were compared directly with every heuristic belonging to the gray group (consisted this time by the Inventive Principles in addition with original Standard Solutions), an indirectly with all those heuristics eliminated during the previous stage.

All subsequent comparisons followed this pattern. Naturally, the percentage of eliminated heuristics from each group grew with each step.

4. Comparison of Heuristics

As briefly explained before, the first step of this work was to compare the Inventive Principles with the Standard Solutions, from which several solutions were eliminated. The main reason for this, as Mao, et al. (2007) criticize in their article, is that many solutions appear in different TRIZ contexts, seeming to be a mixture of patterns of evolution, inventive principles and effects. Standard Solutions such as 2.2.2 – Fragmentation of S2, 3.1.4 – Simplification of the Bi- and Poly-Systems, and 2.2.4 – Dynamization justify the criticism, as they have the same sense as Inventive Principles 1 – Segmentation, 6 – Universality, and 15 – Dynamicity, respectively.

Savransky (2000) also criticized the Standard Solutions. His main point is about some redundant heuristics like 5.5.3, which merely explains previous Standards 5.5.1 and 5.5.2, and other obvious ones like 2.4.7, 4.3.1, and 4.4.5. These last ones give tips on application of physical effects and phenomena. Savransky points that these take place in any Technical System or Technological Process, still serving as example of any good invention. Taking this into consideration, such heuristics were eliminated.

On the other hand, over half of the Standard Solutions were maintained, due to the fact that they bring some patterns of evolution as complementary heuristics (what did not occur among the Inventive Principles), and due to the special attention given to promote the use of mechanical and magnetic fields. Besides, the class of Standard Solutions specifically dedicated to detection and measurement didn’t appear previously among the Inventive Principles and thus was almost entirely included into the final list. However, Standard Solution 4.1.2 – Applying copies, for example, was excluded by Inventive Principle 26 – Copying, as happened with sub-class 4.3 – Enforcing Measurement Su-Field Models, which had its heuristics excluded by Inventive Principles 24 - Mediator and 28 - Mechanical Vibration. In both cases, the Inventive Principles were just adapted to fit the function of measurement and detection.

At the end of this step, all unmatched Standard Solutions (a total of 46) were added to the final list. They are listed on Table 1.

The work proceeded with analysis of the 121H (short way of referring to the 121 Heuristics). Less than half of the them was maintained. Some heuristics appear to have been derived from the principles themselves, like heuristics 3.2 and 3.3 – which refer to the use of empty spaces in an object to store or to pass a second object inside or through it –, just as Inventive Principle 4 – Nesting does. Other examples are 121 Heuristics 4.4, 5.12, and 5.14, which relate to Inventive Principles 19 – Periodic Action, 21 – Rushing Through, and 8 – Counterweight, respectively.

Table 1. Standard Solutions added to the final list

Class 1. Building and Destroying Su-Field Models
Class 1.1. Building Su-Field Models: 1.1.1, 1.1.2, 1.1.3, 1.1.4, 1.1.5, 1.1.8
Class 1.2. Destroying Su-Field Models: 1.2.1, 1.2.2, 1.2.3, 1.2.4, 1.2.5
Class 2. Enhancing Su-Field Models
Class 2.1. Transitioning to Complex Su-Field Models: 2.1.2
Class 2.3. Enforcing by Matching Rhythms: 2.3.2
Class 2.4. Ferromagnetic-Field Models: 2.4.2, 2.4.4, 2.4.5, 2.4.6, 2.4.11, 2.4.12
Class 3. Transition to the Super-System and Micro-Levels
Class 3.1. Transitioning to Bi- and Poly-Systems: 3.1.2, 3.1.3, 3.1.5
Class 3.2. Transitioning to the Micro-Level: 3.2.1
Class 4. Standard Solutions for Detection and Measurement
Class 4.1. Indirect Methods: 4.1.1, 4.1.3, 4.2.1, 4.2.2, 4.2.3, 4.2.4, 4.4.1, 4.5.1, 4.5.2
Class 5. Standards for Applying the Standard Solutions
Class 5.1. Introducing Substances: 5.1.1.2, 5.1.1.3, 5.1.1.4, 5.1.1.6, 5.1.1.8, 5.1.1.9
Class 5.2. Introducing Fields: 5.2.1, 5.2.2, 5.2.3
Class 5.3. Phase Transitions: 5.3.2, 5.3.4, 5.3.5
Class 5.4. Peculiarities of Applying Physical Effects and Phenomena: 5.4.1, 5.4.2

As De Carvalho et al. (2003) argument, although the 121 Heuristics and the Inventive Principles were obtained in different periods of time, they were based on dissimilar patent databases. This makes both groups complementary but not copies of each other. A clear proof of this are 121 Heuristics 3.14, 3.15, 6.11, and 8.7, which complement Principle 22 – Convert Harm into Benefit, the only Inventive Principle that addresses directly a negative event. Such heuristics express more general concepts, and innovate mainly by referring to the removal issue, either the system removal from a dangerous environment, or the removal of impurities in the system itself.

Continuing the research, Inventive Principles with specific meanings such as 38 – Accelerated Oxidation did not eliminate any other 121 Heuristics, unlike general ones as 35 – Transformation of Properties. The abstraction level of the heuristics was not considered as a criterion of elimination. Inclusion of general design concepts, as exemplified by 121 Heuristics 1.12, 1.13, 1.15, 1.16, and 2.18, related to global optimum parameters; and specific engineering ones, like 121 Heuristics 1.10, 2.16, 6.18, and 6.19, that focus on the reduction of costs and waste generation, specific parameters not explicitly shown on the Contradiction Table.

