

TRIZ

In a few words: The Resolution of a problems Technical and Physical Contradictions in order to create an Ideal System and Ideal Solution.

Overview

TRIZ, also known as the Theory of Inventive Problem Solving (TIPS), provides a methodology for creative engineering design. TRIZ (a Russian acronym for Theory of Inventive Problem Solving) is a problem solving technique originally developed by Genrich S. Altshuller in the 1950s. TRIZ theory holds that there are two types of problems people face: Problems with generally known solutions and problems with unknown solutions.

Problems with known solutions can generally be resolved by a relatively simple search of information found in books, technical journals, or with subject matter experts. These solutions follow a generic problem-solving model somewhat along the following lines:



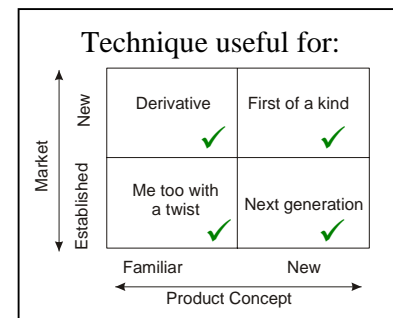
In this model, a problem of a similar nature to the one we now face is first found. This similar problem already has a known solution, from which a solution to our problem can be derived. An example (from Glenn Mazur's excellent site on TRIZ), is that of designing a rotating cutting machine (the problem). For this machine to function to the required specifications, a powerful but low 100 rpm motor is required. Since most AC motors are high rpm (3600 rpm), the similar standard known problem is how to reduce the speed of an AC motor. The standard known solution to this problem is a gearbox or transmission. From this point, a gearbox for the cutting machine can now be designed with appropriate dimensions, weight, rpm, torque, etc.

The second type of problem, known as an Inventive Problem, is one to which no solution is known and one that may contain contradictory requirements.

To try and solve these problems, methods such as brainstorming and trial-and-error are often used. Depending on how complex the problem is, the number of trials may vary. If the solution lies within one's area of expertise, then the number of trials will be fewer. If the solution is not within that field, then the inventor must look beyond his experience and knowledge to new fields such as chemistry or electronics, for example. The number of trials will then grow larger depending on how well the inventor can master psychological innovation stimulating tools like brainstorming, intuition, and creativity. A further problem is that psychological tools like experience and intuition are very difficult to transfer to other people within an organization.

Psychological inertia

This leads to a problem referred to as psychological inertia, where the solutions being considered are within one's own experience and we therefore do not look at alternative technologies to develop new



concepts. This relates closely to the Gestalt principle known as the law of Prägnanz, which states that psychological organisation will always be as concise, simple and unified as immediate events permit. In other words, our brain will take the route requiring the least amount of effort or energy in the achievement of solving a problem.

An ideal solution to a clutch problem, for example, may be electromechanical, but is outside the experience of the mechanical engineer and so remains untried and may even be invisible to him.

History

Genrich S. Altshuller, born in the former Soviet Union in 1926, developed a better approach, relying not on psychology but on technology. Serving in the Soviet Navy as a patent expert in the 1940s, his job was to help inventors apply for patents. He found, however, that he was often asked to assist in solving problems as well. He found that the psychological tools did not meet the rigors of inventing in the 20th century. This therefore led him to search for a better method of problem solving. Altshuller was looking for a theory of invention that would satisfy the following conditions:

- Be a systematic, step-by-step procedure
- Be a guide through a broad solution space to direct to the ideal solution
- Be repeatable and reliable and not dependent on psychological tools
- Be able to access the body of inventive knowledge
- Be able to add to the body of inventive knowledge
- Be familiar enough to inventors by following the general approach to problem solving

Altshuller examined a large number of patents, looking for the hallmarks of truly creative inventions. He found that over 90% of the problems faced by inventors had been solved in various technical fields using any of only about forty fundamental inventive principles. In over 1,500,000 patents examined, only 40,000 had somewhat inventive solutions; the rest were just improvements.

Altshuller more clearly defined an inventive problem as one in which the solution causes another problem to appear (increasing the strength of a metal plate, for example, causing its weight to get heavier). Usually, inventors must resort to a trade-off and compromise between the features and thus do not achieve an ideal solution. In his study of these truly creative patents, Altshuller found that many described a solution that eliminated or resolved the contradiction and required no trade-off.

He found that often the same problems had been solved over and over again using one of only forty fundamental inventive principles. If later inventors had possessed knowledge of the work of earlier ones, solutions could have been discovered more quickly and efficiently.

As a result of this research, he and his colleagues made a new classification of these patents without regard to their industry basis. By removing the subject matter Altshuller was able to elucidate the problem solving process. He categorized the patent solutions into five levels:

Level	Examples
Level 1: Routine design problems solved by methods well known within the specialty or inside a company. (About 32% of the solutions occurred at this level.)	The ability to change the size of weighted (lead) shoes for divers to fit different size feet by adjusting their length. (It is curious that this development occurred only in the 1960's, some 70 years after the invention of divers' shoes; i.e., for 70 years all divers used uncomfortable shoes of the same size.)
Level 2: Minor corrections (45%) to an existing system, by methods known within the industry.	Potatoes can rot as a result of bacteria naturally present on their surface. Heating in boiling water kills the bacteria, but too much heat will cook the inside of the potatoes. The potatoes can be exposed for a short time (5 seconds) to a 700°C flame. This kills the surface bacteria without affecting the inside of the potatoes. Welding two different metals together (such as copper and aluminum) can present a challenge. One useful technique is to use a spacer made of a metal that can be welded to both of the incompatible metals.
Level 3: Fundamental improvements (18%) to an existing system which	Cattle feed consists of various cut grasses that have been mixed with special equipment. Producing the grass mixture by sowing the various

resolve contradictions, by methods known outside the industry.	grasses together yields a crop that is difficult to till. Furthermore, one grass species may suppress the others. The grasses can be sown in narrow parallel strips, and harvested across the strips. Thus, the grasses will get mixed in the receiving bin of the mower. An electromechanical relay element has a finite number of switching cycles. Substituting a cheap semiconductor relay element increases the number of switching cycles and decreases the switching time and weight of device.
Level 4: New generations (4%) using a new scientific (rather than technological) principle to perform the primary functions of the system.	Microscope, steam engine, photocopy machine, atomic force microscope.
Level 5: Rare scientific discoveries or pioneering inventions (less than 1%) of essentially a new system.	Discovery of x-rays, penicillin, DNA, laser, high-Tc superconductors.

He also noted that with each succeeding level, the source of the solution required broader knowledge and more solutions to consider before an ideal one could be found.

Level	Degree of inventiveness	% of solutions	Source of knowledge	Approximate # of solutions to consider
1	Apparent solution	32%	Personal knowledge	10
2	Minor improvement	45%	Knowledge within company	100
3	Major improvement	18%	Knowledge within the industry	1000
4	New concept	4%	Knowledge outside the industry	100,000
5	Discovery	1%	All that is knowable	1,000,000

With each succeeding level, the knowledge required of the inventor, as well as the potential profit from the invention, increases. So does the psychological inertia that can prevent the recognition of a different approach to a problem solution, one that lies outside one's own direct experience. Altshuller therefore searched for a methodology that, by overcoming these psychological barriers, would help in creating higher-level innovative solutions. The approach Altshuller developed did not try to reproduce the thinking process of the original inventors, but rather to synthesize a methodology that, if followed, would guide a would-be inventor to the same types of solutions. He distilled the problems, contradictions, and solutions in all the patents he studied into a theory of inventive problem solving which he named TRIZ.

The Theory of Inventive Problem Solving

The TRIZ method is based on three major principles:

- The Resolution of Technical and Physical Contradictions
- The Evolution of Systems
- The Ideal System and Ideal Solution.

The fundamental essence of TRIZ resides in the resolution of contradictions. A contradiction arises when mutually exclusive demands are placed on the same system. Improvement or resolution of one of the demands then leads to deterioration of others. Finding the physical contradictions that are the hidden root of the technical problem is the key to resolving the contradiction.

For a plane can take off easily, for example, its wing area must be large but a large wing area also causes high drag at supersonic speeds. A compromise solution would be to have a medium sized wing area and, though this would work, it would compromise the quality of both the ease of take-off and the supersonic speed.

The power of TRIZ is that it does not accept this type of compromise and states the problem as it ideally should be: the airplane wings must be large, and they must be small. However, the plane needs large

wings and small wings at different times. A solution therefore presents itself in which the plane could both take off easily and fly with low drag by using retractable wings.

One of the more interesting laws of TRIZ is the Law of Increasing Ideality. It states that technical systems evolve toward increasing degrees of ideality, where ideality is defined as the quotient of the sum of the system's useful effects, U_i , divided by the sum of its harmful effects, H_j .

$$Ideality = \frac{\sum U_i}{\sum H_j}$$

Useful effects include all the positive results of the system's functioning. Harmful effects include all the negative effects such as cost, undesired increase in size, energy consumed, pollution, danger, etc. The ideal state is one in which there are only benefits and no harmful effects.

