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Classification of TRIZ Inventive Principles and Sub-Principles for Process Engineering Problems

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Abstract. The paper proposes a classification approach of 40 Inventive Principles with an extended set of 160 sub-principles for process engineering, based on a thorough analysis of 155 process intensification technologies, 200 patent documents, 6 industrial case studies applying TRIZ, and other sources. The authors define problem-specific sub-principles groups as a more precise and productive ideation technique, adaptable for a large diversity of problem situations, and finally, examine the anticipated variety of ideation using 160 sub-principles with the help of MATCEM-IBD fields.

Keywords: TRIZ, 40 Inventive Principles, process engineering, process innovation.

1 Introduction

The scope of process innovation and intensification in process engineering (PE) is interdisciplinary, diverse and complex. It focuses on design, operation, control, and optimization of chemical, physical and biological processes and has applications in a wide range of industrial sectors. However, the typical scenarios for developing vital innovations in PE are not easy as it may be initially perceived. Process engineering problems are specific and complex situations involving multiple physical-chemical parameters, processing methods, and process equipment [1]. Furthermore, process intensification (PI) and implementation of new technologies and eco-innovative solutions in process engineering often lead to numerous additional negative side effects and secondary problems, resulting in three types of engineering contradictions [2], as illustrated in Fig. 1.

The Theory of Inventive Problem Solving (TRIZ) is one of the most comprehensive, systematically organized invention and creative thinking methodologies for enhancing the intensification of processes in PE [3, 4]. One of the main advantages of TRIZ is that it helps to find new inventive solutions for a given problem in a systematic way by using the entire potential of science, engineering and outside of the originally formulated problem field [5, 6].

TRIZ has already found successful applications in PE, such as new development of chemical or biochemical products and technologies [7, 8, 9], problem-solving with inventive principles and standard solutions [10, 11], TRIZ evolutionary forecast of equipment [12] and technologies [13]. Authors outline in their recent paper [3] that the fundamentals and objectives of Process Intensification [14-17] are highly consistent with the evolution laws of technical systems in the TRIZ methodology. Among numerous

components of TRIZ, the 40 Inventive Principles belong to the tools most frequently mentioned in research papers [18] and used in practice [19].

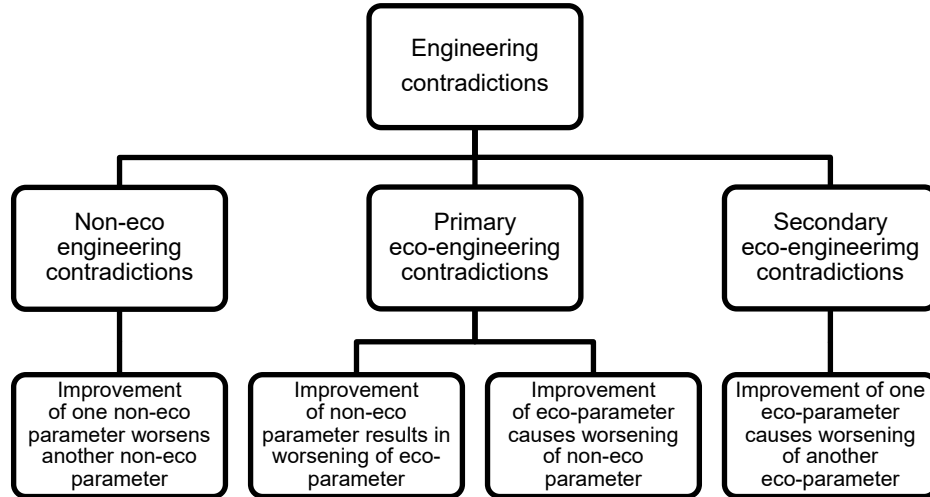


Fig. 1. Types of engineering contradictions in process intensification [2]