Some of the 121 Heuristics had a very close sense to the Inventive Principles. However, only apparent similarity did not justify the exclusion of any of the 121 Heuristics, since some had an additional meaning. The 57 remaining heuristics were added to the final list that can be found in Appendix A.

The research proceeded with consideration of the 6 new Inventive Principles and sub-Principles suggested by Savransky (2000), referred to in this paper as 6 Principles. Only two of them were retained: A – Multistep principle and E – Match of impedances.

This stage of comparison is good to exemplify how the research was performed and how confrontation worked: although 6 Principles B had no equivalent Inventive Principle, Standard Solutions 3.2.1 and 5.4.1 eliminated it; Principle C was eliminated by Inventive Principle 19 – C and indirectly by 121 Heuristics 4.4; Principle D was removed by Inventive Principle 34 and indirectly by Standard Solution 5.1.3; and, finally, Principle F was suppressed by Inventive Principles 5 and 35.

Table 2 shows the above-mentioned procedure, bringing an example of the confrontation process with consequent elimination of heuristics: heuristics in blue cells belonging to the same group (in this case, the 6 Principles) are compared one at a time with the gray ones belonging to the leftmost column, row by row. If a correspondence is found before reaching the bottom of the gray column, then the heuristic in the blue cell is eliminated, and colored white. If no match is found (coded in the table as "N/M"), then the heuristic is added to the end of its column, and colored gray (meaning that such heuristic is original).

Table 2. Example of confrontation process with consequent elimination of heuristics. The blue column represents the group being analyzed and the acronym *N/M* ("No Match") means that no heuristic had either a same or a close sense.

Inventive Principles	**Standard Solutions**	**121 Heuristics**	**6 Principles**
Principle 5. Consolidation a. To consolidate in space homogeneous objects or objects destined for contiguous operations.	3.1.1. Creating Bi- and Poly-Systems Combining the system with another system(s), thus building a more complex bi-system or poly-system.	2.12 To connect homogeneous subsystems or subsystems intended for similar functions. (...) 2.9 To concentrate controls in one place.	F. Concentration-dispersion principle (a) a. Concentrate essential resources, elements, actions in a key place and moment of time (…).
Principle 19. Periodic Action c. To use pauses between impulses to provide additional action.	2.3.3. Matching Incompatible or Previously Independent Actions (...) In general, the pauses in one action should be filled by another useful action.	4.4 To eliminate useless or harmful time intervals. To use pauses between pulses or periodic actions for realization of useful actions.	C. Use of pauses Use pauses between actions to perform similar or different actions; one action is active during pauses of other action.
Principle 34. Rejecting and Regenerating Parts a.To reject or to modify an element (...) after completing its function or becoming useless.	5.1.3. Self-Elimination of Substances After carrying out its work, an introduced substance should disappear (...).	*N/M*	D. Use of epenthetic (insert) parts (...) by using temporary insert, deleting the insert when finished.
Principle 35. Transformation of Properties b. To change the concentration or density.	2.4.12. Rheological Liquids	*N/M*	F. Concentration-dispersion principle
	3.2.1. Transition to the Micro-Level To go from macro-level to micro-level in order to enhance a system in any evolutionary stage. (...)	*N/M*	B. Dissociation-association This principle allows division and coalition on the molecular level.
	5.4.1. Self-controlled Transitions (...) utilization of reversible physical transitions such as ionization-recombination, decomposition-association, etc.	*N/M*	B. Dissociation-association This principle allows division and coalition on the molecular level.

It is noticeable that the last excluded heuristic was 6 Principles – B due to the fact that none of the Inventive Principles had the same sense. It has been eliminated on a further step, when it was compared to the innovative standards.

It is also worth mentioning that Standard Solution 2.4.12 – Rheological Liquids – has little to do with 6 Principles – F. This is caused by the relatively high abstraction level of Inventive Principle 35, which permits a dual interpretation: electro-rheological liquids have the property of changing their viscosity according to the density of the electric field or electric current applied to it (Liu et al., 2010). Therefore, it refers to the concentration and densification of an action or process, whereas 6 Principles – F refers to the concentration of a set of objects (at least two), managing their mutual arrangement and relative quantity.

This is the essence of the process: heuristics belonging to the group in analysis were compared primarily with original heuristics belonging to a gray cell. Sometimes, though, the indirect way ended up eliminating some heuristics, just as happened with 6 Principles – C, which has been also fulfilled by Heuristic 4.4.

The fourth stage of the research was the compilation of the heuristics contained in Mann et al. (2003). In this book, 37 new principles were added to the Inventive Principles. Some of them have a truly original sense, and others are just combinations of the existing ones. The whole set is believed by the authors to be capable of generating stronger solutions.

As might be expected, the Inventive Principles eliminated just a few of the Combined Principles of Mann et al. (2003), since the latter were addressed to fill in the "gaps" left by Altshuller. However, some of them were excluded due to the fact that they did not bring new information to TRIZ. Some Combined Principles and their sub-principles (for example, Combined Principles 46 – Apply Counter-balance and 44 – B – If the object is not round, supplement the existing shape to and overall round shape) are just specifications of more general Inventive Principles (in this case, Counterweight and Spheroidality), looking just like heuristics that have emerged from single peculiar patents, which deviate from the main scope of TRIZ.

The same happened while comparing the Combined Principles to the Standard Solutions. A small number of heuristics were eliminated, but those removed from the final list gave the same impression as the above mentioned ones. However, during the comparison with the 121H, a great number of similarities have been observed. Table 3 shows briefly the main correlations that have been found.

