GEN TRIZ Knowledge Transfer Basic Module

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Manual

Intro
Basic
Advanced
Expert

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Introduction to GEN TRIZ Product Innovation

What is GEN TRIZ Product Innovation?

GEN TRIZ Product/Process/Service Innovation is a powerful suite of tools and methodologies for improving existing products and processes (such as by reducing cost, improving functionality, or both) and for developing new generation products and processes.

In the conventional wisdom, innovation is an inefficient and ineffective process. Statistically, only one idea out of 3,000 raw ideas makes it to the market. Such inefficiency would be unacceptable in any other area (imagine that only one airplane takes off the ground out of 3,000 scheduled to fly), but is not considered shocking for innovation because innovation is perceived as "difficult" and “unpredictable”. Limited resources, psychological inertia, limited breadth of technical knowledge, information overload, tendency to compromise, inability to objectively forecast the technological future and, finally, choosing a wrong problem to solve have all been cited as reasons that prevent innovation. Because of these so called "innovation killers", most innovations are incremental at best and are aimed at improving already existing products.

GEN TRIZ Product/Process/Service Innovation bypasses typical innovation killers by using:

- Analytical tools that identify unsatisfied market needs
- Analytical tools that identify the right problems
- Objective and statistically proven trends of evolution for Engineering Systems
- Problem-solving tools that solve engineering problems without compromise, often leading to breakthrough solutions
- Tools that break through psychological inertia
- Dynamic, cost-efficient, and fast access to a wide range of experts around the world − the Global Knowledge Network

The power of GEN TRIZ Product/Process/Service Innovation lies in its ability to make innovation a predictable, and, therefore, risk-averse process by applying a scientific and methodological framework to solving engineering problems. Importantly, GEN TRIZ Product/Process/Service Innovation is not a substitute for intelligence. Rather, it can be viewed as a multiplication constant to intelligence that serves as a stimulator, an optimizer, and a filter to make the innovation process significantly more productive, efficient, and effective.

Three Stages of GEN TRIZ Product/Process/Service Innovation

A typical process that employs GEN TRIZ Product/Process/Service Innovation includes the following three stages:

Problem Identification: This stage starts from discovery of so-called Main Parameters of Value (PV) – attributes of the product, process, or service that define consumers purchasing decision. It allows correctly identifying unsatisfied market needs. After that, this stage is focusing on analysis of the Engineering System and identification of the "right" problems to solve. These are deep, underlying problems that are causes rather than symptoms and are usually not obvious at the outset. The output of the Problem Identification stage is a set of Key Problems that, when solved, significantly improve the System and enable the technical goals of the initiative to be achieved.

Problem Solving: During this stage, Key Problems identified in the Problem Identification stage are solved using a powerful set of solution tools. The output of the Problem Solving stage is a comprehensive set of proposed technical solutions (Ideas).

Concept Substantiation: During this stage, the proposed solutions developed during the Problem Solving stage are evaluated for practical feasibility based on the technical and business requirements of the Innovation Initiative. Evaluation criteria often include technical and manufacturing constraints, time-to-market requirements, and investment and cost constraints, among others. All solutions must achieve acceptable Main Parameters of Value. The highest scoring solutions are selected and recommended for further development or for further evaluation if this is deemed necessary. This process quickly filters the best solutions, optimizing precious resources and time.

Organization of this Manual

This Manual for Basic Module provides an overview of the following tools that constitute GEN TRIZ Product/Process/Service Innovation:

- Main Parameters of Value Discovery (introductory level): An analytical tool that identifies parameters of the object that effect customers’ purchasing decision
- Function Analysis: An analytical tool that identifies functions, their characteristics, and the cost of the System and Super-system components.
- Cause-Effect Chains Analysis: An analytical tool that identifies the key disadvantages of the analyzed Engineering System by building cause-effect chains that link superficial problems to their fundamental causes.
- Trimming: An analytical tool for improvement of the Engineering System by removing (trimming) certain components and redistributing their useful functions among the remaining components of the Engineering System or its Super-system.
- Inventive Principle Application: Engineering Contradictions and Altshuller's Matrix: a problem-solving tool that provides generalized recommendations for modifying a System to solve a problem formulated as an Engineering Contradiction.
- Resolving Physical Contradictions: A problem-solving tool based on selecting the typical approach for resolving Physical Contradictions, and then identifying a set of appropriate Inventive Principles relating to the selected approach.
- Patent Circumvention (via Trimming): A technique for minor modifications of a patented object that allows to legally circumvent the constraints imposed by competitive patents and obtain the freedom to operate

Figure 1**Error! Reference source not found.** illustrates tools and methods of GEN TRIZ Product/Process/Service Innovation.

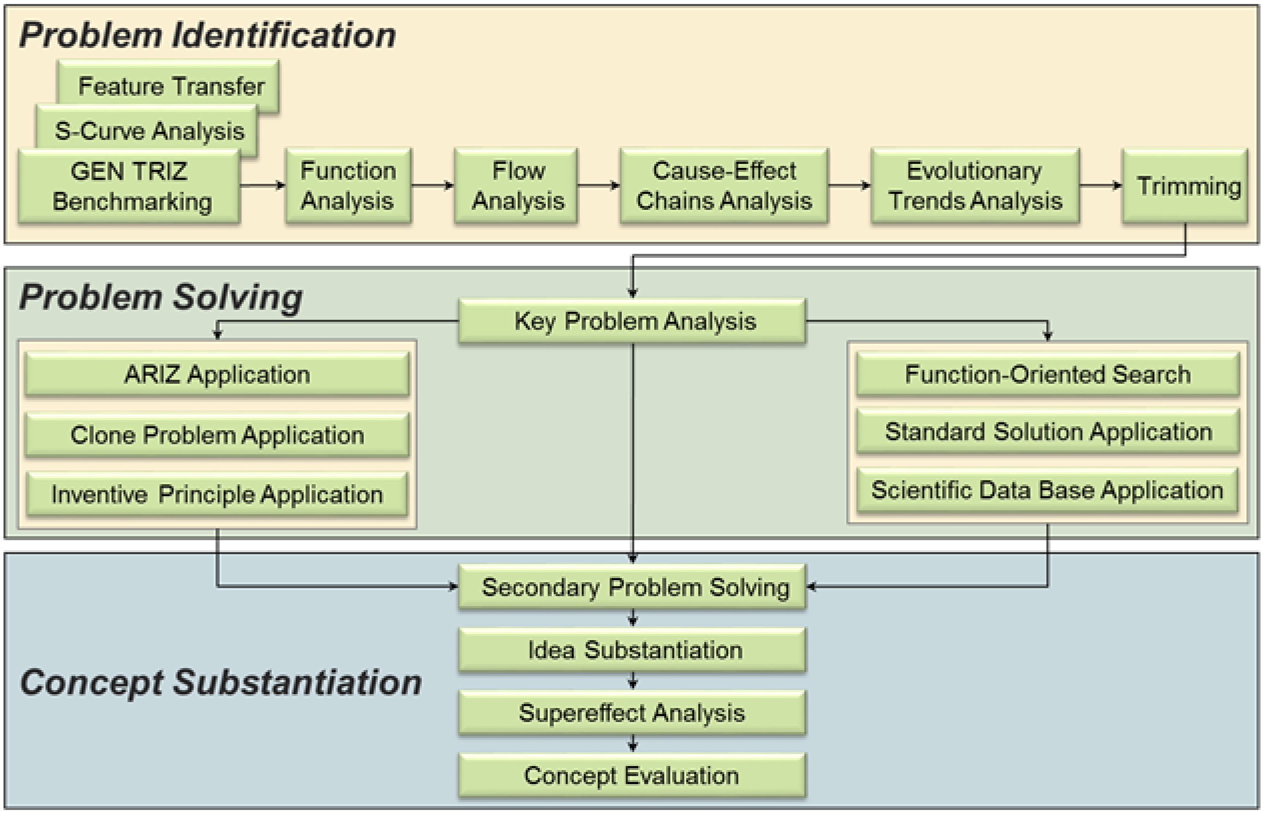


Figure 1 **Innovation Roadmap**

The figure above can also be viewed as a typical roadmap for a Product/Process/Service innovation initiative. However, although most tools are applied for either Problem Identification or Problem Solving, some have dual use (such as Trends of Engineering System Evolution, Trimming, and Feature Transfer). In addition, the selection and focus of individual tools as well as the order in which they are applied within the Problem Identification and Problem Solving stages are defined by the nature of an individual innovation project.

Main Parameters of Value Discovery

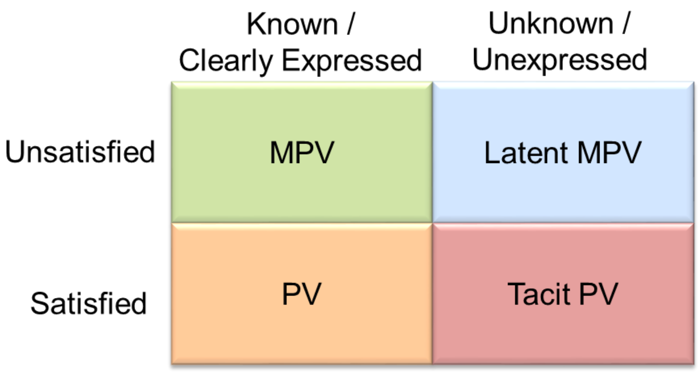
Introduction

GEN TRIZ defines innovation as commercially available significant improvement of a product along at least one Main Parameter of Value (MPV). This definition implies that mere novelty does not constitute innovation. Instead, innovation brings additional value to customers as well as corresponding business rewards to the innovator.

MPV is the GEN TRIZ concept that ties innovation activities with customer purchasing decisions. MPVs are attributes or parameters of a product that influence the customer's purchasing decision.

Types of MPV

Figure 2 illustrates four types of MPV:



	Known / Clearly Expressed	Unknown / Unexpressed
Unsatisfied	MPV	Latent MPV
Satisfied	PV	Tacit PV

Figure 2. **Main Parameters of Value**

- Known and unsatisfied MPV

Potential customers understand them very well; therefore, improvement of these MPV is mandatory. However, all competitors are also aware about them, so this domain is the place of very intensive competition. Improvement of these MPV often is difficult, time-consuming, expensive, and provide just temporarily competitive advantage.

For example, safety is very important parameter of cars. All developers work hard to improve it. To outcompete all of them, it is necessary some extraordinary effort.

- Unknown and unsatisfied MPV

These parameters usually are considered as unchangeable natural limitations of existing products. Potential customers do not ask about their improvement, and developers usually ignore them. However, they limit the product value and thus should be improved.

For this purpose, first it is necessary to identify these latent MPV. There number of applicable techniques: Function Analysis, Evolutionary Trend Analysis, etc. Having candidates to MPV, later on, it is necessary to conduct some marketing research to be sure that improvement of these parameters really could influence purchasing decision.

Improvement of such hidden latent parameters could be highly profitable, because it often provides significant competitive advantage.

For example, millions of cars at any given moment stop at a red traffic light. This means that their drivers must constantly pay attention to the traffic light, determining when it will turn green.

This is annoying. Moreover, people often miss the moment of color change. Other drivers spend time waiting for them, and signal them irritably, adding unnecessary stress to our stressful life. If somebody would offer a device that would detect a color change and inform the driver with a beep, potential buyers would be very grateful.

- Known and satisfied PV

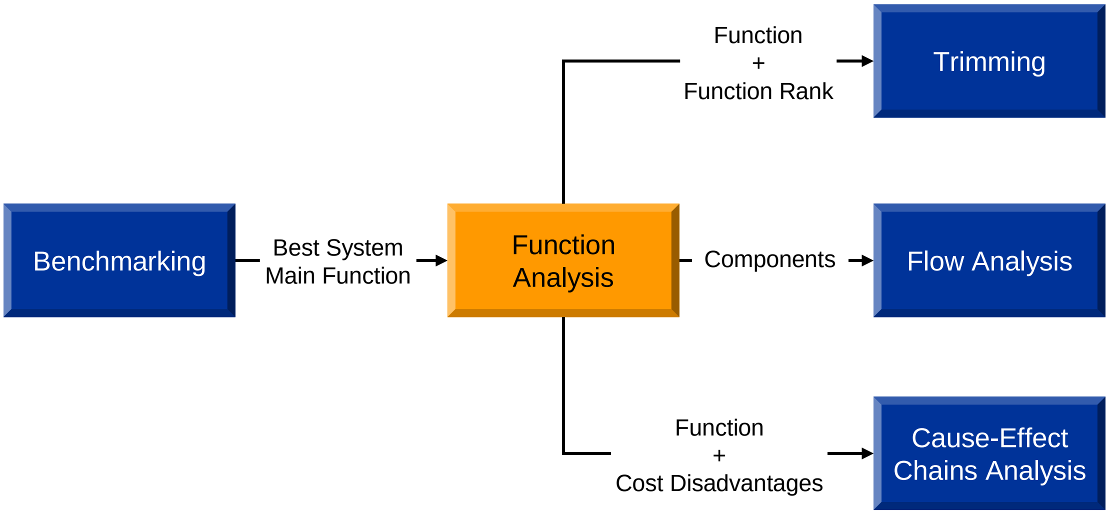
We do not need to satisfy these parameters. We just should not deteriorate them in the process of product improvement. Therefore, these parameters are usually used as a source of restrictions and limitations for innovation projects.