Over the past decades, the 40 TRIZ Inventive Principles have been widely used to solve technical contradictions in various engineering domains and enhanced through adjustments, illustrations and examples for specific fields of application. The 40 Inventive Principles are good for newcomers to TRIZ, simple to use or modify for specific technical domains and can be easily integrated into brainstorming or daily engineers work [3]. Moreover, several studies on Inventive Principles have been conducted to improve the quantity and quality of ideation process for the various engineering domains. The study [20] has grouped Inventive Principles in redesign service approaches (RSA) to solve service problems. Russo and Spreafico [21] classified Inventive Principles through functional behaviour structure (FBS) ontology. Livotov and Petrov [6] established specific groups of Inventive Principles for industrial and business practices. Mann [22] proposed a classification of the Inventive Principles based on three areas of intervention: space, time and interface. Further, the Inventive Principles also have been enhanced by providing engineering interpretations and examples for chemical engineering [23, 24]. Recently, Petrov (2018) presented the “universal” 40 Inventive Principles with engineering illustrations with changed or extended names or formulations of certain principles and sub-principles [25].

Even though many studies have expanded and enhanced Inventive Principles and sub-principles to a broader range of applications, the major challenge for the engineers remains a precise selection of the strongest principles or sub-principles for specific problems and fast solving of primary and secondary contradictions. Therefore, this study classifies and proposes sets of recommended 40 Inventive Principles with 160

sub-principles for different domains in process engineering such as, for example, reduction of environmental impact, intensification of processes involving solids handling, reduction of energy and material losses. The classification method summarizes and evaluates the recent research studies of the authors [2-4, 26] on further development of TRIZ principles for PE, based on thorough analysis of 200 patent documents, 155 process intensification technologies, and 6 comprehensive industrial case studies. Authors of the paper also recommend the specific sub-principles groups as a promising more precise and productive ideation technique, adaptable for a large variety of problem situations. Furthermore, the anticipated variety of ideation using 160 sub-principles is verified with the help of nine MATCEM-IBD fields (Mechanical, Acoustic, Thermal, Chemical, Electric, Magnetic, Intermolecular, Biological and Data Processing).

2 Methodology

In the authors' previous studies [2-4, 26] the top 10-20 most effective and frequently used Inventive Principles in process engineering (PE) have been identified in PE patents, process intensification (PI) technologies, and industrial case studies, and compared with the inventive principles recommended by process intensification strategies [27] and the classical Altshuller matrix [5]. It is important to note that the performed analysis was carried out using the extended version of 40 Inventive Principles with 160 sub-principles proposed in [3] and presented in Appendix, which addresses the needs of process engineering regarding multiple physical-chemical parameters, processing methods, and process equipment. Furthermore, compared with the original number of sub-principles varying between 85 and 95 [5], the new version of the Inventive Principles contains at least 65 additional sub-principles relevant for process engineering. Additionally, the sub-principles have been assigned to MATCEM-IBD fields of interactions in order to evaluate the anticipated variety and completeness of ideation with sub-principles for PE problems.

2.1 Identification and analysis of Inventive Principles in patent documents

The patent literature is the most important and complete source for actual technical information [28, 29]. Identification of inventive principles from the PE patents has been associated with invention goals, processing methods or equipment, and with the specific PE sub-domains. Thus, 150 patent documents in the field of solids handling and 50 patent documents in the field of eco-friendly process intensification technologies, published between 2000 and 2017, were selected and analyzed for this purpose [3, 26]. For example, in the eco-technology patent document US20140299028A1 the goal of invention is the reduction environmental pollution and fouling, when burning coal by adding sorbents to raw material (powder components containing calcium, alumina, silica, iron, magnesium, and a halogen sorbent). The corresponding associated inventive sub-principles are 9a) Counter harm in advance and 11b) Preventive measures.