It is to this state that all product systems strive to evolve. Product developers aim both to design product with greater benefits and to reduce the cost of labor, materials, energy, and harmful side effects. Normally, when improving a benefit would result in increased harmful effects, a trade-off is made, but the Law of Ideality drives designs to eliminate or solve any trade-offs or design contradictions. The ultimate ideal final result would theoretically be a product where the beneficial function exists but the machine itself does not. The evolution of the mechanical spring-driven watch into the electronic quartz crystal watch is a good example of moving towards ideality.

TRIZ Steps

1. **Select a technical problem.**

Usually a system has more than one problem and often the formulation of the main problem is incorrect. TRIZ helps the inventor define the main technical contradiction that he wants to eliminate. A technical contradiction represents the conflict between two parts of a system. For example, if undertaking an action A produces a desired effect, but also results in degradation of property B, A and B would lie on two axes of the Contradiction Matrix. Making the choice of technical contradiction marks the transition from a problem situation to the start of the problem solution. About 60-70% of the time, if a technical contradiction is contained in the Contradiction Matrix the inventor is able to go immediately to step (4) and use the corresponding inventive principle.

2. **Formulate a physical contradiction.**

The inventor should replace the technical contradiction with a physical one in the following form: A given element should have the property A to execute a necessary function, and should have the property "anti-A" to satisfy other conditions of the problem. A physical contradiction results from incompatible requirements on the physical condition of the same element. Successful formulation of a physical contradiction usually shows the problem's nucleus. Intensifying the contradiction often makes the problem solution straightforward, so the inventor can use lists of effects at step 4.

3. **Formulate an ideal solution.**

At this step the inventor should decide how to increase the beneficial factors and eliminate harmful factors. Comparison of the result with the ideal solution demonstrates whether the inventor was right or not in the choice of the major technical contradiction. The ideal solution works as a goal in steps 4-6.

4. **Find resources for the solution, making use of the capabilities of TRIZ.**

At this step the inventor should use the instruments of TRIZ such as the contradiction matrix and principles of inventiveness, etc.

5. **Determine the "strength" of the solutions and choose the best one.**

Here TRIZ recommends comparison of one's solutions with the Ideal Solution and evaluation of the results with a cost-benefit-type analysis. At this point the solution of the problem is accomplished. Usually, the solution is at Level 2-3 if a Technical Contradiction has been resolved,

and at 3-4 is a Physical Contradiction has been resolved. The next two steps are used to predict the development of the system in the future and to improve the TRIZ process itself.

6. Predict the development of the system considered within the problem.

At this step the inventor should use the TRIZ laws of evolution of technical systems and forecasting techniques. This step allows one to see potential future problems in the system, its subsystems and the super-system (the larger system in which the system considered is itself a subsystem), and to choose possible methods for their solution. In general, this step leads to future work to improve the system and increase the competitive position of the inventor. TRIZ offers a new thinking method, in which one's problem is considered as a "system of systems".

7. Analyze the solution process in order to prevent similar problems.

This step allows the inventor to improve the algorithm itself.

TRIZ example for a beverage can (from Glenn Mazur's website)

Step 1. Identifying the Problem.

A beverage can. An engineered system to contain a beverage. Operating environment is that cans are stacked for storage purposes. Resources include weight of filled cans, internal pressure of can, rigidity of can construction. Primary useful function is to contain beverage. Harmful effects include cost of materials and producing can and waste of storage space. Ideal result is a can that can support the weight of stacking to human height without damage to cans or beverage in cans.

Step 2: Formulate the problem in terms of physical contradictions

Restate the problem in terms of physical contradictions. Identify problems that could occur. Could improving one technical characteristic to solve a problem cause other technical characteristics to worsen, resulting in secondary problems arising? Are there technical conflicts that might force a trade-off?

We cannot control the height to which cans will be stacked. The price of raw materials compels us to lower costs. The can walls must be made thinner to reduce costs, but if we make the walls thinner, it cannot support as large a stacking load. Thus, the can wall needs to be thinner to lower material cost and thicker to support stacking-load weight. This is a physical contradiction. If we can solve this, we will achieve an ideal engineering system.

Step 3: Formulate an ideal solution.

Altshuller extracted from over 1,500,000 worldwide patents 39 standard technical characteristics that cause conflict. These are called the 39 Engineering Parameters and are shown in the table below.

The 39 Engineering Parameters

1. Weight of moving object	14. Strength	27. Reliability
2. Weight of nonmoving object	15. Durability of moving object	28. Accuracy of measurement
3. Length of moving object	16. Nonmoving object Durability	29. Accuracy of manufacturing
4. Length of nonmoving object	17. Temperature	30. Harmful factors acting on object
5. Area of moving object	18. Brightness	31. Harmful side effects
6. Area of nonmoving object	19. Energy spent by moving object	32. Manufacturability
7. Volume of moving object	20. Energy spent by nonmoving object	33. Convenience of use
8. Volume of nonmoving object	21. Power	34. Repairability
9. Speed	22. Waste of energy	35. Adaptability
10. Force	23. Waste of substance	36. Complexity of device
11. Tension, pressure	24. Loss of information	37. Complexity of control
12. Shape	25. Waste of time	38. Level of automation
13. Stability of object	26. Amount of substance	39. Productivity

At this step the inventor should decide how to increase the beneficial factors and eliminate harmful factors. This means finding the contradicting engineering principles. First find the principle that needs to

be changed. Then find the principle that is an undesirable secondary effect. State the standard technical conflict.

The standard engineering parameter that has to be changed to make the can wall thinner is "#4, length of a nonmoving object." In TRIZ, these standard engineering principles can be quite general. Here, "length" can refer to any linear dimension such as length, width, height, diameter, etc. If we make the can wall thinner, stacking-load weight will decrease. The standard engineering parameter that is in conflict is "#11, stress."

The standard technical conflict is: the more we improve the standard engineering parameter "length of a nonmoving object," the more the standard engineering parameter "stress" deteriorates.

Step 4: Look for Analogous Solutions and Adapt to current problem Solution

Altshuller also extracted 40 "inventive principles" from the worldwide patent search. These are hints that will help an engineer find a highly inventive solution to the problem.

To find which inventive principles fits the current problem best, Altshuller created the Table of Contradictions. The Table of Contradictions lists the 39 Engineering Parameters on the X-axis (undesired secondary effect) and Y-axis (feature to improve). In the intersecting cells, are listed the numbers of the appropriate Inventive Principles to use for a solution.

Both these tables are given towards the end of this document

The engineering parameters in conflict for the beverage can are "#4, length of a nonmoving object" and "#11, stress."

The feature to improve (Y-axis) is the can wall thickness or "#4, length of a nonmoving object" and the undesirable secondary effect (X-axis) is loss of load bearing capacity or "#11, stress." Looking these up on the Table of Contradictions, we find the numbers 1, 14, and 35 in the intersecting cell.

Inventive Principle 1. Segmentation

A. Divide an object into independent parts.

- *Replace mainframe computer by personal computers.*
- *Replace a large truck by a truck and trailer.*
- *Use a work breakdown structure for a large project.*

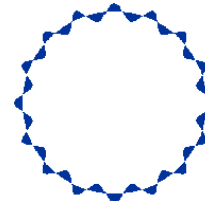
B. Make an object easy to disassemble.

- *Modular furniture*
- *Quick disconnect joints in plumbing*

C. Increase the degree of fragmentation or segmentation.

- *Replace solid shades with Venetian blinds.*
- *Use powdered welding metal instead of foil or rod to get better penetration of the joint.*

For our example, using Inventive Principle 1c. "Increase the degree of an object's segmentation," the wall of the can could be changed from one smooth continuous wall to a corrugated or wavy surface made up of many "little walls." This would increase the edge strength of the wall yet allow a thinner material to be used.



Cross section of corrugated can wall.

Principle 14. Spheroidality - Curvature

A. Instead of using rectilinear parts, surfaces, or forms, use curvilinear ones; move from flat surfaces to spherical ones; from parts shaped as a cube (parallelepiped) to ball-shaped structures.