- Unknown and satisfied (tacit) MPV

Since these parameters are satisfied, it is not necessary to improve them. The problem is that in the process of improvement of other parameters we often unwillingly deteriorate them, just because we are not aware about them. They are one of major sources of secondary problems that emerge in the process of innovations.

For example, users of cordless computer mice suddenly experienced the unexpected problem: the cordless mouse tends to escape! You put it somewhere and cannot find when you most need it. It means that improving the mouse, developers missed one important function of the cord: to hold the mouse near the computer. The cordless mouse does not satisfy this MPV anymore.

Function Analysis



Key Terms

- Function
- Function Analysis
- Substance
- Field
- Auxiliary Function
- Basic Function
- Component
- Main Function
- Basic Function
- Interaction Matrix
- Super-system
- Object of the Function
- Parameter
- Performance Level
- Additional Function
- Function Rank
- Useful Function
- Component Analysis
- Function Carrier
- Harmful Function
- Target

Introduction

Every Engineering System is designed with a purpose: to perform a particular function. For example, a car is designed to move passengers and cargo. From this "function-oriented" point of view, a specific design or technology is just an implementation tool, and, thus, innovation can and should be framed around functions that the Engineering System performs.

Function Analysis is an analytical tool that identifies functions, their characteristics, the cost of components of the analyzed Engineering System, and its the cost of components of the Super-system. Note that Function Analysis can be performed on products as well as on processes. In brief, functions are evaluated in terms of their usefulness, relative significance, and performance level. Analyzing and ranking the relative value of components provides extremely useful insights into which components can be improved, eliminated, or left as they are.

The main goal of Function Analysis is to determine disadvantages of the analyzed Engineering System. Therefore, Function Analysis is a major cornerstone of the Problem Identification process and lays the foundation for many other Problem Identification and Problem Solving tools, such as Trimming, Flow Analysis, Cause-Effect Chains Analysis, etc., that will be described in the subsequent chapters of this manual.

Because Function Analysis is centered on functions, rather than specific components and technologies, it opens new opportunities to pursue "out of the box" thinking. The advantages of using the language of generalized functions include an opportunity to disconnect from a specific industry or technology and seek ideas and solutions in seemingly unrelated areas. This, in turn, enables previously unknown solutions to be considered. This approach significantly increases our ability to improve the System.

Key Stages in Function Analysis

Function Analysis includes the following key stages:

Component Analysis: The various components of the analyzed Engineering System and its Super-system are identified. The Super-system is a higher-level system that is a superset of the analyzed Engineering System (i.e., the analyzed Engineering System is a Component of the Super-system).

Interaction Analysis: All possible interactions between the various Components of the Engineering System and its Super-system are identified.

Function Modeling: The functions performed by the Components of the Engineering System and its Super-system are identified and evaluated.

Cost Analysis: The absolute and relative costs of all Components in the analyzed Engineering System are identified.

Strategic Importance of Function Analysis

Function Analysis is a key methodology and is the foundation for almost all GEN TRIZ problem statement and problem solving tools. The output from Function Analysis is used for many subsequent stages.

As functions are evaluated in terms of their usefulness, relative significance, performance level, and cost, it is possible to develop a normalized value for each function, and dissimilar functions can be compared with one another. This is discussed in the following section, *Component Analysis*.

Analyzing and ranking the relative value of dissimilar functions provides extremely useful insights into which functions to improve, which ones to eliminate, and which ones to leave alone. This is discussed in more detail in the *Trimming* chapter. A key benefit of this methodology is that it addresses the most problematic function(s) first.

Function Analysis can be performed on Engineering Systems or products as well as on processes. In this Basic Module, we will only discuss Function Analysis for products. Function Analysis for processes is discussed in the Advanced Module.

Component Analysis

Component Analysis is a procedure in the Problem Identification stage. It is used to identify the components of an Engineering System. In this procedure, relevant components of the Engineering System are identified, as well as the components with which the Engineering System interacts or co-exists.

The goal of Component Analysis is to identify the components of an Engineering System and its Super-system. The output of Component Analysis is a component model that is used in subsequent stages of Function Analysis. The component model is developed as a list at the desired level of analysis. Separate lists are developed for the Engineering System and the Super-system. During Component Analysis, the focus is only on identifying the main components of the Engineering System. All other analyses are performed at subsequent stages.

Identifying the Components of an Engineering System

The components of an Engineering System can be only a substance, a field, or a combination of both. Substances, such as water, an automobile, and a toothbrush, have rest mass. On the other hand, fields, such as an electric field, magnetic field, and thermal field, do not have rest mass. Fields transmit interactions between substances.

For example, a car is an Engineering System. Some components of the car are the engine, the electrical system, the drive train, and the enclosure for passengers.

Hierarchy of Components

A component of an Engineering System can also be considered as an Engineering System on its own. It will then have its own components. For example, in a car, the electrical system is composed of components such as the alternator, the battery, and wiring. Each of these may again be considered as an Engineering System. For example, the components of the battery are the electrodes, electrolyte, casing, etc.

Therefore, Engineering Systems can be considered as composed of a hierarchy of components. It is important to select the components at the right level of the hierarchy to perform effective analysis.

Selecting the Hierarchical Level

The selection of the hierarchical level depends on the project objectives and constraints. As a guideline, start at the highest level. While determining the hierarchical level, the following points should be considered:

- Selecting a very low level may result in a component model having too many components. This will increase the analysis effort significantly at subsequent stages without commensurate benefits.
- Component Analysis at too high a level may generate a component model that is too generalized and have insufficient information for meaningful analysis at subsequent stages.
- A set of similar components can be considered as one component. For example, the wheel of a car may have six nuts but all six nuts can be considered as one nut.
- Always select components at the same hierarchical level.

Note: Experience suggests that a model should not include more than 12- 15 components. If subsequent stages require that a certain component be analyzed more thoroughly, an individual component model at a lower hierarchical level may be constructed.

Identifying the Components of the Super-system

Engineering Systems exist in an environment and interact or co-exist with other parts of that environment. For example, a car interacts with the passengers, the road, and the air in its environment. A system of which an Engineering System is a part or component is called the Super-system. For the purpose of Component Analysis, the Super-system components are everything that the Engineering System interacts with (Figure 3). For example, if a wheel of a car is the analyzed Engineering System, then the Super-system components include the other parts of the car as well as the road, gasoline, air, water, etc.

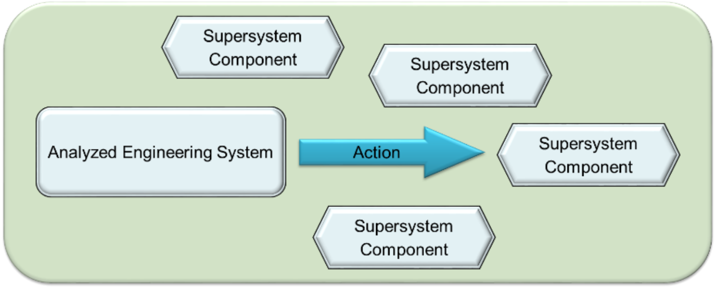


Figure 3. **Components of the Super-system**

Include all the components of the Super-system with which the analyzed Engineering System interacts. You may also include those components of the Super-system that are located near the Engineering System but do not interact with it. These elements may become resources for improving the Engineering System. After the analysis, remove those Components of the Super-system that neither interact with the Engineering System nor are potential resources for it.

Note: The Super-systems of an Engineering System are different for different life stages. For example, while a car is parked in a garage, the garage may be considered as a Super-system for the car; while the car is driving, the street may be considered as a Super-system for the car.

Identifying the Target

Each Engineering System is built to perform some function. We call it a Main Function. The object of the main function is called a Target. For example, the main function of a car is to move passengers and cargo. The Targets of the car are passengers and cargo, and both belong to the Super-system. The parameter change in the Targets is their physical location.

To identify the Target of an Engineering System, first identify the main function by considering the main purpose for which that Engineering System is built. For example, a car may perform many functions like playing music or lighting the road, but its main function is to transport people and cargo from one place to another. The objects of the main function are those components in the Super-system whose parameters change as a result of the main function.

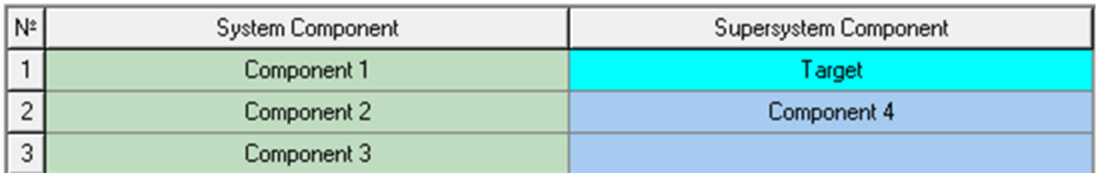
For example, the main function of a toothbrush is to remove plaque from the teeth. Therefore, the Target of toothbrush is plaque and the parameter change in plaque is its location.

Constructing a Component Model

The component model is constructed using the template (Figure 4)

To construct a component model:

1. In the first column, write the name of the Engineering System.
2. In the second column, write the components at the desired level of hierarchy.
3. In the third column, write the Super-system components that interact with the Engineering System or are located close to it.



№	System Component	Supersystem Component
1	Component 1	Target
2	Component 2	Component 4
3	Component 3	

Figure 4. **Component Model Template**

Example: Paint Filling System

To illustrate the various procedures in Component Analysis, we will use the example of the Paint Filling System Engineering System (Figure 5).

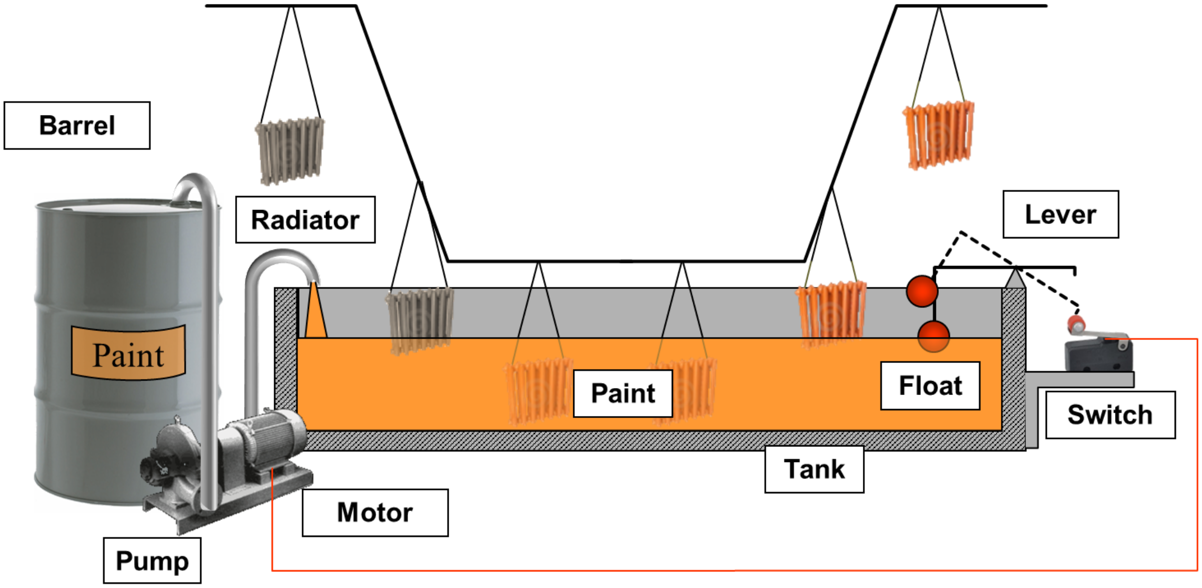


Figure 5. **Paint Filling System**

The above illustration shows a simple view of an Engineering System that is used to paint some machine parts. It consists of a tank containing paint, and a conveyor belt that brings the parts, dips them inside the tank, and after they are painted, takes them away. As more parts get painted, the paint in the tank starts depleting. To replenish the paint inside the Paint Filling System, a system is connected to the tank. This system monitors the paint level inside the tank continuously by using a float. This float is connected to a lever which in turn is connected to a switch.