Table 3. Main correlations between the 121H and the 37 Combined and Special Principles

121 Heuristics	**Combined Principles**
Heuristic 1.8 To adapt the system to the human shape or its organs'.	Principle 61. Adapt A Tool To A Person A. Adapt the activity and/or tools to suit the user, taking into account the user's capabilities and preferences.
Heuristic 4.1 To transfer a process to other operation time. To carry out required action prior to the beginning or after the end of (sub)system's operation.	Principle 58. Postponed Action A. Use time at the end of or after an operation for finishing or correcting.
Heuristic 5.7 To divide a system into two parts – the heavy and the light ones, and to move only the light part.	Principle 42. Divide Into "Heavy" (Large) And "Light" (Small) Parts A. For convenient transportation of a heavy object, divide it into a heavy (large) and a light (small) part, so that only the light part has to be transported.
Heuristic 8.8 To reduce the number of functions of a (sub)system so that it becomes more specific and appropriate only to the main functions and requirements.	Principle 54. Specialization (A) A. Simplify an object, system, or process by making it more specialized.

After the comparison, only 43,8% of the original heuristics were maintained, which represents a total of 46 heuristics, included into 21 Combined Principles. The ones that have been kept are: 41(B,C); 43(D); 48(B,C,E); 49(D,E); 51(A,B,C,D); 53(A,B); 55(A,B); 57(A); 59(C); 62(A,B); 63(A); 64(A); 66(A,B,C); 67(A,B,C); 68(A,B); 69(A,B); 71(A,B,C,D); 72(A); 74(A,C); 76(A,C,D,E); 77(A,B,C).

The fifth and final step of the synthesis of a single list of heuristics was to compare the list of remaining original heuristics with the Templates developed by Yezersky (2006), proposer of the General Theory of Innovation (GTI). According to the author, GTI is not competitive, but complimentary to TRIZ (Yezersky, 2008).

As expected, a significant amount of the Templates were eliminated. Only 22 heuristics were left out of 63. Template 6, for example, had the same tips about measurement and detection operations introduced by the Standard Solutions, being entirely removed from the list. The same happened with most heuristics of Template 7 (Standard Restrictions on a Potential Solution) that also described the same ideas as class 5 of Standard Solutions.

All remaining Templates introduced new concepts, especially those that stimulate the use of a part of an object instead of it as a whole, and those that promote the elimination or postponement of auxiliary actions. Another template that deserves mention is Template 1.1 that brings one of the most important concepts embedded in the patterns of evolution of TRIZ, addressing the issue of dealing with the causes instead of effects. This one was not eliminated for the same reason as many standards: it had not shown up previously as a heuristic.

The remaining Templates are: 1.1, 1.2, 2.1(a), 2.2(a,b,c,d,e), 3.3(e), 4.1(f), 4.2(b,c), 5.1(b,c), 5.2(b), 7.1.1 (c), 7.1.2 (a), 7.2 (b,c,d), 7.3.1(a,c).

With all these steps, the compilation of a single list of heuristics was considered complete.

5. Results

The main result is the final list of 263 heuristics that can be found in the Appendix.

Through the work done, it was possible to organize the heuristics developed by leading authors in the field of TRIZ and Systematic Innovation under a new single index. The number of heuristics removed reached a mark of 43.9%.

Fig. 2 shows the increasing elimination percentage achieved along the evolution of the research, discriminating the percentage of novel and eliminated heuristics for each different group of heuristics. There is a sharp leap when we look at the 6 Principles, but this can be explained by the smaller number of heuristics in it.

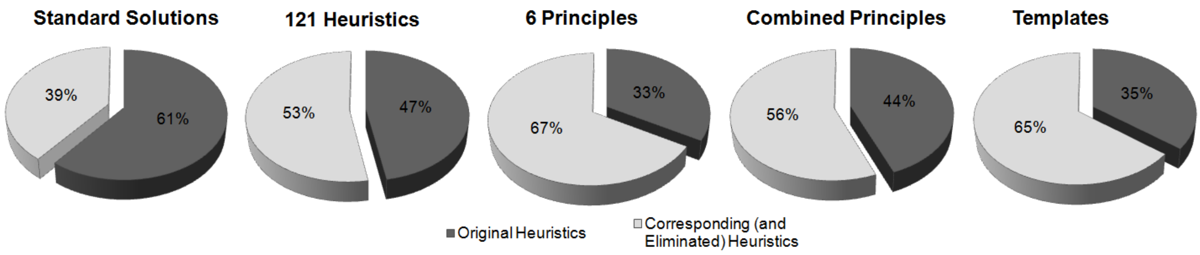

Fig. 2. Percentage of original and corresponding (and eliminated) heuristics in the five main groups of heuristics.

6. Analysis and Conclusions

Our most important conclusion is that the research objective was attained, with the creation of a single list of heuristics for inventive problem solving.

The final list is valuable, because it includes heuristics for solving problems of a wider range of areas of knowledge than each of the original groups studied separately and the single reference provided can spare a problem solvers' time presumably significantly.

The final list can be a first step towards the unification of all available heuristic-based problem solving theories, methodologies and methods.

This research can also be seen as a historical timeline of TRIZ and its derivatives. The chronological perspective allowed us to understand the root of many recently suggested heuristics and eliminate a large number of non-original ones. This can help TRIZ development, because its strengths are made clear, as well as its deficiencies and gaps.

Finally, despite the expressive number of heuristics suppressed in this work, the total still remains high. With this in mind, the list compiled so far is believed to be the first step to the creation of a minimum set of universal heuristics for inventive problem solving, motivating future research.

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Appendix A. List of TRIZ-related Heuristics for Problem Solving

A.1. Inventive Principles

Principle 1. Segmentation
- A. To divide an object into independent parts.
- B. To make an object sectional (for easy assembly and disassembly).Increase the degree of fragmentation or segmentation.
- C. To increase the degree of an object’s segmentation

Principle 2. Extraction
- A. To extract the “disturbing” part or property from an object.
- B. To extract only the necessary part or property from an object.