- *Use arches and domes for strength in architecture.*

B. Use rollers, balls, spirals, domes.

- *Spiral gear (Nautilus) produces continuous resistance for weight lifting.*
- *Ball point and roller point pens for smooth ink distribution*

C. Go from linear to rotary motion, use centrifugal forces.

- *Produce linear motion of the cursor on the computer screen using a mouse or a trackball.*
- *Replace wringing clothes to remove water with spinning clothes in a washing machine.*

Using Inventive Principle 14 a., the perpendicular angle at which most can lids are welded to the can wall can be changed to a curve. Spheroidality Strengthens Can's Load Bearing Capacity



- *Use spherical casters instead of cylindrical wheels to move furniture.*

Principle 35. Parameter changes

- Change an object's physical state (e.g. to a gas, liquid, or solid).
 - *Freeze the liquid centers of filled candies, then dip in melted chocolate, instead of handling the messy, gooey, hot liquid.*
 - *Transport oxygen or nitrogen or petroleum gas as a liquid, instead of a gas, to reduce volume.*
- Change the concentration or consistency.
 - *Liquid hand soap is concentrated and more viscous than bar soap at the point of use, making it easier to dispense in the correct amount and more sanitary when shared by several people.*
- Change the degree of flexibility.
 - *Use adjustable dampers to reduce the noise of parts falling into a container by restricting the motion of the walls of the container.*
 - *Vulcanize rubber to change its flexibility and durability.*
- Change the temperature.
 - *Raise the temperature of food to cook it. (Changes taste, aroma, texture, chemical properties, etc.)*
 - *Lower the temperature of medical specimens to preserve them for later analysis.*

Change the composition to a stronger metal alloy used for the can wall to increase the load bearing capacity.

The 40 Inventive Principles of TRIZ

Principle 1. Segmentation

- Divide an object into independent parts.
 - *Replace mainframe computer by personal computers.*
 - *Replace a large truck by a truck and trailer.*
 - *Use a work breakdown structure for a large project.*
- Make an object easy to disassemble.
 - *Modular furniture*
 - *Quick disconnect joints in plumbing*
- Increase the degree of fragmentation or segmentation.
 - *Replace solid shades with Venetian blinds.*
 - *Use powdered welding metal instead of foil or rod to get better penetration of the joint.*

Principle 2. Taking out

- Separate an interfering part or property from an object, or single out the only necessary part (or property) of an object.
 - *Locate a noisy compressor outside the building where compressed air is used.*
 - *Use fiber optics or a light pipe to separate the hot light source from the location where light is needed.*
 - *Use the sound of a barking dog, without the dog, as a burglar alarm.*

Principle 3. Local quality

- Change an object's structure from uniform to non-uniform, change an external environment (or external influence) from uniform to non-uniform.
 - *Use a temperature, density, or pressure gradient instead of constant temperature, density or pressure.*
- Make each part of an object function in conditions most suitable for its operation.
 - *Lunch box with special compartments for hot and cold solid foods and for liquids*
- Make each part of an object fulfill a different and useful function.
 - *Pencil with eraser*
 - *Hammer with nail puller*
 - *Multi-function tool that scales fish, acts as a pliers, a wire stripper, a flat-blade screwdriver, a Phillips screwdriver, manicure set, etc.*

Principle 4. Asymmetry

- Change the shape of an object from symmetrical to asymmetrical.
 - *Asymmetrical mixing vessels or asymmetrical vanes in symmetrical vessels improve mixing (cement trucks, cake mixers, blenders).*

- *Put a flat spot on a cylindrical shaft to attach a knob securely.*
- B. If an object is asymmetrical, increase its degree of asymmetry.
- *Change from circular O-rings to oval cross-section to specialized shapes to improve sealing.*
 - *Use astigmatic optics to merge colors.*

Principle 5. Merging

- A. Bring identical or similar objects closer together (or merge them); assemble identical or similar parts to perform parallel operations.
- *Personal computers in a network*
 - *Thousands of microprocessors in a parallel processor computer*
 - *Vanes in a ventilation system*
 - *Electronic chips mounted on both sides of a circuit board or subassembly*
- B. Make operations contiguous or parallel; bring them together in time.
- *Link slats together in Venetian or vertical blinds.*
 - *Medical diagnostic instruments that analyze multiple blood parameters simultaneously Mulching lawnmower*

Principle 6. Universality

- A. Make a part or object perform multiple functions; eliminate the need for other parts.
- *Handle of a toothbrush contains toothpaste*
 - *Child's car safety seat converts to a stroller*
 - *Mulching lawnmower (Yes, it demonstrates both Principles 5 and 6, Merging and Universality.)*
 - *Team leader acts as recorder and timekeeper.*
 - *CCD (Charge coupled device) with micro-lenses formed on the surface*

Principle 7. "Nested doll"

- A. Place one object inside another; place each object, in turn, inside the other.
- *Measuring cups or spoons*
 - *Russian dolls*
 - *Portable audio system (microphone fits inside transmitter, which fits inside amplifier case)*
- B. Make one part pass through a cavity in the other.
- *Extending radio antenna*
 - *Extending pointer*
 - *Zoom lens*
 - *Seat belt retraction mechanism*
 - *Retractable aircraft landing gear stow inside the fuselage (also demonstrates Principle 15, Dynamism).*

Principle 8. Anti-weight

- A. To compensate for the weight of an object, merge it with other objects that provide lift.
- *Inject foaming agent into a bundle of logs, to make it float better.*
 - *Use helium balloon to support advertising signs.*
- B. To compensate for the weight of an object, make it interact with the environment (e.g. use aerodynamic, hydrodynamic, buoyancy and other forces).
- *Aircraft wing shape reduces air density above the wing, increases density below wing, to create lift. (This also demonstrates Principle 4, Asymmetry.)*
 - *Vortex strips improve lift of aircraft wings.*
 - *Hydrofoils lift ship out of the water to reduce drag.*

Principle 9. Preliminary anti-action

- A. If it will be necessary to do an action with both harmful and useful effects, this action should be replaced with anti-actions o control harmful effects.
- *Buffer a solution to prevent harm from extremes of pH.*
- B. Use initial stresses in an object to oppose known undesirable working stresses.
- *Pre-stress rebar before pouring concrete.*
 - *Masking anything before harmful exposure: Use a lead apron on parts of the body not being exposed to X-rays. Use masking tape to protect the part of an object not being painted*

Principle 10. Preliminary action

- A. Perform, before it is needed, the required change of an object (either fully or partially).
- *Pre-pasted wall paper*

- *Sterilize all instruments needed for a surgical procedure on a sealed tray.*
- B. Pre-arrange objects such that they can come into action from the most convenient place and without losing time for their delivery.
- *Kanban arrangements in a Just-In-Time factory*
 - *Flexible manufacturing cell*

Principle 11. Beforehand cushioning

- A. Prepare emergency means beforehand to compensate for the relatively low reliability of an object.
- *Magnetic strip on photographic film that directs the developer to compensate for poor exposure*
 - *Back-up parachute*
 - *Alternate air system for aircraft instruments*

Principle 12. Equipotentiality

- A. In a potential field, limit position changes (e.g. change operating conditions to eliminate the need to raise or lower objects in a gravity field).
- *Spring loaded parts delivery system in a factory*
 - *Locks in a channel between 2 bodies of water (Panama Canal)*
 - *"Skilllets" in an automobile plant that bring all tools to the right position (also demonstrates Principle 10, Preliminary Action)*

Principle 13. 'The other way round'

- A. Invert the action(s) used to solve the problem (e.g. instead of cooling an object, heat it).
- *To loosen stuck parts, cool the inner part instead of heating the outer part.*
 - *Bring the mountain to Mohammed, instead of bringing Mohammed to the mountain.*
- B. Make movable parts (or the external environment) fixed, and fixed parts movable).
- *Rotate the part instead of the tool.*
 - *Moving sidewalk with standing people*
 - *Treadmill (for walking or running in place)*
- C. Turn the object (or process) 'upside down'.
- *Turn an assembly upside down to insert fasteners (especially screws).*
 - *Empty the grain from containers (ship or railroad) by inverting them.*

Principle 14. Spheroidality - Curvature

- A. Instead of using rectilinear parts, surfaces, or forms, use curvilinear ones; move from flat surfaces to spherical ones; from parts shaped as a cube (parallelepiped) to ball-shaped structures.
- *Use arches and domes for strength in architecture.*
- B. Use rollers, balls, spirals, domes.
- *Spiral gear (Nautilus) produces continuous resistance for weight lifting.*
 - *Ball point and roller point pens for smooth ink distribution*
- C. Go from linear to rotary motion, use centrifugal forces.
- *Produce linear motion of the cursor on the computer screen using a mouse or a trackball.*
 - *Replace wringing clothes to remove water with spinning clothes in a washing machine.*
 - *Use spherical casters instead of cylindrical wheels to move furniture.*

Principle 15. Dynamics

- A. Allow (or design) the characteristics of an object, external environment, or process to change to be optimal or to find an optimal operating condition.
- *Adjustable steering wheel (or seat, or back support, or mirror position...)*
- B. Divide an object into parts capable of movement relative to each other.
- *The "butterfly" computer keyboard, (also demonstrates Principle 7, "Nested doll".)*
- C. If an object (or process) is rigid or inflexible, make it movable or adaptive.
- *The flexible boroscope for examining engines*
 - *The flexible sigmoidoscope, for medical examination*

Principle 16. Partial or excessive actions

- A. If 100 percent of an object is hard to achieve using a given solution method, the problem may be considerably easier to solve by using 'slightly less' or 'slightly more' of the same method.
- *Over spray when painting, then remove excess. (Or, use a stencil--this is an application of Principle 3, Local Quality and Principle 9, Preliminary anti-action).*
 - *Fill, then "top off" when filling the gas tank of your car.*