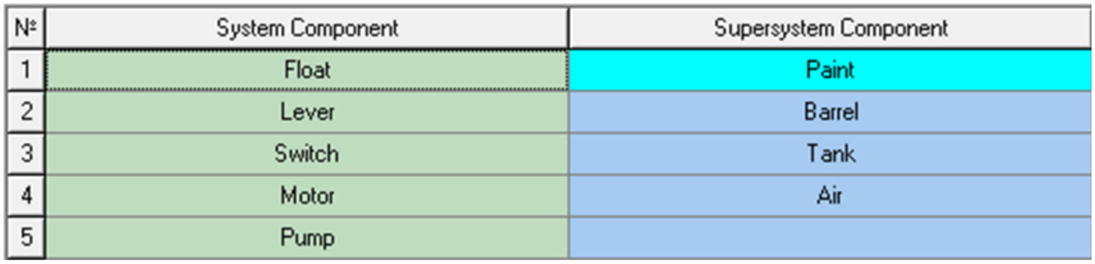
As the paint level decreases in the tank, the float moves down and the lever connected to the float switches the motor on. The motor drives the pump that starts pumping paint from the barrel into the Paint Filling System.

As the paint level starts increasing, the float starts moving up and, when it reaches a certain level, the attached lever switches the motor off and the flow of paint from the barrel to the tank stops.

Since the float is continuously in touch with the paint, it gets heavier as layers of paint solidify on its surface. Over time, the float becomes very heavy and does not move up even when the paint level increases. When this occurs, the lever remains disconnected from the switch and the motor continuously pumps paint into the tank, leading to overflow of the paint.

Applying the Component Analysis Algorithm to the Paint Filling System

Here is the component model for the Paint Filling System (Figure 6):



№	System Component	Supersystem Component
1	Float	Paint
2	Lever	Barrel
3	Switch	Tank
4	Motor	Air
5	Pump	

Figure 6**. Component Model for the Paint Filling System**

To create the component model for the Paint Filling System:

1. In the first column, write `Paint Filling System' because the Paint Filling System is the Engineering System for analysis and subsequent improvement.
2. In the second column, list all the main components of the Paint Filling System. Use the highest level of component hierarchy.
3. In the third column, list the components of the Super-system that interact with the components of the Paint Filling System.

Interaction Analysis

Components of an Engineering System interact with each other when they come in physical contact with each other. Interaction between two components is a necessary condition for one component to perform a function on the other. Therefore, to understand the functions that components of an Engineering System perform, first it is necessary to understand the interactions between the various components of the Engineering System.

Interaction Analysis is an analytical procedure to identify the interactions of the components of an Engineering System with each other as well as with the components of the Super-system. Interaction Analysis is one of the procedures in a series of interconnected procedures in the Function Analysis stage.

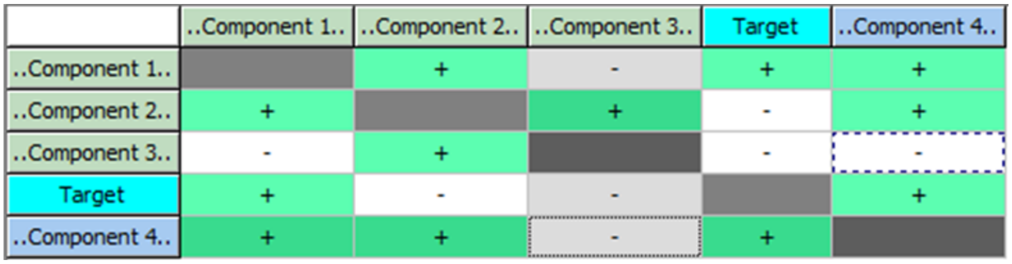
Constructing an Interaction Matrix

An Interaction Matrix contains all possible interactions between components. The row and the column headings of this Matrix contain all of the components of the Engineering System and the Super-system. These components are listed in the same order in the row and the column headings as shown in the following table. A plus (+) sign in a cell of the table indicates an interaction of the components listed in both the row and column heads for that cell (Figure 7).

The Interaction Matrix indicates which components interact with which other components. However, it does not provide additional details about the interactions. More details about these interactions are identified during the Function Modeling phase of Function Analysis.

To construct an Interaction Matrix:

1. Construct a table with the number of columns and rows equal to the number of components in the component model.
2. Starting with column one, write one component in each column head, in the same order as they are listed in the component model. Repeat this step for the rows, starting with the first row head.
3. Look at the component in the first row head and then look at the component in the first column head. If the two components interact, mark a plus `+' sign in the cell at the intersection of the first row and first column. If the two components do not interact, mark a minus `-' sign. Repeat this step until all the cells in the first row are marked.
4. Repeat step 3 for all the rows until all the cells of the matrix are marked.
5. Check for the symmetry of the matrix by looking at the diagonal. The diagonal from the top-left to the bottom-right should contain only cell that contain the same component at the row head and the column head. If the matrix is not symmetrical, look for errors and make corrections.
6. Check for comprehensiveness of the matrix. If a component in the matrix does not interact with any other component, re-analyze the interaction for that component and correct the cell markings. If it is determined that there is no interaction for that component, remove it from the Interaction Matrix.



	..Component 1..	..Component 2..	..Component 3..	Target	..Component 4..
..Component 1..		+	-	+	+
..Component 2..	+		+	-	+
..Component 3..	-	+		-	-
Target	+	-	-		+
..Component 4..	+	+	-	+	

Figure 7. **Interaction Matrix Template**

Example: Paint Filling System

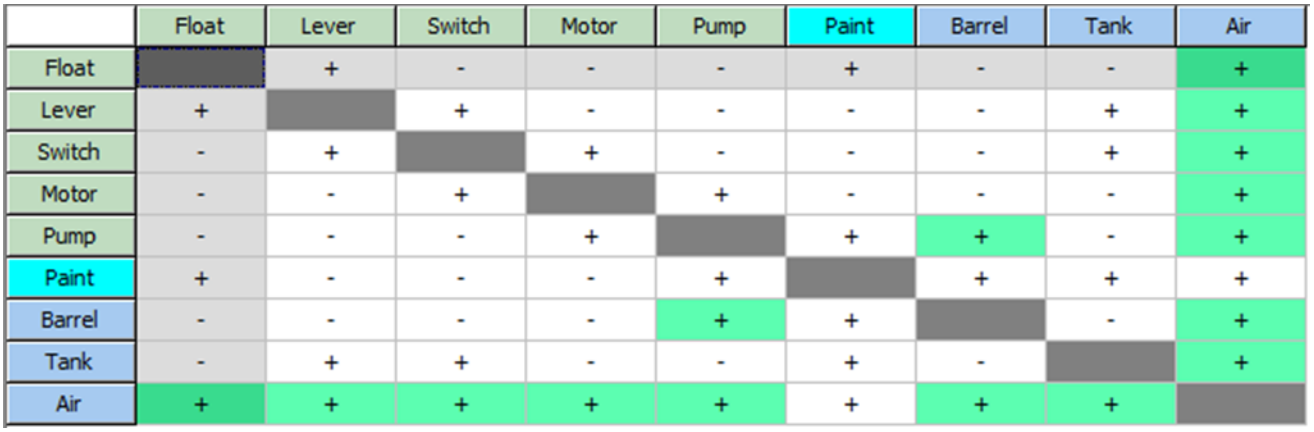
To create an Interaction Matrix for the Paint Filling System:

1. Create an Interaction Matrix with rows and columns equal to the number of components identified in the component model. Since the component model (as shown in the *Component Analysis* section) of the Paint Filling System contains ten components, make ten rows and columns in the Interaction Matrix.

Note: Include the components of the Engineering System as well as those of the Super-system in the Interaction Matrix.

2. Write the names of the components in the row and column headings in the same order as they appear in the component model. First, write the components of the Paint Filling System, and then write those of the Super-system.
3. Check the components in the rows against the components in the columns. If two components interact with each other, put a plus `+' sign in the respective cell. For example, in the following table, float interacts with lever, paint, and air; therefore, the respective cells are marked with `+' signs.

Here is the Interaction Matrix for the Paint Filling System (Figure 8):



	Float	Lever	Switch	Motor	Pump	Paint	Barrel	Tank	Air
Float		+	-	-	-	+	-	-	+
Lever	+		+	-	-	-	-	+	+
Switch	-	+		+	-	-	-	+	+
Motor	-	-	+		+	-	-	-	+
Pump	-	-	-	+		+	+	-	+
Paint	+	-	-	-	+		+	+	+
Barrel	-	-	-	-	+	+		-	+
Tank	-	+	+	-	-	+	-		+
Air	+	+	+	+	+	+	+	+	

Figure 8. **Interaction Matrix for the Paint Filling System**

Function Modeling

Every Engineering System is built for a specific purpose: to deliver specific function(s). For example, the main function of a car is to move passengers and cargo. This functionality is delivered as a result of the functions performed by the various components of the Engineering System. Hence, an Engineering System is, in essence, a complex combination of functions. This view of an Engineering System gives importance to the functions and not to the components and technologies because the critical functions of the Engineering System remain constant, while components and technologies may change. Function Modeling is the procedure to construct the functional representation of the Engineering System.

Function Modeling involves identifying and evaluating the functions performed by the components of the Engineering System. The functions are evaluated for:

- Category (useful or harmful)
- Relative significance
- Quality of performance (for useful functions)

The results of Function Modeling are used by subsequent stages for improving the Engineering System.

Outcome of Function Modeling

The outcome of Function Modeling is a Function Model of the Engineering System. The Function Model captures the functions with their properties, such as the Function Carrier, the Object of the Function, the function rank, and the function performance. The Function Model is used as input in the subsequent stages of problem identification and solution of the Engineering System.

Defining a Function

Function is an action performed by one Component to change or maintain a parameter of another Component. As shown in the following illustration, an object that performs a function is called the Function Carrier, while the object on which the function is performed is called the Object of the Function (Figure 9):

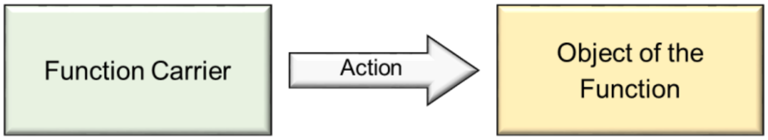


Figure 9. Function

For example, a hammer (Function Carrier) moves a nail (Object of the Function) leading to a change of the parameter (physical position) of the nail (Figure 10):

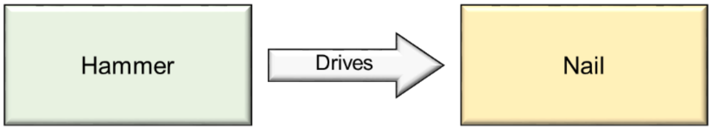


Figure 10. Function of a hammer

Three conditions must be met for the existence of a Function:

1. Both the Function Carrier and the Object of the Function must be Components
2. The Function Carrier and the Object of the Function have to interact to each other
3. parameter of one of the objects has to be changed or maintained as a result of the interaction

Several functions can be performed during one interaction. For example, if fire heats chocolate, the parameters that change as a result are:

- The state of the chocolate changes from solid to liquid
- The temperature changes
- The viscosity changes

Formulating the Main Function

Each Engineering System is built to perform a Main Function(s). The object of the Main Function is called the Target (Figure 11):

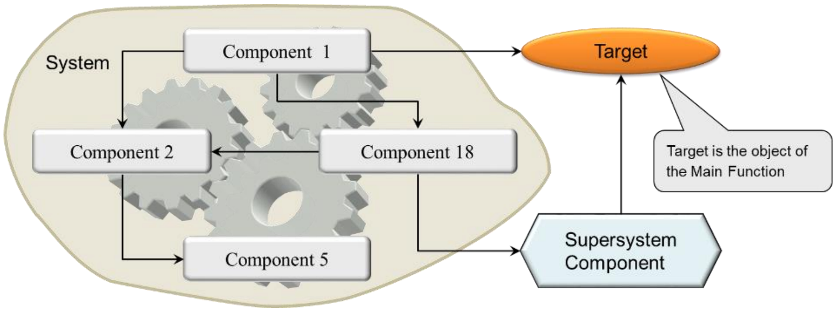


Figure 11. **Target**

For example, the main function of a car is to move passengers and cargo. The Targets of the car are passengers and cargo, and both belong to the Super-system. The parameter change in the Targets is their physical location.