Principle 3. Local Quality
- A. To transit from homogeneous to heterogeneous structure of an object or outside environment (action).
- B. To carry-out different functions with different parts of an object.
- C. To place each part of an object in conditions that are most favorable for its operation.

Principle 4. Asymmetry
- A. To replace symmetrical form(s) with asymmetrical form(s).
- B. To increase the degree of asymmetry of an object, if it is already asymmetrical.

Principle 5. Consolidation
- A. To consolidate in space homogeneous objects or objects destined for contiguous operations.
- B. To consolidate in time homogeneous or contiguous operations.

Principle 6. Universality
- A. To remove other elements by making an object perform several different functions.

Principle 7. Nesting (“Matrioshka”)
- A. To place one object inside another. That object is placed inside a third one. And so on…

B. To pass one object through a cavity in another object.

Principle 8. Counterweight

A. To compensate for the weight of an object by combining it with another object that provides a lifting force.

B. To compensate for the weight of an object with aerodynamic or hydrodynamic forces influenced by the outside environment.

Principle 9. Prior Counteraction

A. To preload countertension to an object to compensate excessive and undesirable stress.

Principle 10. Prior action

A. To perform required changes to an object completely or partially in advance.

B. To place objects in advance so that they can go into action immediately from the most convenient location.

Principle 11. Cushion in Advance

A. To compensate for the relatively low reliability of an object with emergency measures prepared in advance.

Principle 12. Equipotentiality

A. To change the conditions of the work in such a way that it will not require lifting or lowering an object.

Principle 13. Do It in Reverse

A. To implement an opposite action instead of the direct action dictated by a problem(i.e., cooling instead of heating).

B. To make the moveable part of an object, or outside environment, stationary – and the stationary part moveable.

C. Turn an object upside-down.

Principle 14. Spheroidality

A. To replace linear parts with curved parts, flat surfaces with spherical surfaces, and cube shapes with ball shapes.

B. To use rollers, balls, spirals.

C. To replace linear motion with rotational motion; utilize centrifugal force.

Principle 15. Dynamicity

A. To alter the characteristics of an object, or outside environment, to provide optimal performance at each stage of operation.

B. To make an immobile object mobile. To make it interchangeable.

C. To divide an object into elements capable of changing their position relative to each other.

Principle 16. Partial or Excessive Action

A. To achieve more or less of the desired effect, if it is difficult to obtain 100% of a desired effect.

Principle 17. Transition Into a New Dimension

A. To transit one-dimensional movement, or placement, of objects into two-dimensional; two-dimensional to three-dimensional, etc.

B. To utilize multi-level composition of objects.

C. To incline an object, or place it on its side.

D. To utilize the opposite side of a given surface.

E. To project optical lines onto neighboring areas, or onto the reverse side, of an object.

Principle 18. Mechanical Vibration

A. To utilize oscillation.

B. To increase its frequency to ultrasonic, if oscillation exists.

C. To use the frequency of resonance.

D. To replace mechanical vibrations with piezo-vibrations.

E. To use ultrasonic vibrations in conjunction with an electromagnetic field.

Principle 19. Periodic Action
A. To replace a continuous action with a periodic one (impulse).
B. To change its frequency of an action that is already periodic.
C. To use pauses between impulses to provide additional action.
Principle 20. Continuity of Useful Action
A. To carry out an action without a break. All parts of the object should constantly operate at full capacity.
B. To remove idle and intermediate motion.
C. To replace “back-and-forth” motion with a rotating one.
Principle 21. Rushing Through
A. To perform harmful and hazardous operations at a very high speed.
Principle 22. Convert Harm into Benefit
A. To utilize harmful factors – especially environmental – to obtain a positive effect.
B. To remove one harmful factor by combining it with another harmful factor.
C. To increase the degree of harmful action to such an extent that it ceases to be harmful.
Principle 23. Feedback
A. To introduce feedback.
B. To change feedback if it already exists.
Principle 24. Mediator
A. To use an intermediary object to transfer or carry-out an action.
B. To connect temporarily the original object to one that is easily removed.
Principle 25. Self Service
A. To make an object service itself and carry-out supplementary and repair operations.
B. To make use of waste material and energy.
Principle 26. Copying
A. To use a simplified and inexpensive copy in place of a fragile original or an object that is inconvenient to operate.
B. To replace a visible optical copy with an infrared or ultraviolet copy.
C. To replace an object (or system of objects) with their optical image. The image can then be reduced or enlarged.
Principle 27. Dispose
A. To replace an expensive object with a cheap one, compromising other properties (i.e., longevity).
Principle 28. Replacement of Mechanical System
A. To replace a mechanical system with an optical, acoustic, thermal or olfactory system.
B. To use an electric, magnetic or electromagnetic field to interact with an object.
C. To replace fields that are: stationary with mobile; fixed with changing in time; random with structured.
D. To use fields in conjunction with ferromagnetic particles.
Principle 29. Pneumatic or Hydraulic Construction
A. To 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 hydrostatics cushions.
Principle 30. Flexible Membranes or Thin Films
A. To replace customary constructions with flexible membranes or thin film.
B. To isolate an object from its outside environment with flexible membranes or thin films.
Principle 31. Porous Material
A. To make an object porous, or use porous elements (inserts, covers, etc.).
B. To fill the porous of an object already porous with some substance in advance.
Principle 32. Changing the Color
A. To change the color of an object or its environment.

B. To change the degree of translucency of an object or its environment.
C. To use color additives to observe an object, or process, which is difficult to see.
D. To employ luminescent traces or trace atoms if such additives are already used.

Principle 33. Homogeneity
A. To make out objects interacting with the main object of the same material (or material with similar properties) as the main object.