Principle 17. Another dimension

- A. To move an object in two- or three-dimensional space.
 - *Infrared computer mouse moves in space, instead of on a surface, for presentations.*
 - *Five-axis cutting tool can be positioned where needed.*
- B. Use a multi-story arrangement of objects instead of a single-story arrangement.
 - *Cassette with 6 CD's to increase music time and variety*
 - *Electronic chips on both sides of a printed circuit board*
 - *Employees "disappear" from the customers in a theme park, descend into a tunnel, and walk to their next assignment, where they return to the surface and magically reappear.*
- C. Tilt or re-orient the object, lay it on its side.
 - *Dump truck*
- D. Use 'another side' of a given area.
 - *Stack microelectronic hybrid circuits to improve density.*

Principle 18. Mechanical vibration

- A. Cause an object to oscillate or vibrate.
 - *Electric carving knife with vibrating blades*
- B. Increase its frequency (even up to the ultrasonic).
 - *Distribute powder with vibration.*
- C. Use an object's resonant frequency.
 - *Destroy gall stones or kidney stones using ultrasonic resonance.*
- D. Use piezoelectric vibrators instead of mechanical ones.
 - *Quartz crystal oscillations drive high accuracy clocks.*
- E. Use combined ultrasonic and electromagnetic field oscillations.
 - *Mixing alloys in an induction furnace*

Principle 19. Periodic action

- A. Instead of continuous action, use periodic or pulsating actions.
 - *Hitting something repeatedly with a hammer*
 - *Replace a continuous siren with a pulsed sound.*
- B. If an action is already periodic, change the periodic magnitude or frequency.
 - *Use Frequency Modulation to convey information, instead of Morse code.*
 - *Replace a continuous siren with sound that changes amplitude and frequency.*
- C. Use pauses between impulses to perform a different action.
 - *In cardio-pulmonary respiration (CPR) breathe after every 5 chest compressions.*

Principle 20. Continuity of useful action

- A. Carry on work continuously; make all parts of an object work at full load, all the time.
 - *Flywheel (or hydraulic system) stores energy when a vehicle stops, so the motor can keep running at optimum power.*
 - *Run the bottleneck operations in a factory continuously, to reach the optimum pace. (From theory of constraints, or task time operations)*
- B. Eliminate all idle or intermittent actions or work.
 - *Print during the return of a printer carriage--dot matrix printer, daisy wheel printers, inkjet printers.*

Principle 21. Skipping

- A. Conduct a process, or certain stages (e.g. destructible, harmful or hazardous operations) at high speed.
 - *Use a high-speed dentist's drill to avoid heating tissue.*
 - *Cut plastic faster than heat can propagate in the material, to avoid deforming the shape.*

Principle 22. "Blessing in disguise" or "Turn Lemons into Lemonade"

- A. Use harmful factors (particularly, harmful effects of the environment or surroundings) to achieve a positive effect.
 - *Use waste heat to generate electric power.*
 - *Recycle waste (scrap) material from one process as raw materials for another.*
- B. Eliminate the primary harmful action by adding it to another harmful action to resolve the problem.
 - *Add a buffering material to a corrosive solution.*
 - *Use a helium-oxygen mix for diving, to eliminate both nitrogen narcosis and oxygen poisoning from air and other nitrox mixes.*
- C. Amplify a harmful factor to such a degree that it is no longer harmful.
 - *Use a backfire to eliminate the fuel from a forest fire.*

Principle 23. Feedback

- A. Introduce feedback (referring back, cross-checking) to improve a process or action.
- *Automatic volume control in audio circuits*
 - *Signal from gyrocompass is used to control simple aircraft autopilots.*
 - *Statistical Process Control (SPC) -- Measurements are used to decide when to modify a process. (Not all feedback systems are automated!)*
 - *Budgets -- Measurements are used to decide when to modify a process.*
- B. If feedback is already used, change its magnitude or influence.
- *Change sensitivity of an autopilot when within 5 miles of an airport.*
 - *Change sensitivity of a thermostat when cooling vs. heating, since it uses energy less efficiently when cooling.*
 - *Change a management measure from budget variance to customer satisfaction.*

Principle 24. 'Intermediary'

- A. Use an intermediary carrier article or intermediary process.
- *Carpenter's nailset, used between the hammer and the nail*
- B. Merge one object temporarily with another (which can be easily removed).
- *Pot holder to carry hot dishes to the table*

Principle 25. Self-service

- A. Make an object serve itself by performing auxiliary helpful functions
- *A soda fountain pump that runs on the pressure of the carbon dioxide used to "fizz" the drinks. This assures that drinks will not be flat, and eliminates the need for sensors.*
 - *Halogen lamps regenerate the filament during use--evaporated material is re-deposited.*
 - *To weld steel to aluminum, create an interface from alternating thin strips of the 2 materials. Cold weld the surface into a single unit with steel on one face and copper on the other, then use normal welding techniques to attach the steel object to the interface, and the interface to the aluminum. (This concept also has elements of Principle 24, Intermediary, and Principle 4, Asymmetry.)*
- B. Use waste resources, energy, or substances.
- *Use heat from a process to generate electricity: "Co-generation".*
 - *Use animal waste as fertilizer.*
 - *Use food and lawn waste to create compost.*

Principle 26. Copying

- A. Instead of an unavailable, expensive, fragile object, use simpler and inexpensive copies.
- *Virtual reality via computer instead of an expensive vacation*
 - *Listen to an audiotape instead of attending a seminar.*
- B. Replace an object, or process with optical copies.
- *Do surveying from space photographs instead of on the ground.*
 - *Measure an object by measuring the photograph.*
 - *Make sonograms to evaluate the health of a fetus, instead of risking damage by direct testing.*
- C. If visible optical copies are already used, move to infrared or ultraviolet copies.
- *Make images in infrared to detect heat sources, such as diseases in crops, or intruders in a security system.*

Principle 27. Cheap short-living objects

- A. Replace an inexpensive object with a multiple of inexpensive objects, comprising certain qualities (such as service life, for instance).
- *Use disposable paper objects to avoid the cost of cleaning and storing durable objects.*
 - *Plastic cups in motels, disposable diapers, many kinds of medical supplies.*

Principle 28. Mechanics substitution

- A. Replace a mechanical means with a sensory (optical, acoustic, taste or smell) means.
- *Replace a physical fence to confine a dog or cat with an acoustic "fence" (signal audible to the animal).*
 - *Use a bad smelling compound in natural gas to alert users to leakage, instead of a mechanical or electrical sensor.*
- B. Use electric, magnetic and electromagnetic fields to interact with the object.
- *To mix 2 powders, electrostatically charge one positive and the other negative. Either use fields to direct them, or mix them mechanically and let their acquired fields cause the grains of powder to pair up.*
- C. Change from static to movable fields, from unstructured fields to those having structure.

- *Early communications used omnidirectional broadcasting. We now use antennas with very detailed structure of the pattern of radiation.*
- D. Use fields in conjunction with field-activated (e.g. ferromagnetic) particles.
- *Heat a substance containing ferromagnetic material by using varying magnetic field. When the temperature exceeds the Curie point, the material becomes paramagnetic, and no longer absorbs heat.*

Principle 29. Pneumatics and hydraulics

- A. Use gas and liquid parts of an object instead of solid parts (e.g. inflatable, filled with liquids, air cushion, hydrostatic, hydro-reactive).
- *Comfortable shoe sole inserts filled with gel*
 - *Store energy from decelerating a vehicle in a hydraulic system, then use the stored energy to accelerate later.*

Principle 30. Flexible shells and thin films

- A. Use flexible shells and thin films instead of three dimensional structures
- *Use inflatable (thin film) structures as winter covers on tennis courts.*
- B. Isolate the object from the external environment using flexible shells and thin films.
- *Float a film of bipolar material (one end hydrophilic, one end hydrophobic) on a reservoir to limit evaporation.*

Principle 31. Porous materials

- A. Make an object porous or add porous elements (inserts, coatings, etc.).
- *Drill holes in a structure to reduce the weight.*
- B. If an object is already porous, use the pores to introduce a useful substance or function.
- *Use a porous metal mesh to wick excess solder away from a joint.*
 - *Store hydrogen in the pores of a palladium sponge. (Fuel "tank" for the hydrogen car— much safer than storing hydrogen gas)*

Principle 32. Color changes

- A. Change the color of an object or its external environment.
- *Use safe lights in a photographic darkroom.*
- B. Change the transparency of an object or its external environment.
- *Use photolithography to change transparent material to a solid mask for semiconductor processing.*
 - *Similarly, change mask material from transparent to opaque for silk screen processing.*

Principle 33. Homogeneity

- A. Make objects interacting with a given object of the same material (or material with identical properties).
- *Make the container out of the same material as the contents, to reduce chemical reactions.*
 - *Make diamond cutting tools out of diamonds.*

Principle 34. Discarding and recovering

- A. Make portions of an object that have fulfilled their functions go away (discard by dissolving, evaporating, etc.) or modify these directly during operation.
- *Use a dissolving capsule for medicine.*
 - *Sprinkle water on cornstarch-based packaging and watch it reduce its volume by more than 1000X!*
 - *Ice structures: use water ice or carbon dioxide (dry ice) to make a template for a rammed earth structure, such as a temporary dam. Fill with earth, then, let the ice melt or sublime to leave the final structure.*
- B. Conversely, restore consumable parts of an object directly in operation.
- *Self-sharpening lawn mower blades*
 - *Automobile engines that give themselves a "tune up" while running (the ones that say "100,000 miles between tune ups")*

Principle 35. Parameter changes

- A. Change an object's physical state (e.g. to a gas, liquid, or solid).
- *Freeze the liquid centers of filled candies, then dip in melted chocolate, instead of handling the messy, gooey, hot liquid.*
 - *Transport oxygen or nitrogen or petroleum gas as a liquid, instead of a gas, to reduce volume.*
- B. Change the concentration or consistency.