2.2 Identification and analysis of Inventive Principles in PI technologies

In addition to the patent documents, the identification of inventive principles typical for process engineering has been performed by analysis of the existing process intensification (PI) technologies. The PI technological databases are continuously evolving and currently cover a wide range of more than 155 processing methods and equipment, such as equipment involving and not involving chemical reactions, multi-functional reactors, hybrid separation methods, alternative energy sources and others [14, 15]. Many of these PI technologies are not only fully described and documented but also validated or implemented in the industry. The obtained information about underlying inventive principles in PI technologies is as a rule more precise and reliable in comparison to the inventive principles derived from the patents only. For example, our research paper [3] shows the identification of TRIZ inventive principles and sub-principles in a Spiral Flash Dryer [30], a new compact equipment combining the advantages of a flash dryer and of a fluidized bed. Corresponding inventive sub-principles for spiral flash drier are 29a) Gas as a working element; 29d) Fluidization of powders or granulates; 14b) Use sphere, cylinders, cones; 14d) Swirling motion; 17e) Increase contact area between objects or substances; 21b) Boost the process that may result in new useful properties.

Among 155 analyzed PI technologies about 58 technologies can be assigned to the thermal operations and methods. These thermal technologies can be recommended for solving of eco-problems such as high energy consumption and energy losses. The example of the microwave heating technology in Table 1 illustrates the identified characteristic pair of inventive sub-principles, such as 28a) Use electromagnetics and 35d) Change temperature.

Table 1. TRIZ Inventive Principles assigned to the microwave heating technology

N	Key characteristics of the PI technology	TRIZ Inventive Principles	Corresponding sub-principles (inventive operators)
1	Heating of dipole molecules such as water	35 Transform physical and chemical properties	35d) Change temperature
2	Microwaves enhance the motions of free ions/ionic species resulting in even heating.	28 Replace mechanical working principle	28a) Use electromagnetics

Additionally, analysis of 15 strongest process intensification strategies [27] helps to point out the corresponding TRIZ Inventive Principles and sub-principles, as illustrated in Table 2 [26].

Table 2. Classification of TRIZ Inventive Principles in 15 process intensification strategies in PE (fragment)

15 Process Intensification strategies [27]	40 TRIZ Inventive Principles
1. Modification of operating conditions: temperature, pressure, concentration	35. Transformation of the physical and chemical properties: Change an object's aggregate state (35a), change the object's concentration or consistency (35b), change the object's temperature (35d), change process chemistry (35e)
2. New solvents to reduce environmental impact of processes	
3. Modification of fluid phase properties by change of pressure or temperature	40. Composite materials: composition of materials in different aggregate states (40e)
3. Modification of fluid phase properties by addition of gas bubbles or solid particles	39. Inert environment: Inert coatings or additives (39d)
4. Inert species addition in multiphase flow: emulsifying additives, viscosifying agents ...	24. Mediator: intermediate object (24a)
...	...
10. Parallelism in the process, multi-scale design	5. Combining: parallel operations (5a), combine process steps to perform parallel or contiguous operations (5b)
15. Coupling with separation	

2.3 Analysis of Inventive Principles applied in industrial case studies

In 6 case studies the Advanced Innovation Design Approach (AIDA) and TRIZ Inventive Principles have been applied by the authors for process intensification in the field of chemical, pharmaceutical, ceramic, and mineral industries: 1) Separation of ceramic-metal powders, 2) Dry granulation of ceramic powders, 3) Metal ore beneficiation, 4) Granulation of pharmaceutical powders, 5) Drying of pharmaceutical powders, and 6) Mixing of chemical reagents [4]. After the performed problem definition and ranking, the process engineers and researchers applied the enhanced version of 40 Inventive Principles with in total 160 sub-principles. The application of the principles has been performed for each partial problem separately in the recommended order proposed in Table 3 [6], whereby each idea generation phase has been started with statistically strongest principles (group 1), optionally followed by the group 2 in case of design problems or by the group 3 for process optimization problems. The application of TRIZ inventive principles resulted in 234 new solution ideas and 28 patentable concepts, whereby each idea was assigned to one or more inventive sub-principles. To the outcomes of the study [4] belongs the identification of the most effective inventive principles and corresponding sub-principles, which have led to the strongest ideas integrated in 28 innovation concepts.