Principle 34. Rejecting and Regenerating Parts
A. To reject (to discard, to dissolve, to evaporate) or to modify an element of an object during its work process after completing its function or becoming useless.
B. To restore used-up parts of an object during its work.

Principle 35. Transformation of Properties
A. To change the physical state of the system.
B. To change the concentration or density.
C. To change the degree of flexibility.
D. To change the temperature or volume.

Principle 36. Phase Transition
A. To use the phenomena of phase change (i.e., a change in volume, the liberation or absorption of heat, etc.).

Principle 37. Thermal Expansion
A. To use expansion or contraction of material by changing its temperature.
B. To use various materials with different coefficients of thermal expansion.

Principle 38 Accelerated Oxidation
A. To transit from one level of oxidation to the next higher level: 1)Ambient air to oxygenated; 2)Oxygenated to oxygen; 3)Oxygen to ionized oxygen; 4)Ionized oxygen to ozoned oxygen; 5)Ozoned oxygen to ozone; 6)Ozone to singlet oxygen.

Principle 39. Inert Environment
A. To replace a normal environment with an inert one.
B. To introduce a neutral substance or additives into an object.
C. To carry out a process in a vacuum.

Principle 40. Composite Materials
A. To replace homogeneous materials with composite ones.

A.2. Standard Solutions

1.1.1. Building a Su-Field Model: To introduce substances or fields if a given object is unreceptive (or barely receptive) to required changes and the problem description does not include any restrictions for introducing new elements.
1.1.2. Internal Complex Su-Field Model: To introduce into S1 or S2 permanent or temporary additives for increasing controllability, or imparting the required properties to the Su-Field Model if a given object is unreceptive (or barely receptive) to required changes, and the problem description does not include any restrictions for introducing substances and fields.
1.1.3. External Complex Su-Field Model: To attach to S1 or S2 an external temporary or permanent substance, S3, for the purpose of increasing controllability or imparting the required properties to the Su-Field Model, if a given object is unreceptive (or barely receptive) to required changes and the problem description includes restrictions on introducing additives into existing substances S1 and S2.
1.1.4. Su-Field Model with the Environment: To use the environment as an additive if a given object is unreceptive (or barely receptive) to required changes and the problem description includes restrictions on the introduction of additives – either into it or by attaching substances to it.

1.1.5. Su-Field Model with the Environment and Additives: To substitute, to decompose or to introduce additives on the environment if it does not contain the substances required to create a Su-Field Model according to Standard Solution 1.1.4.
1.1.8. Selective Maximum Mode: To use the maximum mode in selected zones and minimum mode in other zones if a selective maximum mode is required. The field then should be:

2. minimum; To introduce a substance capable of generating a local field in all places where maximum influence is required (for example, thermites for thermal influence, explosives for mechanical influence, etc.)

1.2.1. Eliminating Harmful Interaction by Introducing S3: To introduce a third substance, which costs nothing (or close to it), between two substances that not require to be closely adjacent to one another if there are both useful and harmful actions between them in the Su-Field Model.
1.2.2. Eliminating Harmful Interaction by Introducing Modified S1 and/or S2: To introduce a third substance, which is a modification of the existing substances, between two substances that not require to be immediately adjacent to one another if there are both useful and harmful actions between them in the Su-Field Model and the problem description includes restrictions on the introduction of foreign substances.
1.2.3. “Drawing Off” a Harmful Action: To introduce a second substance that ""draws off"" (absorb) the harmful action of a field on a substance.
1.2.4. Counteracting a Harmful Action with F2: To introduce second field (F2) to neutralize or to transform the harmful action occurring between two substances that must be immediately adjacent to one another if there are both useful and harmful actions between them in the Su-Field Model.
1.2.5. “Switching Off” a Magnetic Influence: To switch off the ferromagnetic properties of a substance by demagnetization either under shock or heating above the Curie Point to destroy a Su-Field Model with a magnetic field.
2.1.2. Double Su-Field Model: To apply a second field to S2 if a poorly controlled system needs to be improved but you may not change the elements of the existing system.
2.3.2. Matching the Rhythms of F1 and F2: To match or mismatch the frequencies of applied fields in complex Su-Field Models intentionally.
2.4.2. Ferro-Field Models: To substitute (or to add to) one of the substances of a Su-Field or Pre-Ferro-Field Model with ferromagnetic particles, and apply a magnetic or electromagnetic field to enhance system controllability.

Control efficiency increases with increased fragmentation of the ferromagnetic particles. Thus, Ferro-Field Models evolve according to the following line: granules – powder – finely ground ferromagnetic particles. Control efficiency also increases along the line related to that in which the ferro-particle substance is included: solid substance – granules – powder – liquid.

2.4.4. Applying Capillary Structures in Ferro-Field Models: To utilize the capillary or porous structures inherent in many Ferro-Field Models to enhance them.
2.4.5. Complex Ferro-Field Models: To use additives (such as a coating) to give a non-magnetic object magnetic properties. May be temporary or permanent.
2.4.6. Ferro-Field Models with the Environment: To introduce ferromagnetic particles into the environment, if it is not possible or prohibited either substitute a substance with ferromagnetic particles or to introduce additives.
2.4.11. Electro-Field Models: To utilize the interaction between either an external electromagnetic field and electrical current, or between two currents, if it is difficult to introduce ferromagnetic particles or to magnetize an object. The current can be created either by electrical contact with the source or by electromagnetic induction.
2.4.12. Rheological Liquids: To use an electro-rheological liquid with viscosity controlled by an electric field if magnetic liquid is unusable (for example, a mixture of fine quartz powder with toluene).

