Mathematical Deconstruction on TRIZ's 40 Inventive Principles

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ABSTRACT: TRIZ is a theory of inventive problem solving. The most important part of TRIZ is 40 inventive principles. We found that the principles are still described in natural human language, so we try to give mathematical descriptions. And it is discovered the effectiveness in new breakthrough on the principles. The TRIZ's 40 inventive principles be described by mathematical method. The mathematical description is pure, clear, easy to understand, and powerful to innovative research and development. These mathematical models will provide technical basis for TRIZ theory researchers.
KEYWORD: TRIZ; Inventive principle; Mathematical description

1 INTRODUCTION

TRIZ is the Russian acronym that means The Theory of Inventive Problem Solving. Fundamental contradictions are the most difficult type of problems in the next generation of products [1]. A situation in problem solving where improving one parameter of a system causes deterioration of another parameter is called engineering contradiction. Dr. Genrich S. Altshuller, the creator of TRIZ, analyzed ways of solving and eliminating the contradictions in the world's most significant inventions [2]. He identified 40 inventive principles for solving and eliminating the contradictions [3]. Fast breakthrough solving of the fundamental problems of a new project is a key for its success [4]. We studied the TRIZ's 40 inventive principles, and found that the principles are described by natural human languages, haven't been described by mathematical formula as science does. Now let's try to give new descriptions on TRIZ's 40 inventive principles in mathematical method.

2 MATHEMATICAL DECONSTRUCTION

Principle 1. Segmentation: Divide an object into independent parts; make an object easy to dissemble; increase the degree of fragmentation or segmentation. We describe the principle with number algorithm, for example, 2=1+1, stands for one object built up by 2 parts similar; 10=1+1+1+1+1+1+1+1+1+1, stands for a train composes 10 same cars; or 10=1+2+5+1+1, means a work breakdown structure for a large project.

Principle 2. Taking out: Separate an interfering part or property from an object; single out the only necessary part or property of an object. We describe the principle with number algorithm, 2-1=1, stands for one part of an object is taken away.

Principle 3. Local quality: Change an object's structure or function from uniform to non-uniform; change an external environment from uniform to non-uniform. We describe the principle with number algorithm, 3=1+2=4-1=5-2, stands for one object 3 is build up with 1 and 2, which is non-uniform in structure or function.

Principle 4. Asymmetry: Change the shape of an object from symmetrical to asymmetrical; if an object asymmetrical, increase its degree of asymmetrical. We describe the principle with number comparative algorithm, 1<2 and 1<200, or square vs circle, for example, asymmetrical mixing vessels improve mixing.

Principle 5. Merging: Bring closer together (or merge) identical or similar objects, assemble identical or similar parts to perform parallel operations; make operations continuous, parallel, or bring them together in time. We describe the principle with number comparative algorithm, 1==1==1==1==..., 2==2==2==..., or f(x)==f(x)==f(x)==....

Principle 6. Universality: Make a part or object perform multiple functions; eliminate the need for other parts. We describe the principle with mathematical function's concepts, by definition

domain's formula $x \to x \in (-\infty, +\infty)$ stands for eliminating the need for other parts, and by value field's formula $y \to y \in (-\infty, +\infty)$ stands for performing multiple functions.

Principle 7. 'Nested doll': Place one object inside another; place each object, in turn, inside the other; make one part pass through a cavity in another. We describe the principle with 3 circles' mathematical formula $x^2 + y^2 = 1^2$, $x^2 + y^2 = 2^2$, $x^2 + y^2 = 3^2$, stand for nested structure; $f(x) = f_1(f_2(f_3(x)))$ stands for nested function.

Principle 8. Anti-weight: To compensate for the weight of an object, merge it with other objects; or make it interact with the environment. We describe the principle with mathematical logic formula ~G, stands for anti-weight, for example, use helium balloon to support advertising signs; aircraft wings create lift.

Principle 9. Preliminary anti-action: Create beforehand action in an object that will oppose known undesirable working action. We describe the principle with mathematical formula $y = f(x) - f(x) = 0$, stands for merging anti-action and action together, and undesirable action is diminished.

Principle 10. Preliminary action: Perform, before it is needed; pre-arrange for the most convenience. We describe the principle with mathematical formula $y = a + f(x)$, a stands for preliminary action.