- *Liquid hand soap is concentrated and more viscous than bar soap at the point of use, making it easier to dispense in the correct amount and more sanitary when shared by several people.*
- C. Change the degree of flexibility.
- *Use adjustable dampers to reduce the noise of parts falling into a container by restricting the motion of the walls of the container.*
 - *Vulcanize rubber to change its flexibility and durability.*
- D. Change the temperature.
- *Raise the temperature above the Curie point to change a ferromagnetic substance to a paramagnetic substance.*
 - *Raise the temperature of food to cook it. (Changes taste, aroma, texture, chemical properties, etc.)*
 - *Lower the temperature of medical specimens to preserve them for later analysis.*

Principle 36. Phase transitions

- A. Use phenomena occurring during phase transitions (e.g. volume changes, loss or absorption of heat, etc.).
- *Water expands when frozen, unlike most other liquids. Hannibal is reputed to have used this phenomena when marching on Rome a few thousand years ago. Large rocks blocked passages in the Alps. He poured water on them at night. The overnight cold froze the water, and the expansion split the rocks into small pieces that could be pushed aside.*
 - *Heat pumps use the heat of vaporization and heat of condensation of a closed thermodynamic cycle to do useful work.*

Principle 37. Thermal expansion

- A. Use thermal expansion (or contraction) of materials.
- *Fit a tight joint together by cooling the inner part to contract, heating the outer part to expand, putting the joint together, and returning to equilibrium.*
- B. If thermal expansion is being used, use multiple materials with different coefficients of thermal expansion.
- *The basic leaf spring thermostat: (2 metals with different coefficients of expansion are linked so that it bends one way when warmer than nominal and the opposite way when cooler.)*

Principle 38. Strong oxidants

- A. Replace common air with oxygen-enriched air.
- *Scuba diving with Nitrox or other non-air mixtures for extended endurance*
- B. Replace enriched air with pure oxygen.
- *Cut at a higher temperature using an oxy-acetylene torch.*
 - *Treat wounds in a high pressure oxygen environment to kill anaerobic bacteria and aid healing.*
- C. Expose air or oxygen to ionizing radiation.
- D. Use ionized oxygen.
- *Ionize air to trap pollutants in an air cleaner.*
- E. Replace ozonized (or ionized) oxygen with ozone.
- *Speed up chemical reactions by ionizing the gas before use.*

Principle 39. Inert atmosphere

- A. Replace a normal environment with an inert one.
- *Prevent degradation of a hot metal filament by using an argon atmosphere.*
- B. Add neutral parts, or inert additives to an object.
- *Increase the volume of powdered detergent by adding inert ingredients. This makes it easier to measure with conventional tools.*

Principle 40. Composite materials

- A. Change from uniform to composite (multiple) materials.
- *Composite epoxy resin/carbon fiber golf club shafts are lighter, stronger, and more flexible than metal. The same may be applied to airplane parts.*
 - *Fiberglass surfboards are lighter and more controllable and easier to form into a variety of shapes than wooden ones.*

Altshuller's Table of Contradictions, Part 1

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
		Weight of moving object	Weight of nonmoving object	Length of moving object	Length of nonmoving object	Area of moving object	Area of nonmoving object	Volume of moving object	Volume of nonmoving object	Speed	Force	Tension, pressure	Shape	Stability of object	Strength	Durability of moving object	Durability of nonmoving object	Temperature	Brightness	Energy spent by moving object	Energy spent by nonmoving object
1	Weight of moving object			15, 8, 29, 34		29, 17, 38, 34		29, 2, 40, 28		2, 8, 15, 38	8, 10, 18, 37	10, 36, 37, 40	10, 14, 35, 40	1, 35, 19, 39	28, 27, 18, 40	5, 34, 31, 35		6, 20, 4, 38	19, 1, 32	35, 12, 34, 31	
2	Weight of nonmoving object				10, 1, 29, 35		35, 30, 13, 2		5, 35, 14, 2		8, 10, 19, 35	13, 29, 10, 18	23, 10, 29, 14	26, 39, 1, 40	28, 2, 10, 27		2, 27, 19, 6	28, 19, 32, 22	19, 32, 35		18, 19, 28, 1
3	Length of moving object	8, 15, 29, 34				15, 17, 4		7, 17, 4, 35		13, 4, 8	17, 10, 4	1, 8, 35	1, 8, 10, 29	1, 8, 15, 34	8, 35, 29, 34	19		10, 15, 19	32	8, 35, 24	
4	Length of nonmoving object		35, 28, 40, 29				17, 7, 10, 40		35, 8, 2, 14		28, 10	1, 14, 35	13, 14, 15, 7	39, 37, 35	15, 14, 28, 26		1, 40, 35	3, 35, 38, 18	3, 25		
5	Area of moving object	2, 17, 29, 4		14, 15, 18, 4				7, 14, 17, 4		29, 30, 4, 34	19, 30, 35, 2	10, 15, 36, 28	5, 34, 29, 4	11, 2, 13, 39	3, 15, 40, 14	6, 3		2, 15, 16	15, 32, 19, 13	19, 32	
6	Area of nonmoving object		30, 2, 14, 18		26, 7, 9, 39						1, 18, 35, 36	10, 15, 36, 37		2, 38	40		2, 10, 19, 30	35, 39, 38			
7	Volume of moving object	2, 26, 29, 40		1, 7, 4, 35		1, 7, 4, 17				29, 4, 38, 34	15, 35, 36, 37	5, 35, 36, 37	1, 15, 29, 4	28, 10, 1, 39	9, 14, 15, 7	6, 35, 4		34, 39, 10, 18	2, 13, 10	35	
8	Volume of nonmoving object		35, 10, 19, 14	19, 14	35, 8, 2, 14						2, 18, 37	24, 35	7, 2, 35	34, 28, 35, 40	9, 14, 17, 15		35, 34, 38	35, 6, 4			
9	Speed	2, 28, 13, 38		13, 14, 8		29, 30, 34		7, 29, 34			13, 28, 15, 19	6, 18, 38, 40	35, 15, 18, 34	28, 33, 1, 18	8, 3, 26, 14	3, 9, 35, 5		28, 30, 36, 2	10, 13, 19	8, 15, 35, 38	
10	Force	8, 1, 37, 18	18, 13, 1, 28	17, 19, 9, 36	28, 10	19, 10, 15	1, 18, 36, 37	15, 9, 12, 37	2, 36, 18, 37	13, 28, 15, 12		18, 21, 11	10, 35, 40, 34	35, 10, 21	35, 10, 14, 27	19, 2		35, 10, 21		19, 17, 10	1, 16, 36, 37
11	Tension, pressure	10, 36, 37, 40	13, 29, 10, 18	35, 10, 36	35, 1, 14, 16	10, 15, 36, 25	10, 15, 35, 37	6, 35, 10	35, 24	6, 35, 21	36, 35, 21		35, 4, 15, 10	35, 33, 2, 40	9, 18, 3, 40	19, 3, 27		35, 39, 19, 2		14, 24, 10, 37	
12	Shape	8, 10, 29, 40	15, 10, 26, 3	29, 34, 5, 4	13, 14, 10, 7	5, 34, 4, 10		14, 4, 15, 22	7, 2, 35	35, 15, 34, 18	35, 10, 37, 40	34, 15, 10, 14		33, 1, 18, 4	30, 14, 10, 40	14, 26, 9, 25		22, 14, 19, 32	13, 15, 32	2, 6, 34, 14	
13	Stability of object	21, 35, 2, 39	26, 39, 1, 40	13, 15, 1, 28	37	2, 11, 13	39	28, 10, 19, 39	34, 28, 35, 40	33, 15, 28, 18	10, 35, 21, 16	2, 35, 40	22, 1, 18, 4		17, 9, 15	13, 27, 10, 35	39, 3, 35, 23	35, 1, 32	32, 3, 27, 15	13, 19	27, 4, 29, 18
14	Strength	1, 8, 40, 15	40, 26, 27, 1	1, 15, 8, 35	15, 14, 28, 26	3, 34, 30, 29	9, 40, 28	10, 15, 14, 7	9, 14, 17, 15	8, 13, 26, 14	10, 18, 3, 14	10, 3, 18, 40	10, 30, 35, 40	13, 17, 35		27, 3, 26		30, 10, 40	35, 19	19, 35, 10	35
15	Durability of moving object	19, 5, 34, 31		2, 19, 9		3, 17, 19		10, 2, 19, 30		3, 35, 5	19, 2, 16	19, 3, 27	14, 26, 28, 25	13, 3, 35	27, 3, 10			19, 35, 39	2, 19, 4, 35	28, 6, 35, 18	
16	Durability of nonmoving object		6, 27, 19, 16		1, 10, 35				35, 34, 38					39, 3, 35, 23				19, 18, 36, 40			
17	Temperature	36, 22, 6, 38	22, 35, 32	15, 19, 9	15, 19, 9	3, 35, 39, 18	35, 38	34, 39, 40, 18	35, 6, 4	2, 28, 36, 30	35, 10, 3, 21	35, 39, 19, 2	14, 22, 19, 32	1, 35, 32	10, 30, 22, 40	19, 13, 39	19, 18, 36, 40		32, 30, 21, 16	19, 15, 3, 17	
18	Brightness	19, 1, 32	2, 35, 32	19, 32, 16		19, 32, 26		2, 13, 10		10, 13, 19	26, 19, 6		32, 30	32, 3, 27	35, 19	2, 19, 6		32, 35, 19		32, 1, 19	32, 25, 1, 15
19	Energy spent by moving object	12, 18, 28, 31		12, 28		15, 19, 25		35, 13, 8		8, 15, 35	16, 26, 21, 2	23, 14, 25	12, 2, 29	19, 13, 17, 24	5, 19, 9, 35	28, 35, 6, 18		19, 24, 3, 14	2, 15, 19		
20	Energy spent by nonmoving object		19, 9, 6, 27								36, 37			27, 4, 29, 18	35				19, 2, 35, 32		