Table 3. Recommended order for application of 40 Inventive Principles in the case studies [6]

Group 1: Statistically strongest principles	(35) Transform physical and chemical properties, (10) Prior useful action, (1) Segmentation, (28) Replace mechanical working principle, (2) Leaving out / Trimming, (15) Dynamism and adaptability, (19) Periodic action, (3) Local quality, (17) Shift to another dimension, (13) Inversion, (18) Mechanical vibration, (26) Copying.
Group 2: Principles for solving design prob- lems	(6) Universality, (5) Combining, (29) Pneumatic or hydraulic constructions, (30) Flexible shells or thin films, (7) Nesting / Integration, (8) Anti-weight, (4) Asymmetry, (40) Composite materials, (24) Mediator, (14) Sphericity and Rotation, (23) Feedback and automation, (31) Porous materials, (25) Self-service.
Group 3: Principles for specific problems in Process En- gineering	(16) Partial or excessive action, (27) Disposability, (20) Continuity of useful action, (32) Change colour, (21) Skipping / Rushing through, (11) Preventive measure, (33) Homogeneity, (22) Converting harm into benefit, (39) Inert environment, (37) Thermal expansion, (36) Phase transitions, (38) Strong oxidants, (34) Rejecting and regenerating parts, (12) Equipotentiality, (9) Prior counteraction of harm.

2.4 Identification of inventive principles for solving eco-contradictions with the Altshuller matrix

In their prior research work [26], the authors have applied the classical 39x39 TRIZ Contradiction Matrix, also known as Altshuller matrix [5], for identification of the inventive principles for eco-engineering contradictions in PE with 5 ecologically relevant parameters, such as *Energy consumption of the moving object* (n19) and of the *non-moving object* (n20), *Energy losses* (n22), *Material losses* (n23), *Amount of substance* (n26). The mentioning frequency of the inventive principles has been evaluated from the following eco-contradictions regarding efficiency of energy or material utilization:

- a) 65 primary eco-contradictions resulting from improvement of parameters *Energy consumption of the moving object* (n.19), *Energy consumption of the non-moving object* (n.20), and *Energy losses* (n.22) on the one hand and worsening of the other 34 non-ecological parameters of the Altshuller matrix on the other hand.
- b) 64 primary eco-contradictions resulting from improvement of parameters *Material losses* (n.23), *Amount of substance* (n.26) on the one hand and worsening of the other 34 non-ecological parameters of the matrix on the other hand.

In general, a comparison of most frequently recommended top 10 inventive principles from the Altshuller Matrix with the top 10 inventive principles extracted from 50 eco-patents or 58 thermal operations [26] reveals about 50% overlapping of principles in different top 10 lists.

3 Results

3.1 Identification of strongest Inventive Principles and sub-principles in PE

Table 4 summarizes the recommended or statistically most frequently applied TRIZ Inventive Principles and sub-principles, which were extracted from 8 different sources of information and analysis, such as PE patents, PI technologies, industrial cases studies, scientific literature, classical Altshuller matrix and recommendations presented in the Table 3. Additionally, the ranking method [26] using mean occurrence frequency of principles and sub-principles in different sources allows one to select and to recommend top 10 or top 20 lists of principles and sub-principles for different applications and tasks in process engineering, as shown in the Table 5.

Table 4. Identified most frequently used or recommended TRIZ Inventive Principles and sub-principles for PE problems