To identify the Targets of an Engineering System, first identify the main function by considering the main purpose for which that Engineering System is built. For example, a car may perform many functions, such as playing music or lighting the road, but its main function is to transport people and cargo from one place to another. The Targets are those components in the Super-system whose parameters change as a result of the main function.

For example, the main function of a toothbrush is to remove plaque from the teeth. Therefore, the Target of toothbrush is plaque and the parameter change in plaque is its location.

Categorizing a Function

Functions can be divided into two main categories:

- **Useful functions:** A useful function changes the parameter of the Object of the Function in a desired direction.
- **Harmful functions:** A harmful function worsens the parameter of the Object of the Function. In most cases, improving the performance of an Engineering System requires the removal of these harmful functions.

Illustration of a Function

In the example of brushing teeth using a toothbrush, removing plaque qualifies as a function because:

- Both the toothbrush and the plaque are material objects
- There is interaction between the toothbrush and plaque
- The location of the plaque, which is a parameter value of plaque, is changed

More than one function can be performed by the toothbrush. For example:

- Removing plaque from the teeth
- Removing food from the teeth
- Damaging the gums

“Damaging the gums” is a harmful function, while “removing plaque” and “removing food” are useful functions.

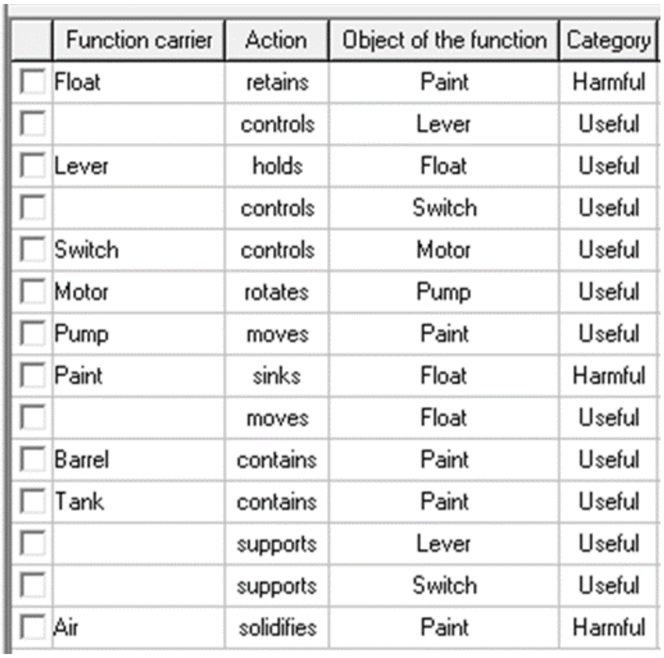
Identifying Functions

You can identify the functions of an Engineering System by referring to the Interaction Matrix (see the *Interaction Analysis* section) for that system. All cells containing a `+' sign in the Interaction Matrix show an interaction between the components in the row and column headings of those cells. The following steps describe how to identify the functions.

To identify the functions:

1. In the first row, write the first component that is in the first row of the Interaction Matrix. For example, in the Interaction Matrix for the Paint Filling System (see the *Interaction Analysis* section), Float is the first component
2. Check all the cells of first row of the Interaction Matrix for a `+' sign, starting from the left column. Once you find a cell with the `+' sign, identify the component at the column head of that cell
3. If the identified component is an Object of the Function to some function of the first component, write the function followed by the name of that component. As the following table shows, Float performs the function `move' on the component Lever (Object of the Function). While identifying functions, do not try to fill other columns in the table. You will fill these later while evaluating each function
4. Repeat steps 1 through 3 for all the rows in the Interaction Matrix

Here are functions of the Paint Filling System Components (Figure 12):



	Function carrier	Action	Object of the function	Category
☐	Float	retains	Paint	Harmful
☐		controls	Lever	Useful
☐	Lever	holds	Float	Useful
☐		controls	Switch	Useful
☐	Switch	controls	Motor	Useful
☐	Motor	rotates	Pump	Useful
☐	Pump	moves	Paint	Useful
☐	Paint	sinks	Float	Harmful
☐		moves	Float	Useful
☐	Barrel	contains	Paint	Useful
☐	Tank	contains	Paint	Useful
☐		supports	Lever	Useful
☐		supports	Switch	Useful
☐	Air	solidifies	Paint	Harmful

Figure 12. **Functions of the Paint Filling System Components**

Evaluating Useful Functions

A useful function changes the parameter of the Object of the Function in a desired direction. For example, the function `removing plaque' changes the location of plaque.

Determining the Performance of Useful Functions

Setting the Criterion for Measuring Performance

The performance of a useful function is measured in terms of certain criterion. It necessary to:

- Select a criterion
- Identify actual and necessary values of the criterion
- Compare this values and identify Level of Performance

Classifying the Levels of Performance

The level of useful function performance is a comparison between the actual value of the function criterion and the required value of this criterion. The most typical criterion is the function parameter. Both insufficient and excessive levels of function performance are Function Disadvantages.

Ranking Useful Functions

The rank of the Function is determined as follows (Figure 13):

1. A function directed at the Target is a Basic Function and has the highest rank

2. A function directed at a Super-system component other than the Target is an Additional Function
3. A function directed at a Component of the Engineering System is an Auxiliary Function
4.

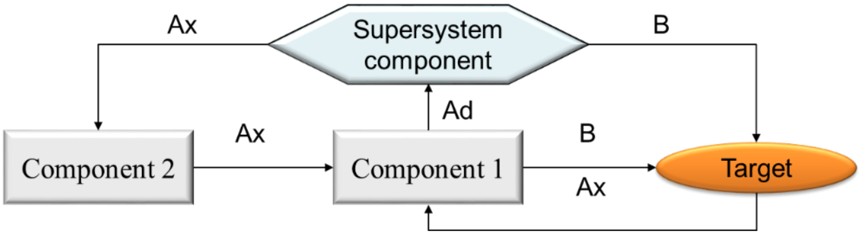


Figure 13. **Determining Function Ranks**

Cost Analysis

If cost reduction is one of the goals of the project for improving the Engineering System, the cost of each component is also identified during the Function Modeling stage. Cost-related information is also used in subsequent stages. For example, the cost of the component is also considered when deciding about the components to be trimmed from the Engineering System.

Two type of costs are identified for each component:

- Absolute Cost
- Relative Cost

Absolute cost is the monetary cost of the component in absolute terms. For example, if a component costs $5, its absolute cost is $5.

Relative cost is the percentage of the absolute cost to the total cost of the Engineering System. For example, if the total cost of the Engineering System is $100 and the cost of a component is $1, then the relative cost of the component is 1%.

Relative cost provides a convenient way of comparing, based on cost, the components of an Engineering System. For example, if two components of an Engineering System cost $5 and $7 respectively, it is very difficult to judge whether the cost difference between the two components is significant or negligible. If, for example, the total cost of the Engineering System is $10, the difference of $2 dollar is significant; however, if the total cost of the Engineering System is $5000, the difference of $2 is negligible.

A high relative cost of a component is considered as a Cost Disadvantage.

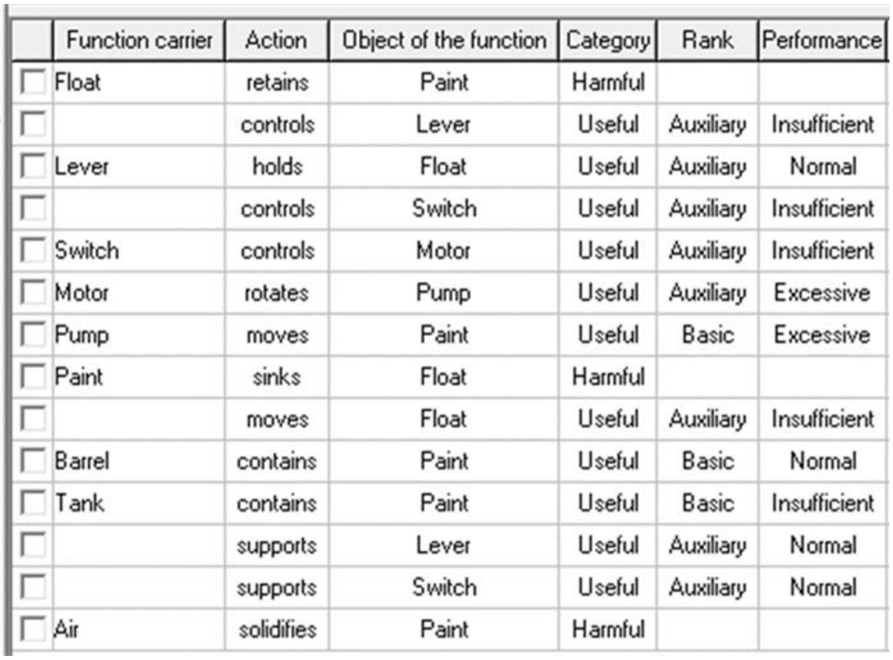
Creating a Function Model

A Function Model captures and organizes all the details of Function Modeling in a tabular form. The algorithm for creating a Function Model is as follows:

1. Formulate the main function of the analyzed Engineering System (Including the Target).

2. Indicate a component (if necessary).
3. Indicate the absolute cost of the component (if necessary).
4. Calculate and indicate the relative cost of the component.
5. Identify and indicate all functions of the indicated component, using the Interaction Matrix.
6. Determine and indicate the category of the Function.
7. Determine and indicate the rank of the function.
8. Determine and indicate the performance level of the function.
9. Repeat steps 1 through 8 for each of the components in the Interaction Matrix (see the *Interaction Analysis* section).

Here is the Function Model of the Paint Filling System in the tabular form (Figure 14):



	Function carrier	Action	Object of the function	Category	Rank	Performance
☐	Float	retains	Paint	Harmful		
☐		controls	Lever	Useful	Auxiliary	Insufficient
☐	Lever	holds	Float	Useful	Auxiliary	Normal
☐		controls	Switch	Useful	Auxiliary	Insufficient
☐	Switch	controls	Motor	Useful	Auxiliary	Insufficient
☐	Motor	rotates	Pump	Useful	Auxiliary	Excessive
☐	Pump	moves	Paint	Useful	Basic	Excessive
☐	Paint	sinks	Float	Harmful		
☐		moves	Float	Useful	Auxiliary	Insufficient
☐	Barrel	contains	Paint	Useful	Basic	Normal
☐	Tank	contains	Paint	Useful	Basic	Insufficient
☐		supports	Lever	Useful	Auxiliary	Normal
☐		supports	Switch	Useful	Auxiliary	Normal
☐	Air	solidifies	Paint	Harmful		

Figure 14. **Function Model of the Paint Filling System in tabular form**

Legend:

B - Basic function

An - Auxiliary function of "n" rank

Ad - Additional function

U - Useful function

H - Harmful function

I - Insufficient level

E - Excessive level

N - Normal level

Here is the Function Model of the Paint Filling System in the graphical form (Figure 15):

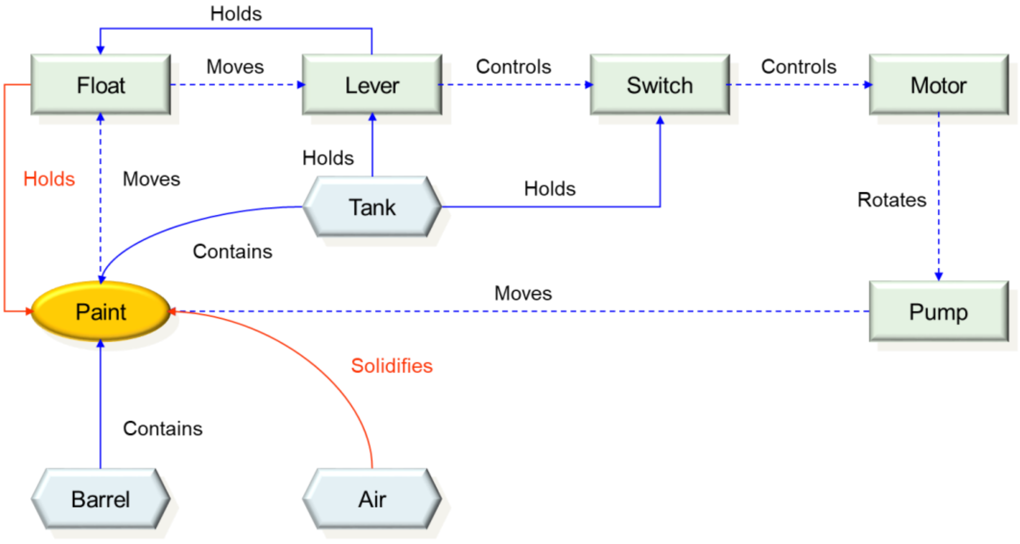


Figure 15. **Function Model of the Paint Filling System in graphical form**

Identifying Functions

To identify the Functions:

1. Write down the components of the Engineering System as well as those of the Super-system as shown in the previous table. Refer to the Interaction Matrix of the Paint Filling System (see the *Interaction Analysis* section) for the list of components.
2. In the first column, write the functions performed by the components as shown in the previous table. Refer to the Interaction Matrix of the Paint Filling System (see the *Interaction Analysis* section) to identify the components with which a component interacts. For example, the first component, Float, performs two functions: `Moves Lever' and `Holds Paint'.