Altshuller's Table of Contradictions, Part 2

		21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
		Power	Waste of energy	Waste of substance	Loss of information	Waste of time	Amount of substance	Reliability	Accuracy of measurement	Accuracy of manufacturing	Harmful factors acting on object	Harmful side effects	Manufacturability	Convenience of use	Repairability	Adaptability	Complexity of device	Complexity of control	Level of automation	Productivity
1	Weight of moving object	12, 36, 18, 31	6, 2, 34, 19	5, 35, 3, 31	10, 24, 35	10, 35, 20, 28	3, 26, 18, 31	3, 11, 1, 27	28, 27, 35, 26	28, 35, 26, 18	22, 21, 18, 27	22, 35, 31, 39	27, 28, 1, 36	35, 3, 2, 24	2, 27, 28, 11	29, 5, 15, 8	26, 30, 36, 34	28, 29, 26, 32	26, 35, 18, 19	35, 3, 24, 37
2	Weight of nonmoving object	15, 19, 18, 22	18, 19, 28, 15	5, 8, 13, 30	10, 15, 35	10, 20, 35, 26	19, 6, 18, 26	10, 28, 8, 3	18, 26, 28	10, 1, 35, 17	2, 19, 22, 37	35, 22, 1, 39	28, 1, 9	6, 13, 1, 32	2, 27, 28, 11	19, 15, 29	1, 10, 26, 39	25, 28, 17, 15	2, 26, 35	1, 28, 15, 35
3	Length of moving object	1, 35	7, 2, 35, 39	4, 29, 23, 10	1, 24	15, 2, 28	29, 35	10, 14, 29, 40	28, 32, 4	10, 28, 29, 37	1, 15, 17, 24	17, 15	1, 29, 17	15, 29, 35, 4	1, 28, 10	14, 15, 1, 16	1, 19, 26, 24	35, 1, 26, 24	17, 24, 26, 16	14, 4, 28, 29
4	Length of nonmoving object	12, 8	6, 28	10, 28, 24, 35	24, 25	30, 29, 14		15, 29, 28	32, 28, 3	2, 32, 10	1, 18		15, 17, 27	2, 25	3	1, 35	1, 26	26		30, 14, 7, 26
5	Area of moving object	19, 10, 32, 18	15, 17, 30, 26	10, 35, 2, 39	30, 26	26, 4	29, 30, 6, 13	29, 9	26, 28, 32, 3	2, 32	22, 33, 28, 1	17, 2, 18, 39	13, 1, 26, 24	15, 17, 13, 16	15, 13, 10, 1	15, 30	14, 1, 13	2, 36, 26, 18	14, 30, 28, 23	10, 26, 34, 2
6	Area of nonmoving object	17, 32	17, 7, 30	10, 14, 18, 39	30, 16	10, 35, 4, 18	2, 18, 20, 4	32, 35, 40, 4	26, 28, 32, 3	2, 29, 18, 36	27, 2, 39, 35	22, 1, 40	40, 16	16, 4	16	15, 16	1, 18, 36	2, 35, 30, 18	23	10, 15, 17, 7
7	Volume of moving object	35, 6, 13, 18	7, 15, 13, 16	36, 39, 34, 10	2, 22	2, 6, 34, 10	29, 30, 7	14, 1, 40, 11	25, 26, 28	25, 28, 2, 16	22, 21, 27, 35	17, 2, 40, 1	29, 1, 40	15, 13, 30, 12	10	15, 29	26, 1	2926, 4	35, 34, 16, 24	10, 6, 2, 34
8	Volume of nonmoving object	30, 6		10, 39, 35, 34		35, 16, 32, 18	35, 3	2, 35, 16		35, 10, 25	34, 39, 19, 27	30, 18, 35, 4	35		1		1, 31	2, 17, 26		35, 37, 10, 2
9	Speed	19, 35, 38, 2	14, 20, 19, 35	10, 13, 28, 38	13, 26		18, 19, 29, 38	11, 35, 27, 28	28, 32, 1, 24	10, 28, 32, 25	1, 28, 35, 23	2, 24, 35, 21	35, 13, 8, 1	32, 28, 13, 12	34, 2, 28, 27	15, 10, 26	10, 28, 4, 34	3, 34, 27, 16	10, 18	
10	Force	19, 35, 18, 37	14, 15	8, 35, 40, 5		10, 37, 36	15, 29, 18, 36	3, 35, 13, 21	35, 10, 23, 24	28, 29, 37, 36	1, 35, 40, 18	13, 3, 36, 24	15, 37, 18, 1	1, 28, 3, 25	15, 1, 11	15, 17, 18, 20	26, 35, 10, 18	36, 37, 10, 19	2, 35	3, 28, 35, 37
11	Tension, pressure	10, 35, 14	2, 36, 25	10, 36, 3, 37		37, 36, 4	10, 14, 36	10, 13, 19, 35	6, 28, 25	3, 35	22, 2, 37	2, 33, 27, 18	1, 35, 16	11	2	35	19, 1, 35	2, 36, 37	35, 24	10, 14, 35, 37
12	Shape	4, 6, 2	14	35, 29, 3, 5		14, 10, 34, 17	36, 22	10, 40, 16	28, 32, 1	32, 30, 40	22, 1, 2, 35	35, 1	1, 32, 17, 28	32, 15, 26	2, 13, 1	1, 15, 29	16, 29, 1, 28	15, 13, 39	15, 1, 32	17, 26, 34, 10
13	Stability of object	32, 35, 27, 31	14, 2, 39, 6	2, 14, 30, 40		35, 27	15, 32, 35		13	18	35, 24, 30, 18	35, 40, 27, 39	35, 19	32, 35, 30	2, 35, 10, 16	35, 30, 34, 2	2, 35, 22, 26	35, 22, 39, 23	1, 8, 35	23, 35, 40, 3
14	Strength	10, 26, 35, 28	35	35, 28, 31, 40		29, 3, 28, 10	29, 10, 27	11, 3	3, 27, 16	3, 27	18, 35, 37, 1	15, 35, 22, 2	11, 3, 10, 32	32, 40, 28, 2	27, 11, 3	15, 3, 32	2, 13, 28	27, 3, 15, 40	15	29, 35, 10, 14
15	Durability of moving object	19, 10, 35, 38		28, 27, 3, 18	10	20, 10, 28, 18	3, 35, 10, 40	11, 2, 13	3	3, 27, 16, 40	22, 15, 33, 28	21, 39, 16, 22	27, 1, 4	12, 27	29, 10, 27	1, 35, 13	10, 4, 29, 15	19, 29, 39, 35	6, 10	35, 17, 14, 19
16	Durability of nonmoving object	16		27, 16, 18, 38	10	28, 20, 10, 16	3, 35, 31	34, 27, 6, 40	10, 26, 24		17, 1, 40, 33	22	35, 10	1	1	2		25, 34, 6, 35	1	10, 20, 16, 38
17	Temperature	2, 14, 17, 25	21, 17, 35, 38	21, 36, 29, 31		35, 28, 21, 18	3, 17, 30, 39	19, 35, 3, 10	32, 19, 24	24	22, 33, 35, 2	22, 35, 2, 24	26, 27	26, 27	4, 10, 16	2, 18, 27	2, 17, 16	3, 27, 35, 31	26, 2, 19, 16	15, 28, 35
18	Brightness	32	19, 16, 1, 6	13, 1	1, 6	19, 1, 26, 17	1, 19		11, 15, 32	3, 32	15, 19	35, 19, 32, 39	19, 35, 28, 26	28, 26, 19	15, 17, 13, 16	15, 11, 1, 19	6, 32, 13	32, 15	2, 26, 10	2, 25, 16
19	Energy spent by moving object	6, 19, 37, 18	12, 22, 15, 24	35, 24, 18, 5		35, 38, 19, 18	34, 23, 16, 18	19, 21, 11, 27	3, 1, 32		1, 35, 6, 27	2, 35, 6	28, 26, 30	19, 35	1, 15, 17, 28	15, 17, 13, 16	2, 29, 27, 28	35, 38	32, 2	12, 28, 35
20	Energy spent by nonmoving object			28, 27, 18, 31			3, 35, 31	10, 36, 23			10, 2, 22, 37	19, 22, 18	1, 4					19, 35, 16, 25		1, 6