Sources	Problem category	Inventive Principles	Sub-principles
1) 150 solids handling patents [3]	Intensification of processes involving solids in ceramic and pharmaceutical industries	40, 35, 14, 29, 5, 24, 6, 33, 1, 18, 9, 15, 20, 25, 28, 31, 13, 17, 22, 34.	40a, 35b, 40c, 6a, 33a, 29a, 20a, 24a, 31a, 9a, 34a, 35d, 1e, 3a, 14a, 14b, 14c, 15c, 18a, 22a.
2) 100 eco-patents [26]	Environmental problems and eco-engineering contradictions in PE	25, 2, 22, 15, 9, 1, 29, 34, 35, 40, 5, 21, 33, 10, 11, 14, 28, 37, 3, 8.	2a, 25b, 22a, 25a, 15a, 21a, 29a, 33a, 34a, 1a, 5b, 9a, 9b, 10a, 11b, 35b, 37a, 40a, 3a, 14a.
3) 155 PI-technologies [3]	Intensification of processing technologies, equipment and methods	14, 29, 35, 2, 5, 36, 6, 28, 24, 18, 30, 1, 10, 7, 13, 8, 15, 17, 19, 20.	36a, 2e, 14c, 29e, 6b, 28a, 14b, 35a, 35d, 5a, 30e, 18a, 24b, 29a, 35b, 2a, 5b, 10a, 20a, 19d.
4) 58 thermal PI technologies [26]	Reduction of energy consumption and losses	35, 5, 2, 29, 28, 36, 10, 20, 24, 30, 7, 13, 6, 17, 1, 15, 31, 34, 3, 9.	29e, 2e, 35d, 35a, 36a, 5a, 28a, 5b, 10a, 20a, 30e, 35b, 2a, 6a, 13d, 24b, 5c, 7a, 7b, 24a.
6) 15 PI strategies [27]	Supporting of process intensification strategies	35, 40, 39, 24, 17, 8, 5, 1, 3, 19, 15, 25.	35a, 35b, 35c, 35d, 35e, 40e, 39a, 24a, 17e, 17b, 8d, 5a, 5b, 1a, 3a, 19a, 15a, 25b, 25c.
7) 6 industrial case studies [4]	Processes involving solids handling	35, 14, 13, 3, 28, 1, 5, 22, 2, 16, 17, 10, 40, 24, 6, 31, 29, 25, 19, 15.	35b, 13d, 28a, 3c, 14b, 22a, 1d, 3d, 14c, 16a, 35c, 2b, 5b, 10a, 24c, 40a, 1a, 2e, 6b, 14a.
8) Altshuller contradiction matrix [5]	Reduction of energy consumption and losses	35, 10, 18, 3, 29, 28, 40, 31, 2, 15.	
	Reduction of material consumption and losses	35, 19, 2, 18, 11, 15, 28, 7, 1, 38.	

3.2 Sets of recommended Inventive Principles and sub-principles for PE

As presented in Table 5, the following sets of TRIZ Inventive Principles and sub-principles can be recommended for efficient ideation and systematic problem solving in specific domains of PE, such as intensification of processing technologies, equipment and methods in general (1), environmental problems (2), intensification of processes involving solids handling (3).

The authors also advocate the view that application of statistically strongest sub-principles is more efficient, less time-consuming and can be characterized by more precise ideation. For example, the top 15 inventive principles for solving environmental contradictions contain 61 sub-principles. Evidently, the use of the strongest 20...25 sub-principles with higher ranking significantly reduces time expenditures for idea generation.

Table 5. Recommended sets of top 10 TRIZ Inventive Principles and sub-principles for ideation in process engineering

Set	Problem category	Inventive Principles and sub-principles
1	Intensification of processing technologies, equipment and methods	Top 10 Inventive Principles: 14. Sphericity and Rotation, 29. Pneumatic or hydraulic constructions, 35. Transform physical and chemical properties, 2. Leaving out / Trimming, 5. Combining, 36. Phase transitions, 6. Universality, 28. Replace mechanical working principle, 24. Mediator, 18. Mechanical vibration.
		Top 10 sub-principles: 36(a), 2(e), 14(c), 29(e), 6(b), 28(a), 14(b), 35(a), 35(d), 5(a).
2	Environmental problems and eco-engineering contradictions	Top 10 Inventive Principles: 35. Transform physical and chemical properties, 2. Leaving out / Trimming, 5. Combining, 25. Self-service / Use of resources, 29. Pneumatic or hydraulic constructions, 28. Replace mechanical working principle, 15. Dynamism and adaptability, 22. Converting harm into benefit, 10. Prior useful action, 9. Prior Counteraction of harm.
		Top 10 sub-principles: 2(a), 29(e), 25(b), 2(e), 22(a), 35(d), 5(b), 10(a), 35(a), 28(a).
3	Intensification of processes involving solids handling	Top 10 Inventive Principles: 35. Transform physical and chemical properties, 40. Composite materials, 14. Sphericity and rotation, 28. Replace mechanical working principle, 13. Inversion, 3. Local quality, 1. Segmentation, 5. Combining, 29. Pneumatic or hydraulic constructions, 24. Mediator.
		Top 10 sub-principles: 40(a), 35(b), 28(a), 13(d), 14(b), 22(a), 14(c), 29(a), 40(c), 16(a)