3.1.2. Enhanced Links in Bi- and Poly-Systems: To further develop the links between Bi- and poly-systems to enhance them. This can be done by connecting them via rigid links or toward the dynamization of the links.
3.1.3. System Transition 1b: Increasing the Differences Between Elements: To increase the differences between Bi- and poly-systems' elements (System Transition 1-b): from identical elements (e.g., a set of identical pencils), to elements with shifted features (a set of pencils of various colors), to a set of different elements (a case of drawing instruments), to a combination of inverted features – or element and anti-element (a pencil with an eraser).
3.1.5. System Transition 1c: Opposite Features of the Whole and its Parts: To separate incompatible features of Bi- and poly-systems between the system as a whole and its parts (System Transition 1-c). As a result, the system is utilized on two levels, with the whole system having feature F, and its parts or particles having the opposite feature, anti-F.
3.2.1. System Transition 2: Transition to the Micro-Level: To go from macro-level to micro-level in order to enhance a system in any evolutionary stage. The system or its parts is substituted by a substance capable of performing the required action under the influence of some field.
4.1.1. Replacing Detection or Measurement with System Change: To modify the system in a way that eliminates the need for measuring or detecting it.
4.1.3. Measurement as Two Consecutive Detections: To carry out two consecutive detections of change if you have a problem with detection or measurement and it is impossible to eliminate these processes and it is inappropriate to manipulate a copy of an object instead of the object itself.
4.2.1. Measurement Su-Field Model: To use a field at an output with a regular or double Su-Field Model if it is difficult to measure or detect an incomplete Su-Field Model.
4.2.2. Complex Measurement Su-Field Model: To introduce easily-detected additives to detect or measure a system or its part.
4.2.3. Measurement Su-Field Model with the Environment: To introduce additives capable of generating an easily-detected (or easily-measured) field into the environment if a system is difficult to detect or measure at certain moments in time, and it is impossible to introduce additives; changes in the state of the environment will provide information about changes in the system.
4.2.4. Obtaining Additives in the Environment: To produce additives in the environment itself, for example, through its destruction or by changing its phase state, if it is impossible to introduce additives into the environment directly. In particular, gas or vapor bubbles obtained by electrolysis, cavitation, or other methods are often applied.
4.4.1. Measurement Pre-Ferro-Field Model: To add or to make use of a ferromagnetic substance and a magnetic field in a system (by means of permanent magnets or loops of electric current) to facilitate measurement.
4.5.1. Transition to Bi- and Poly-Systems: To use two or more measuring/detection systems, or make multiple measurements/detections if a single measurement system does not give sufficient accuracy.
4.5.2. Direction of Evolution: Systems for measurement and/or detection evolve in the following direction:

1. To measure a function
2. To measure the first derivate of the function
3. To measure the second derivate of the function

5.1.1.2. To introduce a field instead of the substance
5.1.1.3. To apply an external additive instead of an internal one
5.1.1.4. To introduce a small amount of a very active additive
5.1.1.6. To introduce the additive temporarily
5.1.1.8. To obtain required additives via decomposition of introduced chemicals
5.1.1.9 To obtain required additives through decomposition of either the environment or the object itself, by electrolysis or phase transformation, for example.

5.2.1. Multiple Use of Available Fields: To apply, first and foremost, existing fields whose carriers are the substances involved of a Su-Field Model if it is necessary to introduce a field.
5.2.2. Introducing Fields from the Environment: To apply fields existing in the environment if it is necessary to introduce a field, but is impossible to apply existing fields whose carriers are the substances involved of a Su-Field Model.
5.2.3. Utilizing Substances Capable of Originating Fields: To apply fields that can be generated by substances existing in the system or the environment.
5.3.2. Phase Transition 2: Dynamic Phase State – To utilize substances capable of changing their phase state depending on the work conditions.
5.3.4. Phase Transition 4: Transition to a Dual Phase State – To substitute a mono-phase state for a dual-phase state.
5.3.5. Phase Interaction: To create interactions between the parts or phases of the system in order to enhance its effectiveness.
5.4.1. Self-controlled Transitions: To use an object that can periodically transit itself to different physical states through the utilization of reversible physical transitions such as ionization-recombination, decomposition-association, etc.
5.4.2. Amplifying the Output Field: To use a substance-transformer in the near-critical state if a strong action under a weak influence is required. Energy is accumulated in the substance and the influence works as a trigger.

A.3. 121 Heuristics

1.5 To give a convex (or more convex) shape to a system carrying a load.
1.6 To compensate the undesirable shape by accretion with the opposite outline form.
1.7 To carry out a system in the form of other technique with similar function or purpose; part(s) of either a human body, an animal or a plant.
1.8 To adapt the system to the human shape or its organs'.
1.9 To use a natural principle of formation found in (alive or inanimate) nature in similar conditions of work.
1.10 To separate a flat or volumetric raw material either in a rational or optimal way; to change the shape of details for more complete use of a raw material.
1.11 To design the shape of details as close as possible to the shapes and sizes cutout parts.
1.12 To find the global – optimum shape of a system.
1.13 To find the best integral shape of the system (e.g., visual allocation of the main subsystems or functional elements, elimination of unimportant and auxiliary subsystems or details).
1.14 To use various kinds of symmetry and asymmetry, dynamic and static properties of the form, rhythm, nuance and contrast.
1.15 To carry out harmonic coordination of shapes of various (sub)systems or elements.
1.16 To choose (to create) the most beautiful shape of the system and its casing.
2.4 To attach an additional specialized tool to the base system.
2.6 To replace a source of energy, type of drive, color, or other parameter.
2.8 To change the configuration of (sub)systems essentially, in order to reduce layout expenses.
2.11 To use a uniform drive, uniform control system or power supply.
2.15. To combine (unite) obviously or traditionally incompatible (sub)systems, by removing the arising contradictions.
2.16. To choose a raw material that ensures minimal labor input during the processing or manufacturing of subsystems (and/or elements).
2.18. To find the global - optimum structure.
3.6 To change the direction of action of an operation (or a whole process) or environment.