Altshuller's Table of Contradictions, Part 3

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
		Weight of moving object	Weight of nonmoving object	Length of moving object	Length of nonmoving object	Area of moving object	Area of nonmoving object	Volume of moving object	Volume of nonmoving object	Speed	Force	Tension, pressure	Shape	Stability of object	Strength	Durability of moving object	Durability of nonmoving object	Temperature	Brightness	Energy spent by moving object	Energy spent by nonmoving object
21	Power	8, 36, 38, 31	19, 26, 17, 27	1, 10, 35, 37		19, 38	17, 32, 13, 38	35, 6, 38	30, 6, 25	15, 35, 2	26, 2, 36, 35	22, 10, 35	29, 14, 2, 40	35, 32, 15, 31	26, 10, 28	19, 35, 10, 38	16	2, 14, 17, 25	16, 6, 19	16, 6, 19, 37	
22	Waste of energy	15, 6, 19, 28	19, 6, 18, 9	7, 2, 6, 13	6, 38, 7	15, 26, 17, 30	17, 7, 30, 18	7, 18, 23	7	16, 35, 38	36, 38			14, 2, 39, 6	26			19, 38, 7	1, 13, 32, 15		
23	Waste of substance	35, 6, 23, 40	35, 6, 22, 32	14, 29, 10, 39	10, 28, 24	35, 2, 10, 31	10, 18, 39, 31	1, 29, 30, 36	3, 39, 18, 31	10, 13, 28, 38	14, 15, 18, 40	3, 36, 37, 10	29, 35, 3, 5	2, 14, 30, 40	35, 28, 31, 40	28, 27, 3, 18	27, 16, 18, 38	21, 36, 39, 31	1, 6, 13	35, 18, 24, 5	28, 27, 12, 31
24	Loss of information	10, 24, 35	10, 35, 5	1, 26	26	30, 26	30, 16		2, 22	26, 32						10	10		19		
25	Waste of time	10, 20, 37, 35	10, 20, 26, 5	15, 2, 29	30, 24, 14, 5	26, 4, 5, 16	10, 35, 17, 4	2, 5, 34, 10	35, 16, 32, 18		10, 37, 36, 5	37, 36, 4	4, 10, 34, 17	35, 3, 22, 5	29, 3, 28, 18	20, 10, 28, 18	28, 20, 10, 16	35, 29, 21, 18	1, 19, 26, 17	35, 38, 19, 18	1
26	Amount of substance	35, 6, 18, 31	27, 26, 18, 35	29, 14, 35, 18		15, 14, 29	2, 18, 40, 4	15, 20, 29		35, 29, 34, 28	35, 14, 3	10, 36, 14, 3	35, 14	15, 2, 17, 40	14, 35, 34, 10	3, 35, 10, 40	3, 35, 31	3, 17, 39		34, 29, 16, 18	3, 35, 31
27	Reliability	3, 8, 10, 40	3, 10, 8, 28	15, 9, 14, 4	15, 29, 28, 11	17, 10, 14, 16	32, 35, 40, 4	3, 10, 14, 24	2, 35, 24	21, 35, 11, 28	8, 28, 10, 13	10, 24, 35, 19	35, 1, 16, 11		11, 28	2, 35, 3, 25	34, 27, 6, 40	3, 35, 10	11, 32, 13	21, 11, 27, 19	36, 23
28	Accuracy of measurement	32, 35, 26, 28	28, 35, 25, 26	28, 26, 5, 16	32, 28, 3, 16	26, 28, 32, 3	26, 28, 32, 3	32, 13, 6		28, 13, 32, 24	32, 2	6, 28, 32	6, 28, 32	32, 35, 13	28, 6, 32	28, 6, 32	10, 26, 24	6, 19, 28, 24	6, 1, 32	3, 6, 32	
29	Accuracy of manufacturing	28, 32, 13, 18	28, 35, 27, 9	10, 28, 29, 37	2, 32, 10	28, 33, 29, 32	2, 29, 18, 36	32, 28, 2	25, 10, 35	10, 28, 32	28, 19, 34, 36	3, 35	32, 30, 40	30, 18	3, 27, 40			19, 26	3, 32	32, 2	
30	Harmful factors acting on object	22, 21, 27, 39	2, 22, 13, 24	17, 1, 39, 4	1, 18	22, 1, 33, 28	27, 2, 39, 35	22, 23, 37, 35	34, 39, 19, 27	21, 22, 35, 28	13, 35, 39, 18	22, 2, 37	22, 1, 3, 35	35, 24, 30, 18	18, 35, 37, 1	22, 15, 33, 28	17, 1, 40, 33	22, 33, 35, 2	1, 19, 32, 13	1, 24, 6, 27	10, 2, 22, 37
31	Harmful side effects	19, 22, 15, 39	35, 22, 1, 39	17, 15, 16, 22		17, 2, 18, 39	22, 1, 40	17, 2, 40	30, 18, 35, 4	35, 28, 3, 23	35, 28, 1, 40	2, 33, 27, 18	35, 1	35, 40, 27, 39	15, 35, 22, 2	15, 22, 33, 31	21, 39, 16, 22	22, 35, 2, 24	19, 24, 39, 32	2, 35, 6	19, 22, 18
32	Manufacturability	28, 29, 15, 16	1, 27, 36, 13	1, 29, 13, 17	15, 17, 27	13, 1, 26, 12	16, 40	13, 29, 1, 40	35	35, 13, 8, 1	35, 12	35, 19, 1, 37	1, 28, 13, 27	11, 13, 1	1, 3, 10, 32	27, 1, 4	35, 16	27, 26, 18	28, 24, 27, 1	28, 26, 27, 1	1, 4
33	Convenience of use	25, 2, 13, 15	6, 13, 1, 25	1, 17, 13, 12		1, 17, 13, 16	18, 16, 15, 39	1, 16, 35, 15	4, 18, 39, 31	18, 13, 34	28, 13, 35	2, 32, 12	15, 34, 29, 28	32, 35, 30	32, 40, 3, 28	29, 3, 8, 25	1, 16, 25	26, 27, 13	13, 17, 1, 24	1, 13, 24	
34	Repairability	2, 27, 35, 11	2, 27, 35, 11	1, 28, 10, 25	3, 18, 31	15, 13, 32	16, 25	25, 2, 35, 11	1	34, 9	1, 11, 10	13	1, 13, 2, 4	2, 35	11, 1, 2, 9	11, 29, 28, 27	1	4, 10	15, 1, 13	15, 1, 28, 16	
35	Adaptability	1, 6, 15, 8	19, 15, 29, 16	35, 1, 29, 2	1, 35, 16	35, 30, 29, 7	15, 16	15, 35, 29		35, 10, 14	15, 17, 20	35, 16	15, 37, 1, 8	35, 30, 14	35, 3, 32, 6	13, 1, 35	2, 16	27, 2, 3, 35	6, 22, 26, 1	19, 35, 29, 13	
36	Complexity of device	26, 30, 34, 36	2, 36, 35, 39	1, 19, 26, 24	26	14, 1, 13, 16	6, 36	34, 25, 6	1, 16	34, 10, 28	25, 16	19, 1, 35	29, 13, 28, 15	2, 22, 17, 19	2, 13, 28	10, 4, 28, 15		2, 17, 13	24, 17, 13	27, 2, 29, 28	
37	Complexity of control	27, 26, 28, 13	6, 13, 28, 1	16, 17, 26, 24	26	2, 13, 15, 17	2, 39, 30, 16	29, 1, 4, 16	2, 18, 26, 31	3, 4, 16, 35	36, 28, 40, 19	35, 36, 37, 32	27, 13, 1, 39	11, 22, 39, 30	27, 3, 15, 28	19, 29, 39, 25	25, 24, 6, 35	3, 27, 35, 16	2, 24, 26	35, 38	19, 35, 16
38	Level of automation	28, 26, 18, 35	28, 26, 35, 10	14, 13, 17, 28	23	17, 14, 13		35, 13, 16		28, 10	2, 35	13, 35	15, 32, 1, 13	18, 1	25, 13	6, 9		26, 2, 19	8, 32, 19	2, 32, 13	
39	Productivity	35, 26, 24, 37	28, 27, 15, 3	18, 4, 28, 38	30, 7, 14, 26	10, 26, 34, 31	10, 35, 17, 7	2, 6, 34, 10	35, 37, 10, 2		28, 15, 10, 36	10, 37, 14	14, 10, 34, 40	35, 3, 22, 39	29, 28, 10, 18	35, 10, 2, 18	20, 10, 16, 38	35, 21, 28, 10	26, 17, 19, 1	35, 10, 38, 19	1