3.3 Anticipated variety of ideation based on 160 inventive sub-principles

In addition to the quantity and quality of ideas, the ideas breath or variety belongs to the major objective measures of ideation effectiveness [31]. One of the common approaches to assess the ideas variety stipulates that every idea must be assigned to the eight engineering MATCEM-IB fields known in TRIZ: Mechanical, Acoustic, Thermal, Chemical, Electric, Magnetic, Intermolecular, and Biological [4, 32]. A more uniform distribution of the ideas over the eight fields corresponds to a higher of breadth or variety. As the variety is strongly influenced by the ideation techniques [32], this section analyses how it can be affected by use of 160 inventive sub-principles. For this purpose, 160 sub-principles have been assigned to 11 categories, presented in Fig. 2. The category “Independent” includes sub-principles, which don’t relate directly to any field or engineering domain, like for example 1e) *Segment process* or 2d) *Trim process steps*. The category “Universal” includes the sub-principles which can be assigned to any of fields, like 4b) *Enhance asymmetry*. To these categories belong respectively 36 and 29 sub-principles. The idea generation with the independent or universal sub-principles doesn’t compulsorily lead to a change of the “field” in the working principle of a technical system. The remaining 95 sub-principles can be distributed with multiple selection between Mechanical (52 sub-principles), Acoustic (5), Thermal (19), Chemical (25), Electric and Magnetic (14), Intermolecular (13) and Biological (1) fields. Additionally, 6 sub-principles (23a, 23b, 23c, 23d, 26d, 26e) has been exclusively assigned to the introduced Data processing or Information field.

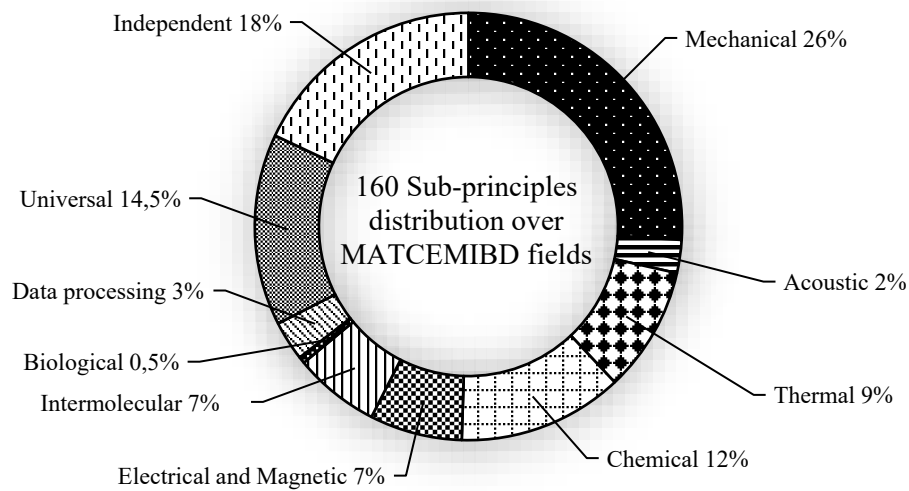


Fig. 2. Distribution of the 160 sub-principles over MATCEM-IBD fields, universal and independent categories (multiple selection for the MATCEM-IBD fields possible).