Principle 11. Preliminary cushioning: Prepare emergency means beforehand to compensate for the relatively lower reliability of an object. We describe the principle with mathematical formula $y = a + f(x)$, c stands for preliminary 'cushion'.

Principle 12. Equipotentiality: In a potential field, limit position changes. We describe the principle with mathematical formula $f(x_1) = f(x_2) = f(x_3) = \cdots$, stands for a function is always equal in the domain of $x \in x_1, x_2, x_3, \cdots$.

Principle 13. 'The other way round': Invert the action(s) used to solve problem; make the movable part fixed, and the fixed movable; turn the object (or the process) 'upside down'. We describe the principle with mathematical inverse function $y = f(x) \to y = f^{-1}(x)$, stands inversed thinking.

Principle 14. Spheroid-Curvature: Instead of using rectilinear structure, use curvilinear ones; use rollers, balls, spirals, domes; go from linear to rotary motion, use centrifugal forces. We describe the principle with mathematical formula $\rho = \left| (1 + y'^2)^{3/2} \big/ y'' \right| \in [0, +\infty)$, stands for curvature ρ should not always be ∞, in other word, structure should not always be rectilinear, which can be variable in different curvature.

Principle 15. Dynamics: Allow (or design) the characteristic of an object, environment, or process to change to be optimal, or to find an optimal operating condition; divide an object into parts capable of relative movement; if an object (or process) rigid or inflexible, make it movable or adaptive. We describe the principle with Lagrange dynamic equation $\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_j}\right) - \frac{\partial T}{\partial q} = Q_j$, T is the generalized energy described with generalized coordinate q_j and velocity $\dot{q}_j$; Q_j is generalized force relative to q_j.

Principle 16. Partial or excessive actions: If 100 percent of an object is hard to achieve, using a given solution method by 'slightly less' or 'slightly more' of the method, the problem may be considerably easier to solve. We described the principle with mathematical function $y=f(x)\pm\Delta y$ ($\Delta y \leq \varepsilon$, ε is a finite small real number), stands for slightly partial or excessive actions, for example, to fill tank of your car till it overflows, then 'top off'.

Principle 17. Another dimension: To move an object in 2- or 3- dimensional space; use multi-story arrangement for objects; tilt or re-orient an object. We describe the principle with a set of mathematical function $f_1(x)$, $f_2(x, y)$, $y = f_3(x, y, z)$, $\cdots$, $y = f_n(x, y, z, \cdots, t_1, t_2, t_3, \cdots)$, stand for function could be changed and varies according to dimensions.

Principle 18. Mechanical vibration: Cause an object to oscillate or vibrate; increase its frequency; use ultrasonic resonance, piezoelectric vibrators, electromagnetic field oscillations. We describe the principle with one freedom mechanical vibration equation

$$\ddot{x}(t) + 2\xi\omega_n \dot{x}(t) + \omega_n^2 x(t) = \omega_n^2 A \cos \omega t$$

$$x(t) = X \cos(\omega t - \phi)$$

$$X = A / \sqrt{[1 - (\omega / \omega_n)^2]^2 + (2\xi\omega / \omega_n)^2}$$

X is the magnitude of vibration; x is the displacement of the object, ω is the frequency of vibration, ω_n is inherent frequency.

Principle 19. Periodic action: Instead of continuous action, use periodic or pulsating actions; if an action is already periodic, change the periodic magnitude or frequency; use pauses between impulses to perform a different action. We describe the principle with mathematical function $y=A(t) \times f(x)=A(t) \times f(x+T)$, the value domain of y, is $y>0$, $y<0$, or $y=0$. The change between the 3 states means pulsating action, a period of $f(x)=0$ means

pause, $A(t)$ is the magnitude that can be changed with time, T is size of cycle.

Principle 20. Continuity of useful action: Carry on work continuously; eliminate all idle, intermittent actions or work. We described the principle with mathematical formula $\lim_{a<t<b} f(x,t) \to C$, t stands for time, which during a period [a, b]. The formula means the function acts almost the same as constant C.

Principle 21. Skipping: Conduct a process, or certain stages at high speed. We described the principle with mathematical formula $\lim_{\Delta t \to 0} f(x, \Delta t)$, Δt stands for a period of time. The formula means the function acts during a very short of time.