Ranking the Functions

In the second column, enter the function rank for all the functions. For example:

- For the component Pump, the function `Moves Paint' is a basic function because Paint is the Target.
- For the component Tank, the function `Contains Paint' is a basic function `B' because the Paint is the Target.

- For the component Air, the function `Solidifies Paint' is a harmful function `H' because it makes the float heavy and, therefore, leads to malfunction of the Engineering System.
- For the component Float, the function `Moves Lever' is an auxiliary function because its Object of the Function is a component of the analyzed Engineering System.

Note: Only rank the functions performed by components of the Engineering System. Do not rank the functions performed by the components of the Super-system.

Determining the Performance Level of Functions

In the fourth column, enter the performance level for each function. For example:

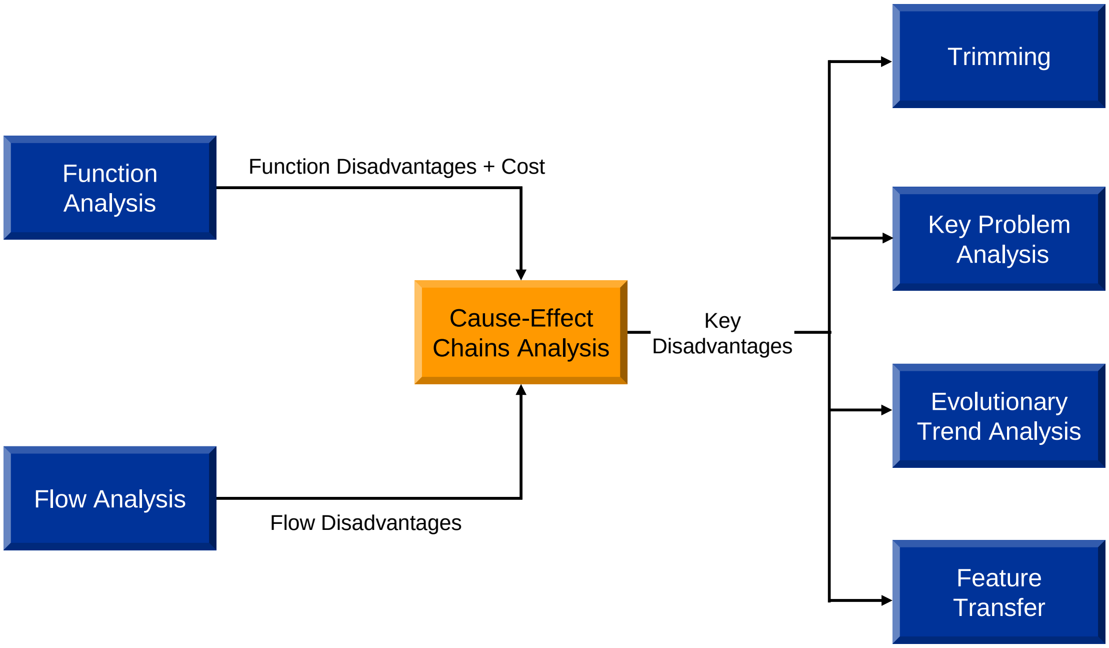
- For the component Float, the performance level of the function `Moves Lever' is insufficient because Float cannot move the lever normally as it gains weight.
- For the component Pump, the performance level of the function `Moves Paint' is excessive because the pump continues to move paint into the tank even when the paint level is sufficient.

Summary

This chapter described one of the most important and powerful tools in the GEN TRIZ methodology: Function Analysis. Here we illustrated how to perform Function Analysis of products; however, Function Analysis can also be performed on technological processes. This will be the topic of the Advanced Course.

The output of Function Analysis - a list of Components and their Cost, Function Rank, and their disadvantages - is used in the following GEN TRIZ tools for Problem Identification: Trimming, Flow Analysis, and Cause-Effect Chains Analysis. Some of these tools will be described in the subsequent chapters of this manual.

Cause-Effect Chains Analysis



Key Terms

Target Disadvantage

Key Disadvantage

Cause-Effect Chains

Intermediate Disadvantage

Cause Disadvantage

Effect Disadvantage

Introduction

Fundamentally, the improvement of any Engineering System is achieved through the elimination of the Key Disadvantages of its Components. However, known or obvious disadvantages that come directly from the project's goals (called Target Disadvantages) or from GEN TRIZ Problem Identification tools such as Function Analysis, Cost Analysis, and Flow Analysis are often not the root of the problem.

Cause-Effect Chains Analysis (CECA) is an analytical tool that identifies Key Disadvantages of the analyzed Engineering System. In particular, the Key Disadvantages are identified by looking for the underlying causes of the Target Disadvantages. For every Target Disadvantage, a Cause-Effect Chain is created by asking, "Why does this disadvantage exist?" As you probe deeper, you may find that the identified causes are disadvantages having other underlying causes. The end of the Cause-Effect Chain is usually determined by physical, chemical, biological, or geometrical limits. Such disadvantages cannot be further broken down into underlying causes. We should select Key Disadvantages, which have to be eliminated to achieve the project goal, somewhere near them. Importantly, CECA encompasses all disadvantages of the analyzed Engineering System as it receives inputs from all GEN TRIZ Problem Identification tools that are aimed at revealing disadvantages of the System: Function Analysis, Cost Analysis, and Flow Analysis.

Why identify Key Disadvantages rather than try to resolve Target Disadvantages that lie on the surface? For one, Function Analysis, Cost Analysis, and Flow Analysis typically reveal a rather large number of disadvantages. However, many of these disadvantages are caused by only a few underlying Key Disadvantages. Identifying and solving problems at the level of Key Disadvantages automatically eliminates all other disadvantages in the Cause-Effect Chain (including Target Disadvantages). Additionally, the Key Disadvantages are typically formulated at the level of basic sciences and, therefore, are more easily resolved compared to, say, Target Disadvantages. Finally, in the typical innovation initiative situation, Key Disadvantages have never been addressed prior to the application of the GEN TRIZ methodology while Target Disadvantages have been worked on extensively with unsatisfactory results.

This picture illustrates different types of disadvantages (Figure 16):

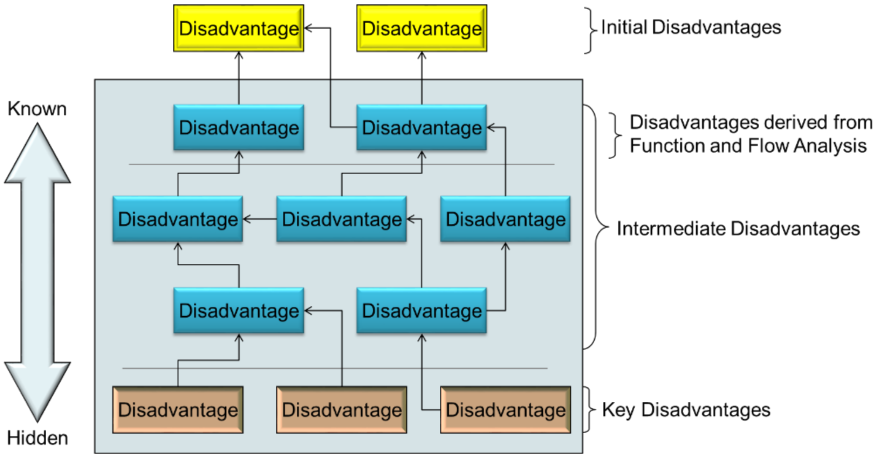


Figure 16. **Types of Disadvantages**

Note: Target Disadvantages are inverted project goals.

It is always best to eliminate Key Disadvantages. Usually, they are far away from the Target Disadvantages and should reveal problems that have not been addressed so far. Also, the Key Disadvantages are typically at a level of basic sciences and are more easily resolved.

Note: Regardless of which problem you decide to solve, every attempt should be made to identify the Key Disadvantages. Reaching the level of Key Disadvantages ensures that you have covered the whole landscape of possible disadvantages.

Defining Cause-Effect Chains

A Cause-Effect Chain is a chain of disadvantages such that a disadvantage is the cause of the disadvantage ahead of it and simultaneously the effect of the previous disadvantage. Cause-Effect Chains start from the Target Disadvantages and end when the Key Disadvantages are found.

For example, as shown in the following figure (Figure 17), the Target Disadvantage is a headache. A headache is caused by high blood pressure. High blood pressure is caused by excess salts in the blood. Excessive concentration of salt relates to the wrong diet. We can continue analysis or stop her and select this fact as the Key Disadvantage.

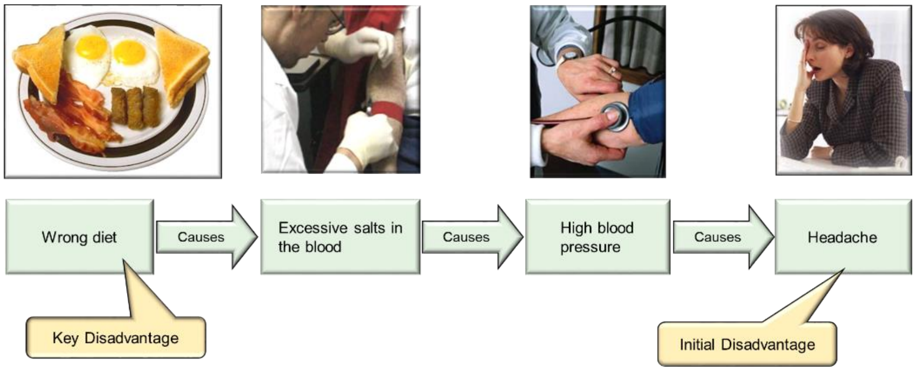


Figure 17. **Headache example**

Selection of Key Disadvantages

To select Key Disadvantages, it is necessary to use two criteria. Key Disadvantages should be:

- Non-trivial (hidden, unknown)
- Relatively easy to address (if possible)

Note: There may be more than one Key Disadvantage for a Target Disadvantage.

Key Disadvantages in an Engineering System exist because of some physical, biological, chemical, or geometrical features of the components. To remove the Key Disadvantages, these features or their parameter values usually need to be changed.

Removal of Key Disadvantages has a cascading effect in the Cause-Effect Chains: that is, removing a Key Disadvantage removes a large number of disadvantages that are connected to the Key Disadvantage in the Cause-Effect Chain.

Algorithm for Cause-Effect Chains Analysis

Cause-Effect Chains are built graphically as shown in the following figure (Figure 18). The rectangles in the figure contain the disadvantages, and the arrows connect them in Cause-Effect Chains. Arrows originate from the cause and point towards the effect.