The performed analysis of sub-principles assignment to MATCEM-IBD fields depicts a rather unbalanced distribution with 26% of mechanical sub-principles on the one hand, and 3% data processing or 0,5% biological sub-principles on the other hand. This

fact should be taken into consideration by the selection of the sub-principles for specific application sets in order to enable a higher ideation variety. At the same time the extension of classical 40 Inventive Principles with additional sub-principles helps to increase the shares of chemical (12%), thermal (9%) and intermolecular (7%) sub-principles relevant for process engineering.

4 Conclusions

The selection of strongest inventive principles for specific problems in process engineering remains more challenging due to the complexity of interdisciplinary problem situations. The presented research classifies 40 TRIZ Inventive Principles and sub-principles for their applications in different problem and innovation situations in process engineering with the objective to enable a fast selection of strongest ideation operators in the industrial practice. The proposed approach of multi-source identification of strongest inventive principles from complementary patent or technology databases and literature can be also applied in other engineering domains. The authors advocate that the idea generation with strongest sub-principles can significantly improve ideation efficiency in quantity, quality and variety in the early stage of innovation process. This statement can be the subject matter of a future research. The performed interdisciplinary and completeness analysis of 160 inventive sub-principles relating to the MATCEM-IBD fields attests balanced results for process engineering but reveals a necessity of taking into account additional informational and biological sub-principles.

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Appendix: 40 Inventive Principles and 160 sub-principles without description and examples [3, 26]

1. **Segmentation**: 1(a) Segment object; 1(b) Dismountable design; 1(c) Segment to microlevel; 1(d) Segment function; 1(e) Segment process.
2. **Leaving out / Trimming**: 2(a) Take out disturbing parts; 2(b) Trim components; 2(c) Trim functions; 2(d) Trim process steps; 2(e) Extract useful element.
3. **Local quality**: 3(a) Non-uniform object; 3(b) Non-uniform environment; 3(c) Different functions; 3(d) Optimal conditions; 3(e) Opposite properties.
4. **Asymmetry**: 4(a) Asymmetry; 4(b) Enhance asymmetry; 4(c) Back to symmetry.
5. **Combining**: 5(a) Combine similar objects; 5(b) Combine functions; 5(c) Combine different properties; 5(d) Combine complementary properties; 5(e) Combine opposing properties.
6. **Universality**: 6(a) Universal object; 6(b) Universal process.
7. **Nesting / Integration**: 7(a) Nested objects; 7(b) Passing through cavities; 7(c) Telescopic systems.
8. **Anti-weight**: 8(a) Use counterweight; 8(b) Buoyancy; 8(c) Aero- or hydrodynamics; 8(d) Use gravitational or centrifugal forces.
9. **Prior Counteraction of harm**: 9(a) Counter harm in advance; 9(b) Anti-stress; 9(c) Cooling in advance; 9(d) Rigid construction.
10. **Prior useful action**: 10(a) Prior useful function; 10(b) Pre-arrange objects; 10(c) Prior process step.
11. **Preventive measure / Cushion in advance**: 11(a) Safety cushion; 11(b) Preventive measures.
12. **Equipotentiality**: 12(a) Keep altitude; 12(b) Equipotentiality; 12(c) Avoid fluctuations.
13. **Inversion**: 13(a) Inversed action; 13(b) Make fixed parts to movable; 13(c) Upside down; 13(d) Reversed sequence; 13(e) Invert environment.
14. **Sphericity and Rotation**: 14(a) Ball-shaped forms; 14(b) Spheres and cylinders; 14(c) Rotary motion; 14(d) Swirling motion; 14(e) Centrifugal forces.