Principle 22. 'Blessing in disguise' or 'Turn lemons into lemonade': Use harmful factors to achieve a positive effect; eliminate the primary harmful action by adding it to another harmful action. We described the principle with mathematical function $y_1=f(x)<0$, then $y_2=-f(x)>0$. Or, $f_1(x)<0$, $f_2(x)<0$, then it is possible $f_1(x)-f_2(x)>0$. '<0' means harmful, '>0' means beneficial.

Principle 23. Feedback: Introduce feedback to improve a process or action; if feedback already used, change its magnitude or influence. We described the principle with mathematical function $y=f(x, k*y)$. y is also belong to variable domain, k is the magnitude of feedback.

Principle 24. 'Intermediary': Use an intermediary article or intermediary process; merge one object temporarily with another. We described the principle with mathematical function $y=f(x)=(f(x)+g(x))-g(x)$. y is a usefulness, $f(x)$ is the function that brings the usefulness, $g(x)$ is the 'intermediary'.

Principle 25. Self-service: Make an object serve itself by performing auxiliary helpful functions; use waste resources, energy, or substances. We described the principle with mathematical function $y+\Delta y=f(x+\Delta y)$. y is a usefulness, $f(x)$ is the function that brings the usefulness, Δy is the by-product of function $f(x)$, which is useless, but can be a part of variable, or say raw material, even as driving source.

Principle 26. Copying: Instead of an unavailable , expensive, fragile object, use simple and inexpensive copies; replace an object, or process with optical copies; if visible optical copies are already used, move to infrared or ultraviolet copies. We described the principle with mathematical function $f(x) \to f(y) \to f(z)$. $f(x)$, $f(y)$, $f(z)$ stand for a function or an object's structure; '$\to$' means mapping between two functions or structures.

Principle 27. Cheap short-living objects: Replace an expensive object with a multiple of inexpensive objects. We describe the principle with mathematical function $f(x) = f_1(x) + f_2(x) + \cdots$ in structure, or $f(x) = f_1(x, 0 < t < t_1) + f_2(x, t_1 < t < t_2) + \cdots$ in structure and time, t stands for time. For example, use disposable paper objects to avoid the cost of cleaning and storing durable objects.

Principle 28. Mechanics substitution: replace a mechanical means with sensory (optical, acoustic, taste, or smell); use electric, magnetic and electromagnetic fields to interact with the object. We describe the principle with mathematical function

$$f(x) = f_1(optical) + f_2(acoustic) + f_3(taste) + f_4(smell) + f_1(physics\_field).$$

Principle 29. Pneumatics and hydraulics: Use gas and liquid parts instead of solid parts. We describe the principle with mathematical formula $f(state) = f(solid / gas / liquid / field)$, in which '/' means 'or'.

Principle 30. Flexible shells and thin films: Use flexible shells and thin films instead of three dimensional structures; isolate the object from external environment using flexible shells and thin films. We described the principle with mathematical formula:

$\lim_{\Delta x \to 0}(\Delta x \times \Delta y \times \Delta z) = thin\_film$ or $flexible\_shell$, we extend the concept by mathematical operation, and get a few valuable results , for example,

$\lim_{\substack{\Delta x \to 0 \\ \Delta y \to 0}}(\Delta x \times \Delta y \times \Delta z) = thin\_silk$ or $flexible\_wire$, by this way, we get silk or wire;

$\lim_{\substack{\Delta x \to 0 \\ \Delta y \to 0 \\ \Delta z \to 0}}(\Delta x \times \Delta y \times \Delta z) = thin\_powder$, we get powder.

$$\lim_{\substack{\Delta x \le \delta \to \sum_{i=1}^{\infty} \Delta x_i \\ \Delta y \le \delta \to \sum_{i=1}^{\infty} \Delta y_i \\ \Delta z \le \delta \to \sum_{i=1}^{\infty} \Delta z_i \\ \Delta time \to 0}} (\Delta x \times \Delta y \times \Delta z, \Delta time) =$$ explosion.

We consider time as a variable, suppose δ is a finite real number, and during a very short of time, a volume material splits into infinite small parts. This is explosion. This is a new approach of an innovative principle by mathematical method.