To create a Cause-Effect Chains Analysis model:

1. Write the first Target Disadvantage in a rectangle and label it 1 as shown in the following figure.
2. Find the cause of Disadvantage 1. Write the cause in another rectangle and label this disadvantage as 2. Now draw an arrow from the cause to the disadvantage.
3. Repeat step 2 until you reach a cause that does not have an underlying disadvantage.

To find these causes:

- Check the list of disadvantages from Function Analysis, Cost Analysis, and Flow Analysis.
- Use a scientific formula. For example, if the Key Disadvantage is distance, D=SxT. The causes could be found in speed and time.
- Ask experts.

You may sometimes find more than one underlying causes for a disadvantage. If the underlying causes are independent of each other, write `OR' near the arrows joining the causes and the disadvantage. However, if the causes are related to each other in such a way that removal of one automatically removes the other, write `AND' near the arrows as shown in the following figure. For example, fire is caused by fuel and oxygen. If either fuel or oxygen is removed, the fire stops. Therefore, in this situation `AND' is written near the arrows.

4. Repeat step 1 through 3 for all the Target Disadvantages.

As shown in the following figure (Figure 18), you can have interconnected chains, where a disadvantage from one of the chains is the cause of disadvantages in other chains.

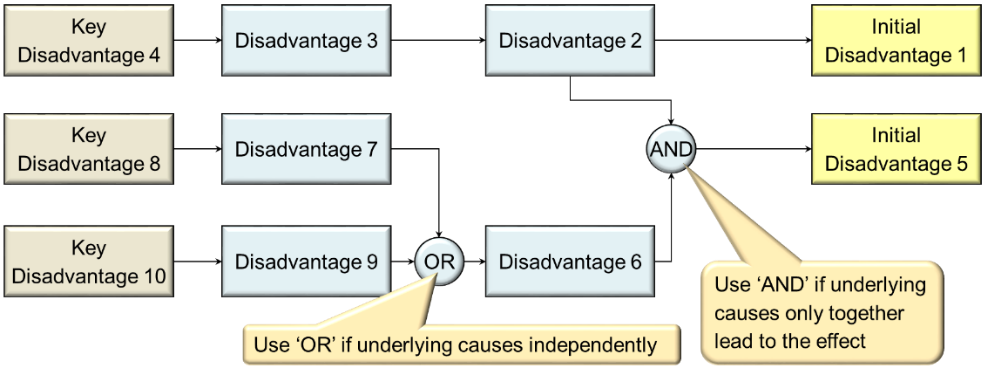


Figure 18. Model of Cause-Effect Chain Analysis

Example: Coffee Bag

To enable instant coffee brewing, coffee is filled in coffee bags that are made of paper, as shown in the following figure (Figure 19):

Figure 19**. Example: Coffee Bag**

The disadvantage of these coffee bags is their high cost, and the project goal is to reduce the cost of the coffee bags. To find a solution to the problem, first the Key Disadvantages must be identified. By constructing a Cause-Effect Chains Analysis model, you can identify the Key Disadvantages of the coffee bag.

To construct the coffee bag Cause-Effect Chains Analysis model:

1. Write the Target Disadvantage `High cost of coffee brewing bag' in a rectangle as shown in the following figure.
2. Since the cause of the Target Disadvantage is `Excessive amount of coffee' used in the coffee bags, write this cause in another box and connect it to the Target Disadvantage with an arrow.

3. Keep repeating this procedure of identifying the underlying causes of the disadvantages until you come to a stage when you cannot find any underlying causes. In the case of `Coffee Bag' these underlying causes are:
   A. The presence of Ca and Mg ions in water.
   B. Pores of the coffee bag are too small.

The disadvantage `Ca and Mg ions in water' is a chemical fact, and the disadvantage `Pores too small' is a geometric fact. These disadvantages cannot be analyzed further for underlying causes and are, therefore, Key Disadvantages. Use a different color for the boxes with Key Disadvantages.

Since these two causes are independent of each other, write `OR' nears the arrows coming towards the disadvantage `Low rate of coffee extraction'.

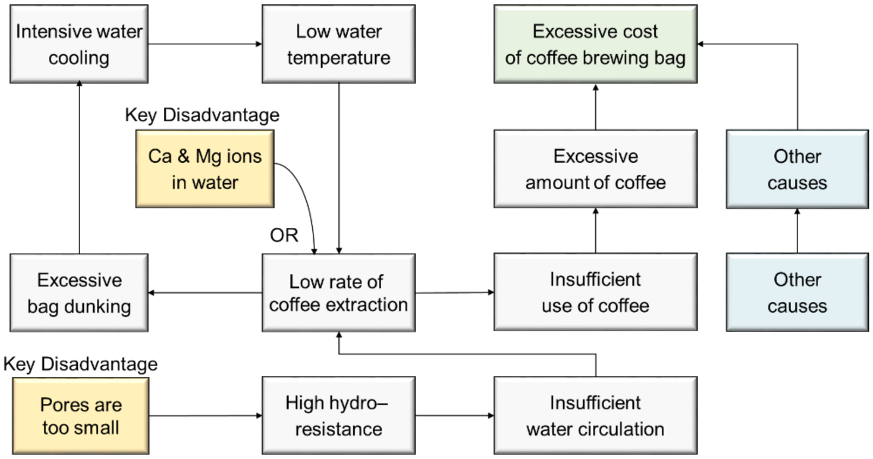
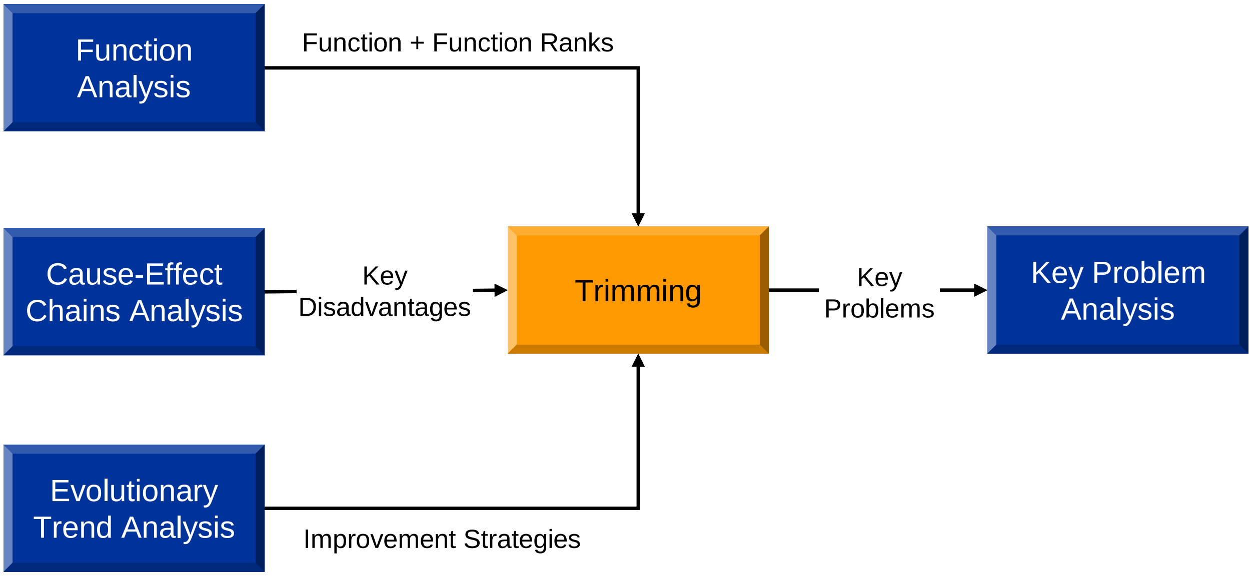


Figure 20. Cause-Effect Chains Analysis Model of Coffee Bag

Summary

In this chapter, we illustrated how Cause-Effect Chains Analysis is used to identify the Key Disadvantages of the analyzed Engineering System. After the Key Disadvantages are identified, they are used as input to the subsequent stages of the GEN TRIZ Problem Identification phase. Often, identified Key Disadvantages are outside of the expertise of professionals working on the System. If this is the case, GEN TRIZ Problem Solving tools, such as Function Oriented Search (FOS) and the Global Knowledge Network (GKN), are used to find the solution in a different area or discipline. These tools will be described in subsequent chapters of this manual.

Trimming



Key Terms

Trimming Model

Trimming Problem

Trimming Rule

Introduction

An elegant and powerful way to improve an Engineering System is to eliminate one or several of its components while retaining (or even improving) the System's functionality. The resulting System will be of higher value compared to the original System because it will have lower cost and will be simpler. While clearly desirable, is it a feasible proposition? Trimming is an analytical tool in the GEN TRIZ methodology that formulates problems of an Engineering System improvement, relating to removing (trimming) certain Components and redistributing their Useful Functions among the remaining Components of the Engineering System or its Super-system. In other words, Trimming ensures that the functionality of the System is preserved by "teaching" other components of the System or its Super-system to perform the Useful Functions of the trimmed components.

An important part of the Trimming process is deciding which Components of the analyzed Engineering System should be trimmed and how. The decisions about it are made based on the output of other GEN TRIZ Problem Identification tools, which provide information about Functions and Cost (Function Analysis), Key Disadvantages (CECA), and Improvement

Strategies (Evolutionary Trend Analysis). Typically, the algorithm, driven by a set of hierarchical rules, recommends elimination of the components that have high cost and/or low functionality. The Components with a number of Key Disadvantages is also a right candidate for Trimming.

Once a Component is selected for elimination, Trimming offers multiple options with regard as to how it can be implemented. These options allow for effective problem statements as well as point towards a spectrum of possible solutions, from incremental to radical. The level of trimming then is what really determines the level of innovation: light trimming usually results in incremental improvements, while radical trimming leads to fundamentally new products.

Selecting the Components for Trimming

Use the following guidelines for selecting the components for trimming.

Guidelines for Selecting the Components for Trimming

- To maximize the improvement to the Engineering System, start Trimming the Components that have the most significant or Key Disadvantages (cost could be one of the disadvantages).
- To reduce the cost and effort of modifying the remaining Components, trim the Components having least functional significance. The reason for doing this is that a small number of insignificant functions usually can be easily redistributed among the remaining Components without major modifications in these Components.
- If acceptable alternatives are not available for redistribution of the Functions of a Component, avoid Trimming that Component.
- The level of Trimming performed could be radical (where major Components of the Engineering System are trimmed) or incremental (where Trimming is limited to minor modifications to the Engineering System). In fact, there may be range of Trimming options from radical to incremental.

Note: The level of Trimming option chosen depends on the business and technical constraints of the project. These constraints dictate the Components that are allowed to be trimmed.

If allowed, start by choosing the most radical Trimming option as this is likely to result in the most dramatic improvement. If this is not permitted or feasible, move to a less radical solution and so on.

Rules for Trimming

A Function Carrier can be considered for Trimming if it satisfies one of the following three rules for Trimming.

Rule A (Figure 21): Object of the Function does not exist (the most radical Trimming)

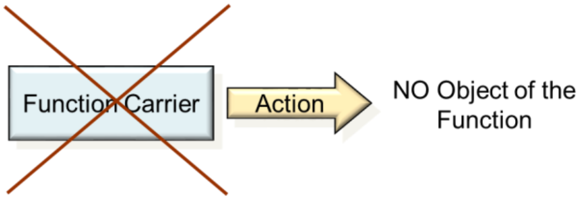


Figure 21. **Rule A of Trimming**

If the Object of a Function does not exist, you do not need the Function Carrier. This situation arises if the Object of the Function has been trimmed in a previous step of trimming. For example, in the Paint Filling System example, the function of the switch is to turn on the motor. If the motor is trimmed, there is no need for the switch and, hence, it can be trimmed.

Rule B: Object of the Function performs the function itself (Figure 22):

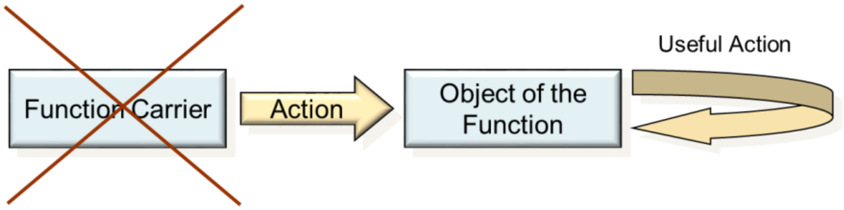


Figure 22. **Rule B of Trimming**

If the Object of the Function can perform the useful function of the Function Carrier, then the Function Carrier can be considered for trimming. For example, in the Paint Filling System example, the Function of the pump is to move paint. If paint would move itself, the pump can be trimmed.