15. **Dynamism and adaptability:** 15(a) Optimal performance; 15(b) Adaptive object; 15(c) Adaptive process; 15(d) Flexible elements; 15(e) Change statics to dynamics.
16. **Partial or excessive action:** 16(a) One step back from ideal; 16(b) Optimal substance amount; 16(c) Optimal action.
17. **Shift to another dimension:** 17(a) Multi-dimensional form; 17(b) Miniaturization; 17(c) Multi-layered structure; 17(d) Tilt object; 17(e) 3D interaction.
18. **Mechanical vibration:** 18(a) Oscillate object; 18(b) Ultrasound; 18(c) Resonance; 18(d) Piezo-electric vibrators; 18(e) Ultrasound with other fields.
19. **Periodic action:** 19(a) Periodic action; 19(b) Change frequency; 19(c) Use pauses; 19(d) Match frequencies; 19(e) Separate in time.
20. **Continuity of useful action:** 20(a) Continuous process; 20(b) Operate at full load; 20(c) Eliminate idle work.
21. **Skipping / Rushing through:** 21(a) Skip hazardous operations; 21(b) Boost the process.
22. **Converting harm into benefit:** 22(a) Utilize harm; 22(b) Remove harm with harm; 22(c) Amplify harm to avoid it.
23. **Feedback and automation:** 23(a) Introduce feedback; 23(b) Enhance feedback; 23(c) Automation; 23(d) Data processing.
24. **Mediator:** 24(a) Intermediate object; 24(b) Temporary mediator; 24(c) Intermediary process.
25. **Self-service / Use of resources:** 25(a) Object serves itself; 25(b) Utilize waste resources; 25(c) Use environmental resources.
26. **Copying:** 26(a) Simple copies; 26(b) Optical copies; 26(c) Invisible copies; 26(d) Digital models; 26(e) Virtual reality.
27. **Disposability / cheap short-living objects:** 27(a) Short-living objects; 27(b) Multiple cheap objects; 27(c) One-way objects; 27(d) Create objects from resources.
28. **Replace mechanical working principle:** 28(a) Use electromagnetics; 28(b) Optical systems; 28(c) Acoustic system; 28(d) Chemical and biosystems; 28(e) Thermal Systems.
29. **Pneumatic or hydraulic constructions:** 29(a) Gaseous or liquid flows; 29(b) Gas or liquid under pressure; 29(c) Use vacuum; 29(d) Fluidization; 29(e) Heat transfer and exchange.
30. **Flexible shells or thin films:** 30(a) Flexible shells or films; 30(b) Flexible isolation; 30(c) Piezoelectric foils; 30(d) Use brushes; 30(e) Use membranes.
31. **Porous material:** 31(a) Add porous elements; 31(b) Fill pores with substance; 31(c) Use capillary effects; 31(d) Physical effects and porosity; 31(e) Structured porosity.
32. **Change colour:** 32(a) Change colour; 32(b) Change transparency; 32(c) Coloured additives; 32(d) Use tracer.
33. **Homogeneity:** 33(a) Similar materials; 33(b) Similar properties; 33(c) Uniform properties.
34. **Rejecting and regenerating parts:** 34(a) Discard useless parts; 34(b) Restore parts; 34(c) Create parts on time and on site.
35. **Transform physical and chemical properties:** 35(a) Change aggregate state; 35(b) Change concentration; 35(c) Change physical properties; 35(d) Change temperature; 35(e) Change chemical properties.
36. **Phase transitions:** 36(a) Phase transitions; 36(b) 2nd order phase transitions
37. **Thermal expansion:** 37(a) Thermal expansion; 37(b) Bi-metals; 37(c) Heat shrinking; 37(d) Shape memory.

- 38. **Strong Oxidants:** 38(a) Oxygen-enriched air; 38(b) Use pure oxygen; 38(c) Use ionized oxygen; 38(d) Use ozone; 38(e) Strong oxidants.
- 39. **Inert environment:** 39(a) Inert environment; 39(b) Inert atmosphere process; 39(c) Process in vacuum; 39(d) Inert coatings or additives; 39(e) Use foams.
- 40. **Composite materials:** 40(a) Composite materials; 40(b) Use anisotropic properties; 40(c) Additives in composites; 40(d) Composite microstructure; 40(e) Combine different aggregate states.