3.11 To proceed from the sequential connection of subsystems to the parallel or mixed. Inversion of expedient.
3.13 To divide a subsystem into two parts: "volumetric" and "non-volumetric"; to take out the first part from the boundaries limiting the volume.
3.14 To take out subsystems that can be affected by harmful factors, far from the zone of their action.
3.15 To transfer the system or its subsystems to other environment where the harmful factors are absent or at least inactive.
3.16 To withdraw from traditional spatial restriction or overall dimensions.
4.1 To transfer a process to other operation time. To carry out required action prior to the beginning or after the end of (sub)system's operation.
4.6 To change the existing sequence of operations or functions fulfillment.
4.7 To proceed from sequential realization of operations to parallel or simultaneous. Inversion of expedient.
5.1 To change the direction of rotation.
5.5 To replace a traditionally complex trajectory by a simpler movement (e.g., along a line or circle). Inversion of expedient.
5.6 To replace a bending by a stretching or compression. To replace compression by stretching.
5.7 To divide a system into two parts – the heavy and the light ones, and to move only the light part.
5.9 To replace friction of sliding by friction of rolling. Inversion of expedient.
6.4 To remove a superfluous material not carrying a functional loading.
6.5 To change surface properties of a (sub)system (e.g., to strengthen a surface or to neutralize properties of a materials on a surface).
6.8 To replace some neighbor systems by systems with other physical and/or chemical properties.
6.9 To use other material (e.g., a cheaper one or a newer one).
6.15 To replace diversity of materials in (sub)systems by adopting a single material. To replace diversity of shape in (sub)systems by a standard shape.
6.16 To produce (sub)systems from materials with different properties that provides the necessary effects (e.g., materials with different thermal expansion coefficients).
6.18 To choose materials so as to minimize waste during manufacturing of details (e.g., to proceed from cutting or machining to hydroforming, extruding, injecting or solid freeform fabrication).
6.19 To proceed to waste-free technologies (e.g., to use a higher valued input material, and compensate this by eliminating manufacturing wastes and/or allowing these to be used for manufacturing other parts).
6.20. To consolidate materials by mechanical, thermal, electro-physical, electrochemical, laser and other kinds of processing.
6.21 To use materials with higher specific characteristics (e.g., corrosion or electrical resistivity).
6.22 To use reinforced, composite, porous and other new perspective materials.
6.23 To use a material with time dependent properties (e.g., rigidity or transparency).
7.4 To differentiate sources of energy and provide backup source(s) of energy. To place a source of energy as close as possible to the working subsystem.
7.5 To perform control, management and drive of each (sub)system independently.
7.8 To divide a system into two parts: hot and cold, and then isolate one from the other.
7.11 To include in a system a necessary (sub)system (or necessary property) and to strengthen it and/or improve conditions of work.

a) To enhance an important subsystem in the system and to improve conditions of its work;

c) To enhance the most important property in the system and to strengthen it.

8.3 To change overall dimensions, volume or length of a (sub)system while switching it to (or from) a working and non-working condition.
8.7. To change the harmful factors so that they cease to be harmful.

8.8 To reduce the number of functions of a (sub)system so that it becomes more specific and appropriate only to the main functions and requirements.
8.9. To exaggerate considerably the sizes or other parameters of a (sub)system and to find applications for this. Inversion of expedient.
8.10 To increase the intensity of technological processes by making an operational working zone in the shape of a platform or closed volume.
8.12 To find global - optimum parameters of a technical (sub)system according to various criteria of development.
8.13 To proceed to other physical principles of action with cheaper or available sources of energy, or with higher efficiency.
8.14 To define those (sub)systems that should also be changed after constructive improvement of any (sub)system, so that the efficiency of the whole system could be increased even more.

A.4. 6 Principles

A. Multistep principle: To increase efficiency of action by using a group of uniform objects instead of the single object.
E. Match of impedances: To determine, during design, the input impedance level and set the system internal impedance to that input signal. If an exact match is impossible, minimize losses by amplifying or attenuating the input signal or dispersing the input signal via a few channels, each of whose impedance can be matched with the system impedance.

A.5. Combined Principles

Principle 41. Reduce The Weight (Size) Of Individual Parts
- B. To strengthen the parts that bear the main load while reducing weight/dimensions of other parts.
- C. To reduce the load in order to reduce the weight/dimensions.

Principle 43. Apply Support
- D. To cover the path, along which an object is to be transported, with a slippery layer of ice, oil, foam, or small balls.

Principle 48. Partial Preliminary Action
- B. To make a notch, score, or perforation.
- C. To reduce local strength.
- E. To “make a road”, that is, to make it easy for tools to proceed in a desired direction.

Principle 49. Concentrate Energy
- D. To change from three-dimensional action to surface action, or to action at a point.
- E. To use specific geometrical shapes.

Principle 51. Create Standards For Comparison
- A. To use a light beam, (or a shadow, a reflection, or a photograph of a light beam) to obtain a model (standard) of a straight line.
- B. To use a liquid surface to represent a horizontal plane to model (standard) of a horizontal surface.
- C. To build a model (standard) of a conic section (circle, ellipse or hyperbola) by pouring a liquid into a cone shaped container. The container can be positioned so the liquid surface forms the desired sectional curve.
- D. To build a model (standard) of a parabolic surface-of-revolution using the surface of a liquid in a gyrating container.

Principle 53. Integration Into A Poly-System
- A. To combine a group of objects and to use them together if the system’s complexity is due to small dimensions of objects it works with.