Rule C: Another Component of the Engineering System or Super-system performs the useful function of the Function Carrier (Figure 23):

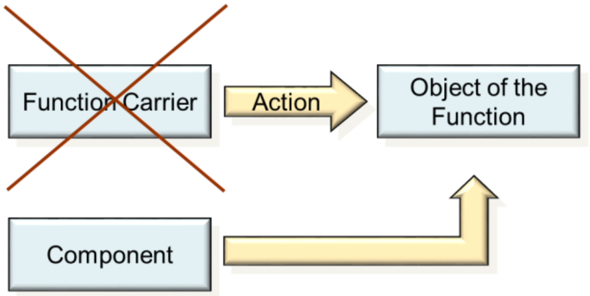


Figure 23. **Rule C of Trimming**

If another Component of the Engineering System or the Super-system can perform the Useful Function of the Function Carrier, then the Function Carrier can be considered for trimming. For example, in the Paint Filling System, if air moves the lever, the float can be trimmed.

Selecting Components for Function Redistribution

The Useful Functions of the trimmed Components can be redistributed to the remaining Components of the Engineering System or the Super-system. You can select a Component as a Function Carrier if it satisfies at least one of the following four conditions:

Condition 1

A Component already performs a similar Function on the Object of the Function.

Note: Similar Function means an action that produces a similar change in the parameter of the Object of the Function.

Condition 2

A Component already performs a similar Function on another object.

Condition 3

A Component performs any other Function on the Object of the Function.

Condition 4

A Component has a set of resources necessary to perform the analyzed Function.

Trimming Models

A Trimming Model is an enhanced Function Model of an Engineering System, as it would exist in the future after Trimming has been performed. A Trimming Model also contains the set of problems that would need to be solved to implement the Trimming Model.

An Engineering System can be trimmed in many different ways. For each of these Trimming alternatives, a different Trimming Model is constructed.

Identifying the Trimming Problems

Trimming a Component should remove the disadvantages associated with that Component. For example, removal of a high-cost Component will reduce the total cost of the Engineering System.

However, removal of Components usually leads to a new set of problems related to making other Components perform the Useful Functions of the trimmed Component. These problems are called Trimming Problems.

Trimming Problems are formulated at each step of Trimming. These are later grouped together and re-worded to eliminate repetition. For each Trimming Model, a separate set of Trimming Problems is formulated. To improve the Engineering System, the Trimming Model is implemented by solving its Trimming Problems.

Creating the Trimming Model

To create a Trimming Model:

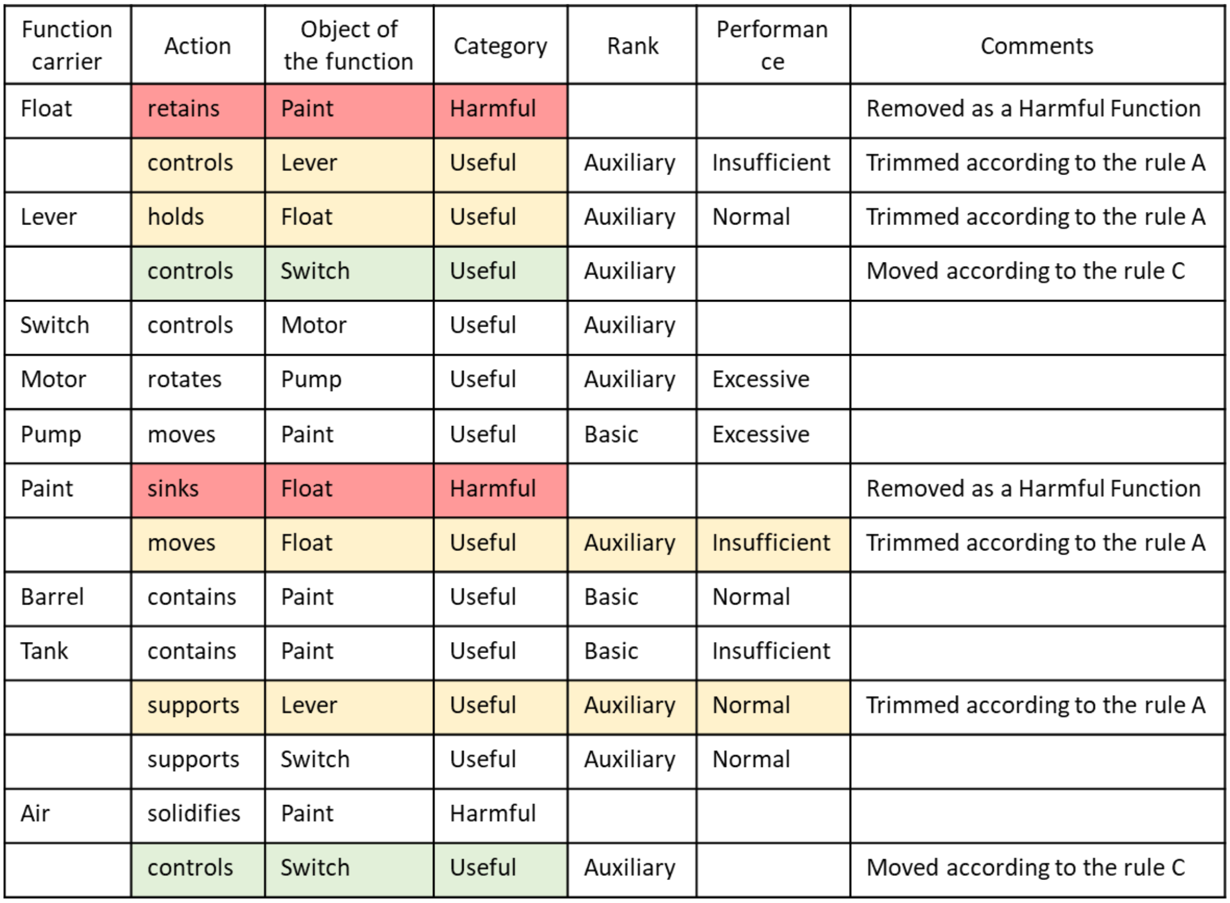
1. Select a component of the Engineering System using the selection guidelines.
2. Identify the first useful function and its rank from the Function Model.
3. Identify the trimming rule for the function.
4. Select the new carrier component for the function.
5. Write the Trimming Problem for the function redistribution.
6. Repeat steps 1 through 5 for all functions of the selected component.
7. Repeat steps 1 through 6 for all components to be trimmed.

Example: Paint Filling System

To create a Trimming Model for the Paint Filling System:

1. Identify the components that can be trimmed from the Function Model of the Paint Filling System (refer to the *Function Modeling* section of the chapter *Function Analysis*). Write the component name in the Components column. For example, Float has a high disadvantage associated with it and, hence, it is a candidate for trimming.
2. For each identified component, enter all the useful functions in the Functions column, and enter all the function ranks in the Rank column.
3. Write the trimming rule for each function. For example, Trimming Rule A can be applied to the function `Moves lever' of the Float because the Object of the Function "Lever" will cease to exist due to trimming.
4. For each function of the trimmed component, select the new carrier using the selection guidelines mentioned in the *Selecting Components for Function Redistribution* section. For example, for the function `Controls switch' of the component `Lever', we may identify another component 'Air' to control the switch.
5. Lastly, write the Trimming Problems for each function of each component. For example, the Trimming Problem for the component `Lever' for the function `Controls switch' is `How to make air control the switch'.

Here is the Trimming Model in tabular form (Figure 24):



Function carrier	Action	Object of the function	Category	Rank	Performance	Comments
Float	retains	Paint	Harmful			Removed as a Harmful Function
	controls	Lever	Useful	Auxiliary	Insufficient	Trimmed according to the rule A
Lever	holds	Float	Useful	Auxiliary	Normal	Trimmed according to the rule A
	controls	Switch	Useful	Auxiliary		Moved according to the rule C
Switch	controls	Motor	Useful	Auxiliary		
Motor	rotates	Pump	Useful	Auxiliary	Excessive	
Pump	moves	Paint	Useful	Basic	Excessive	
Paint	sinks	Float	Harmful			Removed as a Harmful Function
	moves	Float	Useful	Auxiliary	Insufficient	Trimmed according to the rule A
Barrel	contains	Paint	Useful	Basic	Normal	
Tank	contains	Paint	Useful	Basic	Insufficient	
	supports	Lever	Useful	Auxiliary	Normal	Trimmed according to the rule A
	supports	Switch	Useful	Auxiliary	Normal	
Air	solidifies	Paint	Harmful			
	controls	Switch	Useful	Auxiliary		Moved according to the rule C

Figure 24. **Trimming Model for Paint Filling System**

Trimming Problem: How to make Air control Switch?

Summary

In this chapter, we illustrated how to improve an Engineering System using the Trimming tool. The output of the Trimming procedure is one or more Trimming Models that include a set of Trimming Problems for each Component. These Trimming Problems will be solved using GEN TRIZ Problem Solving Tools.

It is worth noting that Trimming has other interesting and important applications beyond initiatives focused on cost reduction or functionality improvement. For example, Trimming is used extensively in the GEN TRIZ Patent Strategies, and, in particular, in Competitive Patent Circumvention.

Inventive Principles Application: Engineering Contradictions and Altshuller’s Matrix

Key Terms

Altshuller’s Matrix

Inventive Principle

Engineering Contradiction

Typical Parameters

Typical Contradiction

Introduction

Inventive Principles were defined by a Russian engineer and inventor Genrich Altshuller who, together with his disciples, analyzed tens of thousands of patents to discover that (1) all engineering problems can be formulated using a limited set of generalized parameters, and (2) all engineering problems can be resolved using a limited set of generalized solutions. Later, this discovery was further supported and strengthened by the analysis of millions of patents. This chapter describes this one of the major achievements of TRIZ: Inventive Principles, Engineering Contradictions, and Altshuller's Matrix.

A non-inventive approach to solving an engineering problem is a compromise. Let us consider, for example, that we have to make an airplane wing larger. If we add more metal, the wing will become larger, but it will also become heavier. This is called an Engineering Contradiction: a situation in which an attempt to improve one parameter leads to the worsening of another parameter. A compromising solution - adding some metal to make a wing somewhat larger but not too much so as not to make it too heavy - does not resolve the Engineering Contradiction, and, thus, fundamentally, is sub-optimal. In contrast, an inventive approach to solving engineering problems would be to resolve this contradiction without compromise: make a wing larger without making it heavier.

Altshuller's Matrix is a problem-solving tool that recommends Inventive Principles for resolving Engineering Contradictions. Inventive Principles are a set of 40 generalized recommendations for modifying a System to resolve an Engineering Contradiction formulated using a set of 39 generalized parameters. Statistical analysis of the correlation between typical Contradictions and Inventive Principles that resolve them yields Altshuller's Matrix. In particular, Altshuller's Matrix recommends 3-4 statistically common Inventive Principles (i.e., statistically proven ways to resolve an Engineering Contradiction) for almost every combination of parameters in the Matrix. Input to Altshuller's matrix comes from Key Problems that are identified during the Problem Identification stage of the GEN TRIZ methodology. These Key Problems have to be reformulated as Engineering Contradictions in order to make use of Altshuller's Matrix. Importantly, the output of Altshuller's Matrix is a recommendation (i.e., an abstract model of the solution) not a specific idea. The art of using the Inventive Principles lies in interpreting the recommendations.

Inventive Principles enable breakthrough solutions that achieve the desired level of performance for all parameters without compromise. The beauty of Inventive Principles lies in following two simple facts:

- There are only 39 generalized parameters that can be used to formulate any Engineering Contradiction
- There are only 40 typical ways, called Inventive Principles, which can be used to resolve all Engineering Contradictions.

At its core, then, Inventive Principles help to reduce the number of potential ideas to be considered while increasing their quality at the same time.

Resolving Engineering Contradictions

The process of identifying Inventive Principles to resolve Engineering Contradictions is shown in the following figure.