Altshuller's Table of Contradictions, Part 4

		21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
		Power	Waste of energy	Waste of substance	Loss of information	Waste of time	Amount of substance	Reliability	Accuracy of measurement	Accuracy of manufacturing	Harmful factors acting on object	Harmful side effects	Manufacturability	Convenience of use	Repairability	Adaptability	Complexity of device	Complexity of control	Level of automation	Productivity
21	Power		10, 35, 38	28, 27, 18, 38	10, 19	35, 20, 10, 6	4, 34, 19	19, 24, 26, 31	32, 15, 2	32, 2	19, 22, 31, 2	2, 35, 18	26, 10, 34	26, 35, 10	35, 2, 10, 34	19, 17, 34	20, 19, 30, 34	19, 35, 16	28, 2, 17	28, 35, 34
22	Waste of energy	3, 38		35, 27, 2, 37	19, 10	10, 18, 32, 7	7, 18, 25	11, 10, 35	32		21, 22, 35, 2	21, 35, 2, 22		35, 22, 1	2, 19		7, 23	35, 3, 15, 23	2	28, 10, 29, 35
23	Waste of substance	28, 27, 18, 38	35, 27, 2, 31			15, 18, 35, 10	6, 3, 10, 24	10, 29, 39, 35	16, 34, 31, 28	35, 10, 24, 31	33, 22, 30, 40	10, 1, 34, 29	15, 34, 33	32, 28, 2, 24	2, 35, 34, 27	15, 10, 2	35, 10, 28, 24	35, 18, 10, 13	35, 10, 18	28, 35, 10, 23
24	Loss of information	10, 19	19, 10			24, 26, 28, 32	24, 28, 35	10, 28, 23			22, 10, 1	10, 21, 22	32	27, 22				35, 33	35	13, 23, 15
25	Waste of time	35, 20, 10, 6	10, 5, 18, 32	35, 18, 10, 39	24, 26, 28, 32		35, 38, 18, 16	10, 30, 4	24, 34, 28, 32	24, 26, 28, 18	35, 18, 34	35, 22, 18, 39	35, 28, 34, 4	4, 28, 10, 34	32, 1, 10	35, 28	6, 29	18, 28, 32, 10	24, 28, 35, 30	
26	Amount of substance	35	7, 18, 25	6, 3, 10, 24	24, 28, 35	35, 38, 18, 16		18, 3, 28, 40	13, 2, 28	33, 30	35, 33, 29, 31	3, 35, 40, 39	29, 1, 35, 27	35, 29, 25, 10	2, 32, 10, 25	15, 3, 29	3, 13, 27, 10	3, 27, 29, 18	8, 35	13, 29, 3, 27
27	Reliability	21, 11, 26, 31	10, 11, 35	10, 35, 29, 39	10, 28	10, 30, 4	21, 28, 40, 3		32, 3, 11, 23	11, 32, 1	27, 35, 2, 40	35, 2, 40, 26		27, 17, 40	1, 11	13, 35, 8, 24	13, 35, 1	27, 40, 28	11, 13, 27	1, 35, 29, 38
28	Accuracy of measurement	3, 6, 32	26, 32, 27	10, 16, 31, 28		24, 34, 28, 32	2, 6, 32	5, 11, 1, 23			28, 24, 22, 26	3, 33, 39, 10	6, 35, 25, 18	1, 13, 17, 34	1, 32, 13, 11	13, 35, 2	27, 35, 10, 34	26, 24, 32, 28	28, 2, 10, 34	10, 34, 28, 32
29	Accuracy of manufacturing	32, 2	13, 32, 2	35, 31, 10, 24		32, 26, 28, 18	32, 30	11, 32, 1			26, 28, 10, 36	4, 17, 34, 26		1, 32, 35, 23	25, 10		26, 2, 18		26, 28, 18, 23	10, 18, 32, 39
30	Harmful factors acting on object	19, 22, 31, 2	21, 22, 35, 2	33, 22, 19, 40	22, 10, 2	35, 18, 34	35, 33, 29, 31	27, 24, 2, 40	28, 33, 23, 26	26, 28, 10, 18			24, 35, 2	2, 25, 28, 39	35, 10, 2	35, 11, 22, 31	22, 19, 29, 40	22, 19, 29, 40	33, 3, 34	22, 35, 13, 24
31	Harmful side effects	2, 35, 18	21, 35, 2, 22	10, 1, 34	10, 21, 29	1, 22	3, 24, 39, 1	24, 2, 40, 39	3, 33, 26	4, 17, 34, 26							19, 1, 31	2, 21, 27, 1	2	22, 35, 18, 39
32	Manufacturability	27, 1, 12, 24	19, 35	15, 34, 33	32, 24, 18, 16	35, 28, 34, 4	35, 23, 1, 24		1, 35, 12, 18		24, 2			2, 5, 13, 16	35, 1, 11, 9	2, 13, 15	27, 26, 1	6, 28, 11, 1	8, 28, 1	35, 1, 10, 28
33	Convenience of use	35, 34, 2, 10	2, 19, 13	28, 32, 2, 24	4, 10, 27, 22	4, 28, 10, 34	12, 35	17, 27, 8, 40	25, 13, 2, 34	1, 32, 35, 23	2, 25, 28, 39		2, 5, 12		12, 26, 1, 32	15, 34, 1, 16	32, 26, 12, 17		1, 34, 12, 3	15, 1, 28
34	Repairability	15, 10, 32, 2	15, 1, 32, 19	2, 35, 34, 27		32, 1, 10, 25	2, 28, 10, 25	11, 10, 1, 16	10, 2, 13	25, 10	35, 10, 2, 16		1, 35, 11, 10	1, 12, 26, 15		7, 1, 4, 16	35, 1, 13, 11		34, 35, 7, 13	1, 32, 10
35	Adaptability	19, 1, 29	18, 15, 1	15, 10, 2, 13		35, 28	3, 35, 15	35, 13, 8, 24	35, 5, 1, 10		35, 11, 32, 31		1, 13, 32	15, 34, 1, 16	1, 16, 7, 4		15, 29, 37, 28	1	27, 34, 35	35, 28, 6, 37
36	Complexity of device	20, 19, 30, 34	10, 35, 13, 2	35, 10, 28, 29		6, 29	13, 3, 27, 10	13, 35, 1	2, 26, 10, 34	26, 24, 32	22, 19, 29, 40	19, 1	27, 26, 1, 13	27, 9, 26, 24	1, 13	29, 15, 28, 37		15, 10, 37, 28	15, 1, 24	12, 17, 28
37	Complexity of control	19, 1, 16, 10	35, 3, 15, 19	1, 13, 10, 24	35, 33, 27, 22	18, 28, 32, 9	3, 27, 29, 18	27, 40, 28, 8	26, 24, 32, 28		22, 19, 29, 28	2, 21	5, 28, 11, 29	2, 5	12, 26	1, 15	15, 10, 32, 28		34, 21	35, 18
38	Level of automation	28, 2, 27	23, 28	35, 10, 18, 5	35, 33	24, 28, 35, 30	35, 13	11, 27, 32	28, 26, 10, 34	28, 26, 18, 23	2, 33	2	1, 26, 13	1, 12, 34, 3	1, 35, 13	27, 4, 1, 35	15, 24, 10	34, 27, 25		5, 12, 35, 26
39	Productivity	35, 20, 10	28, 10, 29, 35	28, 10, 35, 23	13, 15, 23		35, 38	1, 35, 10, 38	1, 10, 34, 28	18, 10, 32, 1	22, 35, 13, 24	35, 22, 18, 39	35, 28, 2, 24	1, 28, 7, 19	1, 32, 10, 25	1, 35, 28, 37	12, 17, 28, 24	35, 18, 27, 2		

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