Principle 31. Porous materials: Make an object porous or add porous elements; if an object is already porous, use the porous to introduce a useful substance or function. We describe the principle with mathematical function

$$y = f(x) = f_1(x) + f_2(x) + f_{31}(x) + \cdots$$

$$y = f(x) = (f_{11}(x) - f_{12}(x)) + (f_{21}(x) - f_{22}(x)) + (f_{31}(x) - f_{32}(x)) + \cdots$$

$y=f(x)$ stands for an object of a function; $f_1(x), f_2(x), f_{31}(x), +\cdots$ stands for diversity development of function or substructure of object; $(f_{11}(x)-f_{12}(x)),\quad (f_{21}(x)-f_{22}(x)),\quad (f_{31}(x)-f_{32}(x)),\cdots$, stands for the porous structure or simplified function.

Principle 32. Color changes: Change the color of an object or its external environment; change the transparency of an object or its external environment. We describe the principle with mathematical function

$$y=f(color)=f(red, blue, yellow, ultrared, ultraviolet)\quad ,$$

$y=f(x)$ stands for a function of an object; the colors are regarded as variables.

Principle 33. Homogeneous grouping: Make objects interacting with a given object of the same material. We describe the principle with mathematical function

$$\exists x\in I, y\in I.\ Then, x+y\in I, x*y\in I\ ,$$

$$\exists x\in R, y\in R.\ Then, x+y\in R, x-y\in R, x*y\in R, x/y\in R\ .$$

Principle 34. Discarding and recovering: Make portions of an object that have fulfilled their functions go away or modified these directly during operation; Conversely, restore consumable parts of an object directly in operation. We describe the principle with mathematical function $y=f(x)=f(x\pm\Delta x)\pm\Delta f(x)$. In which, $f(x)$ stands for a function, which can be modified by adjustment of Δx, or $\Delta f(x)$.

Principle 35. Parameter changes: Change an object's physical states; change the concentration or consistency; change the degree of flexibility; change the temperature. We describe the principle with mathematical function $y=f(x\pm\Delta x,\ y\pm\Delta x,\ z\pm\Delta x,...)$. In which, $x, y, z,...$ stand for different parameters, then y is a function result.

Principle 36. Phase transitions: Use phenomena occurring during phase transition. We describe the principle with mathematical function $y=f(f(\text{gas})\text{->}f(\text{liquid})\text{->}f(\text{solide}))$. In which, '->' means phase transition.

Principle 37. Thermal expansion: Use thermal (or contraction) of material; if thermal expansion is being used, use multiple materials with different coefficients of thermal expansion. We describe the principle with mathematical function $y=a+bi=$ structure (temperature)+ function (temperature). In which, 'a' stands for structure, 'b' stands for function.

Principle 38. Strong oxidants: replace common air with oxygen-enriched air; replace enriched air with pure oxygen; expose air or oxygen to ionizing radiation; replace ozonized with ozone. We describe the principle with mathematical function $y=\lim_{O_2\to strong} f(x,O_2)$. In which, O_2 stands for oxidant, x stand for other substances, then y is a function result.

Principle 39. Inert atmosphere: replace an normal environment with an inert one; add neutral parts, or inert additives to an object. We describe the principle with mathematical function $y=\left|\lim_{t1<t<t2} f(x,y,z,...,t)-C\right|<\varepsilon$,

or $y=\left|\lim_{\substack{t1<t<t2\\ |x-c1|<\varepsilon 1\\ |y-c2|<\varepsilon 2\\ |z-c3|<\varepsilon 3\\ .....}} f(x,y,z,...,t)-C\right|<\varepsilon$. In which, x,y,z,... stand for different parameters or components, ε is a very small positive real number, then y is a function result.

Principle 40. Composite materials: Change from uniform to composite (multiple) materials. We describe the principle with mathematical complex function $y=a+bi+cj+...$ ($a, b, c,...$ stands for different kind of materials, then y is a composite one), for example, airplane parts.

3 CONCLUSIONS

By now, all the TRIZ's 40 inventive principles have been described by mathematical method. The mathematical description is pure, clear, easy to understand, and powerful to innovative research and development. We are also sure that the mathematical models will provide and effective instruction on innovative principles for students, researchers, and practicing engineers.

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