B. To combine a group of objects and then measure or detect the combined signal if a weak signal is difficult to measure or detect.

Principle 55. Reduce Scattering

A. To group objects so that losses due to scattering will be decreased.

B. To give an object a shape that will minimize losses due to scattering. For example, to reduce heat loss, a spherical shape is the best.

Principle 57. Reduce Stages Of Energy Transformation

A. To reduce the number of energy transformations that take place by using a new method of operation.

Principle 59. Field Transformation

C. To introduce an additive in the form of powder, bubbles, threads, films or drops, which will transform the existing field into a required one.

Principle 62. Shape Transformation For Strength

A. To introduce an element with greater mechanical strength, such as ribs, corrugations, double-T shapes, channels, box constructions, etc.

B. To change the shape of the part that is exposed to the wear making it the same as the shape previously produced by wear.

Principle 63. Transform An Object Micro-Structure

A. To alter the structure or composition of an object in order to strengthen the most heavily-loaded or weakest part.

Principle 64. Isolation/Insulation

A. To isolate the system from the source of the harmful effect, in particular in the case of wear, fire, explosion, evaporation, thermal impact, etc.

Principle 66. Change An Undesired Action

A. To influence undesired effect in order to make conditions secure for the system.

B. To redirect the harmful action away from the system.

C. To weaken the harmful effect by stretching out the time during which the action takes place.

Principle 67. Remove Or Modify The Source Of Harm

A. To modify the source of the undesired effect so that the effect cannot occur.

B. To remove the source of harm (or the damaged part) from the system.

C. To trap harmful products.

Principle 68. Modify Or Substitute The System

A. To transform that portion of the system where the harmful effect is believed to take place.

B. To divide your system into parts so that the parts compensate for the harmful effect of other parts.

Principle 69. Increase The System’s Resistance To The Harmful Effect

A. To decrease the sensitivity of the system to a harmful effect.

B. To create “immunity” to the harmful effect.

Principle 71. Localize And/Or Locally Weaken A Harmful Effect

A. To confine the harmful effect to a specific location or time interval.

B. To shelter a harmful substance inside another substance.

C. To weaken a harmful effect at a specific location and/or for a specific period of time.

D. To distribute or dilute the harmful effect.

Principle 72. Mask Defects

A. To multiply the defect so that a pattern develops to hide the defect if a local defect cannot be eliminated.

Principle 74. Reduce Contamination

A. To remove the contaminating effect via excluding the possibility of a contact with contaminated materials.

C. To remove continually small amounts of contaminating substance while operation continues.

Principle 76. Reduce Human Errors

A. To divide critical operations into a series of component operations, each performed by a different person. Then, an occasional error by one person cannot cause undue harm.

C. To prevent dangerous human operator inaction (due to forgetfulness, for example) by requiring some positive action from the operator to keep the system operating normally.

D. To stop the system functioning normally or to go into a safe mode of operation when the operator becomes inactive.

E. To engage feedback to prevent a user from accidentally taking a certain action. Ask for confirmation that the user desires that action.

Principle 77. Block Dangerous Actions

A. To make sure the operator must use both hands to keep them out of a dangerous area, especially when starting the dangerous operation.

B. To set a limit to prevent dangerous operating conditions.

C. To create conditions under which the harmful effect cannot occur.

A.6. Templates

Template 1 – Addressing a problem at a higher system level

Template 1.1 - To deal with the causes instead of the effects.

Template 1.2 - To avoid the need for auxiliary operations.

Template 2 – Problems related to time

Template 2.1. The need for additional time

a) To eliminate the need for an action.

Template 2.2. Postpone an action: If there is a need for delaying an action (functionality of a system), the Primary Function Chain must be broken temporarily and then restored at the needed moment.

a) To turn the system off temporarily;

b) To introduce a temporary blocking (breaking) element;

c) To make the action object temporarily insensitive to the action;

d) To move away temporarily the action object;

e) To take out a new (“foreign”) blocking element that has been introduced into the system by using the resources only.

Template 3 – Problems related to space

Template 3.3. Modify an object/action

e) To modify an action so that it does not require an object to be that big.

Template 4 – Prevent a negative event from happening

Template 4.1. Destroy/modify Flow Source/Path

f) To change the Flow Structure.

Template 4.2. Make the system unavailable for the Flow

b) To fool the Flow: To hide the System (to make the System unrecognizable by the Flow);

c) To misinform the Flow.

Template 5 – Wrong range/output function

Template 5.1. Modify an action (Flow/Path)

b) To create / to destroy the Flow structure;

c) To maximize losses.

Template 5.2. Modify the action object by making objects of an action sensitive / insensitive to the action

b) To place objects where action concentration is high / low.

Template 7 – Standard Restriction on a potential solution

Template 7.1. Introducing a new element when introduction is prohibited

Template 7.1.1 – Ready-to-be-used elements

c) Use of part of an element.

Template 7.1.2. Changing an existing element when prohibited

a) To modify existing elements to obtain the required property (shape, symmetry, dimensions, movement, structure, composition, phase state, electrical conductivity, magnetization, transparency, other physical, chemical and geometrical characteristics).

Template 7.2. Changing an existing element when prohibited

b) To change only a part of an element;

c) To find other elements in the system that have the same characteristic and connect them so that the connection would change the required characteristic;

d) To divide the element into parts, one of which would have the required characteristic and then re-establish connection between the parts.

Template 7.3. Breaking a connection within a system when prohibited

Template 7.3.1. If there is a need to break a connection between two elements because it causes a NE, but it is prohibited or impossible because of a reason (e.g. system functioning will deteriorate), then apply the Separation Principles

a) To break connection temporarily;

c) To break the Flow into two parts and reintegrate them so that the Negative Event disappears.