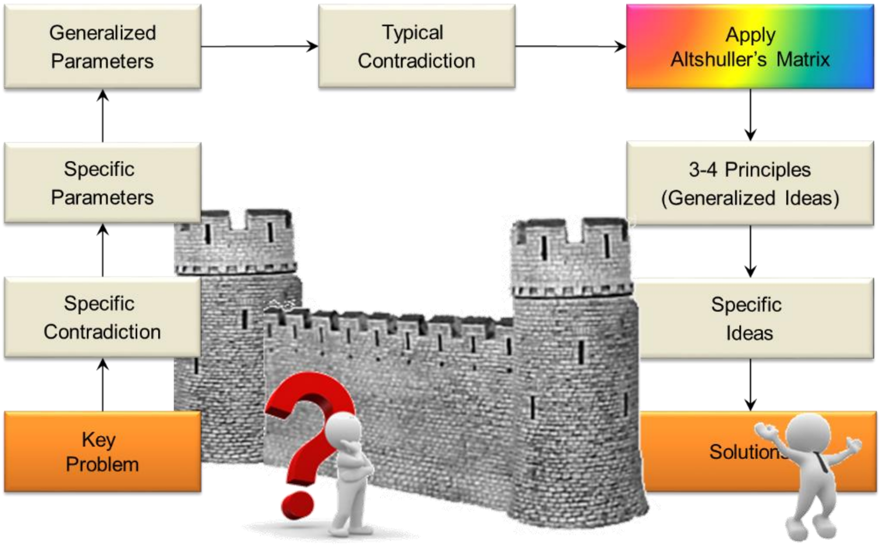


Figure 25. Applying Altshuller's Matrix to Resolve an Engineering Contradiction

Formulating the Engineering Contradiction

Inventive Principles can be applied only if you can formulate the engineering problems in terms of Engineering Contradictions. Engineering Contradictions are written in the form of “IF - THEN – BUT”.

For example, the engineering problem of increasing the strength of a table can be formulated as shown in the following table (Table 1):

Table 1. **Formulating the Engineering Contradiction for a Table example**

	Engineering Contradiction for the table	Alternate Engineering Contradiction for the table
IF	one increases thickness of the table	one reduces thickness of the table
THEN	the table becomes stronger	the table becomes lighter
BUT	the weight of the table increases	but its strength decreases

Identifying the Improving and Worsening Parameters of the Engineering System

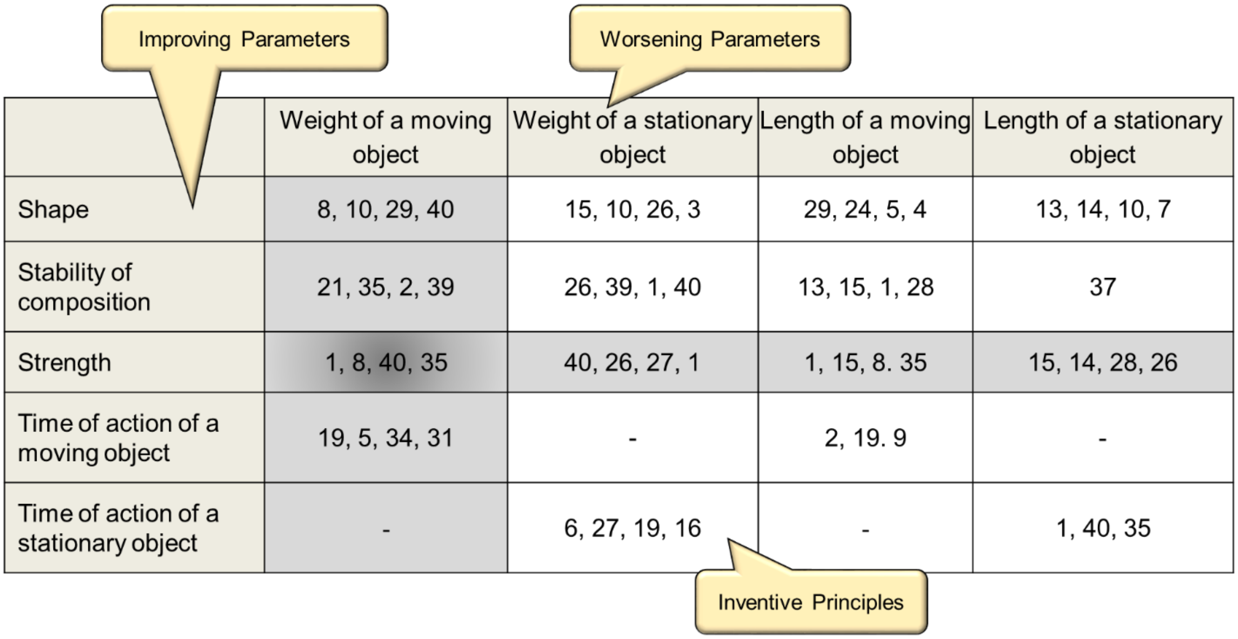
In any Engineering Contradiction, attempt to improve one parameter has a side effect of worsening another parameter. Identify the improving and worsening parameters. For example, in the table problem, the improving parameter is strength of the table and the worsening parameter is weight of the table.

Identifying Typical Parameters

Altshuller identified 39 typical engineering parameters that can represent all Engineering Contradictions. Hence, the improving and worsening parameters you identified in the Engineering Contradiction could be among Altshuller's 39 Typical Parameters. Altshuller's Typical Parameters, however, are generic, whereas the parameters you used may be industry specific. Therefore, you must identify from Altshuller's list those Typical Parameters that are similar in meaning to the specific parameters that you identified.

Altshuller's Matrix

Altshuller created a Contradiction Matrix that has 39 rows and 39 columns. Each row and column head contains one of the 39 Typical Parameters. The parameters in the rows are considered improving parameters, while those in the columns are considered worsening parameters. The Engineering Contradiction is represented by the cell at the intersection of the row containing the improving parameter and the column containing the worsening parameter (Figure 26):



	Weight of a moving object	Weight of a stationary object	Length of a moving object	Length of a stationary object
Shape	8, 10, 29, 40	15, 10, 26, 3	29, 24, 5, 4	13, 14, 10, 7
Stability of composition	21, 35, 2, 39	26, 39, 1, 40	13, 15, 1, 28	37
Strength	1, 8, 40, 35	40, 26, 27, 1	1, 15, 8. 35	15, 14, 28, 26
Time of action of a moving object	19, 5, 34, 31	-	2, 19. 9	-
Time of action of a stationary object	-	6, 27, 19, 16	-	1, 40, 35

Figure 26. **Altshuller's Matrix (partial view)**

To identify the improving Typical Parameter, search the rows of Altshuller's Matrix; to identify the worsening Typical Parameter, search the columns of Altshuller's Matrix.

Identifying the Inventive Principles

When you have identified the improving Typical Parameter and the worsening Typical Parameter, you must identify the cell at the intersection of these two Parameters. The cell may contain some numbers. These numbers, ranging from 1 to 40, refer to the 40 Inventive Principles. The Principles identified in each cell can be used as guidelines for resolving the Engineering Contradiction. Locate the Inventive Principles with the help of the numbers in the cell.

Each Inventive Principle provides a Generalized Inventive Solution (idea) by recommending how to change the Engineering System.

Identifying Specific Solutions

Using these identified Inventive Principles as guidelines, try to identify specific solutions most suitable for solving your engineering problem. Inventive Principles simply provide the general direction; therefore, use your judgment and experience to identify the specific solutions.

Algorithm for Inventive Principles Application

To apply Inventive Principles:

1. Describe the engineering problem to be solved.

2. Formulate the Engineering Contradictions in the form of `If - then - but'.
3. If there is more than one worsening parameter per improving parameter, formulate multiple Engineering Contradictions for each pair of improving and worsening parameters.
4. Identify the improving and worsening parameters in the Engineering Contradictions.
5. Using Altshuller's Matrix, identify the improving and worsening Typical Parameters in the Engineering Contradictions.
6. Identify the Inventive Principles from the cell at the intersection of the improving and worsening Typical Parameters in the Contradiction Matrix.
7. Apply the Inventive Principles to identify the specific solutions most suGEN TRIZble for resolving the Engineering Contradiction.

Example: Turning Machine

The following figure () shows an unmanned turning machine serviced with robots. The turning process creates shavings of scrap material that can jam the cutter and damage a work part, thereby deteriorating system stability. The problem: it is necessary to remove the shavings of scrap material that otherwise can jam the cutter and damage a work part, significantly reducing the process stability.

Because this machine is located in an unmanned factory, one of the solutions identified was to use a special robot equipped with visual sensors and image recognition that could remove the scrap material as it forms. This solution was unacceptable because such a robot is extremely complex and expensive. A simpler solution needed to be found.

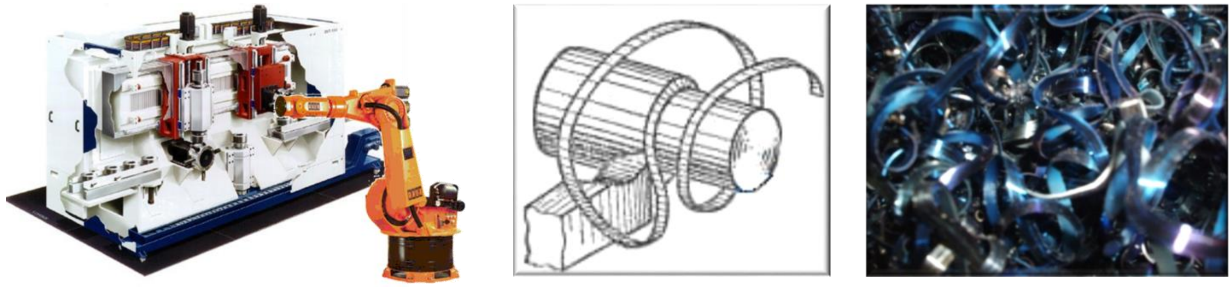


Figure 27**. Example: Turning Machine**

1. Describe the problem

The problem to solve is:

How to increase the process stability by constantly removing a facing from the turning machine without complex and expensive special robot application.

2. Formulate the Engineering Contradiction

Formulate the problem in form of Engineering Contradiction (Figure 28):

	Engineering Contradiction
IF	We use special robot for image recognition
THEN	the shaving would be removed and the process would be stable
BUT	the applied equipment would be extremely complex (and expensive)

Figure 28. **Engineering Contradiction of Turning Machine**

3. Identify the improving and worsening parameters

Since the main goal of the project is to make the process stable, the process stability is the improving parameter. In addition, the complexity of the auxiliary robot is worsened and, hence, it is the worsening parameter (Figure 29):

	Parameters in the Contradiction
Improving Parameter	Process stability
Worsening Parameter	Robot complexity

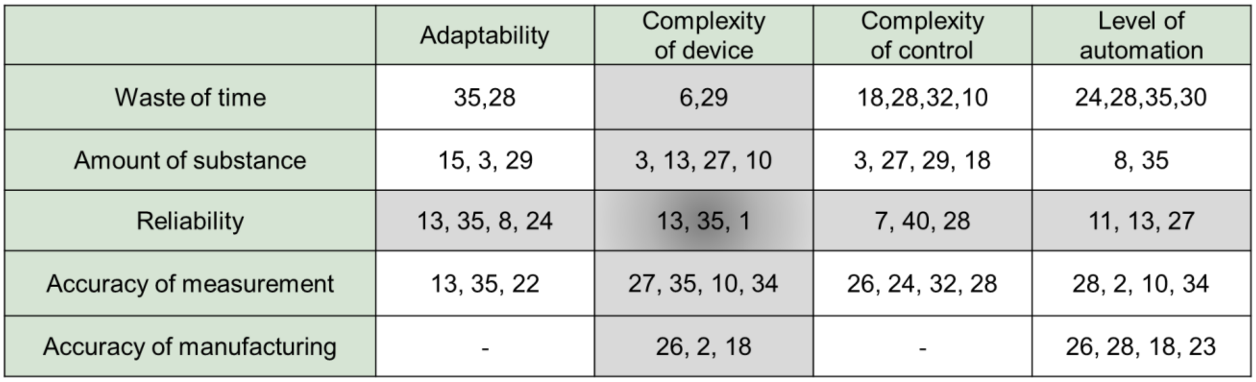
Figure 29. **Improving and Worsening Parameters of Turning Machine**

4. Identify the Typical Parameters (Figure 30):

	Specific Parameter	Typical Parameter
Improving Parameter	Process stability	Reliability
Worsening Parameter	Robot complexity	Complexity of Device

Figure 30. **Specific and Typical Parameters of Turning Machine**

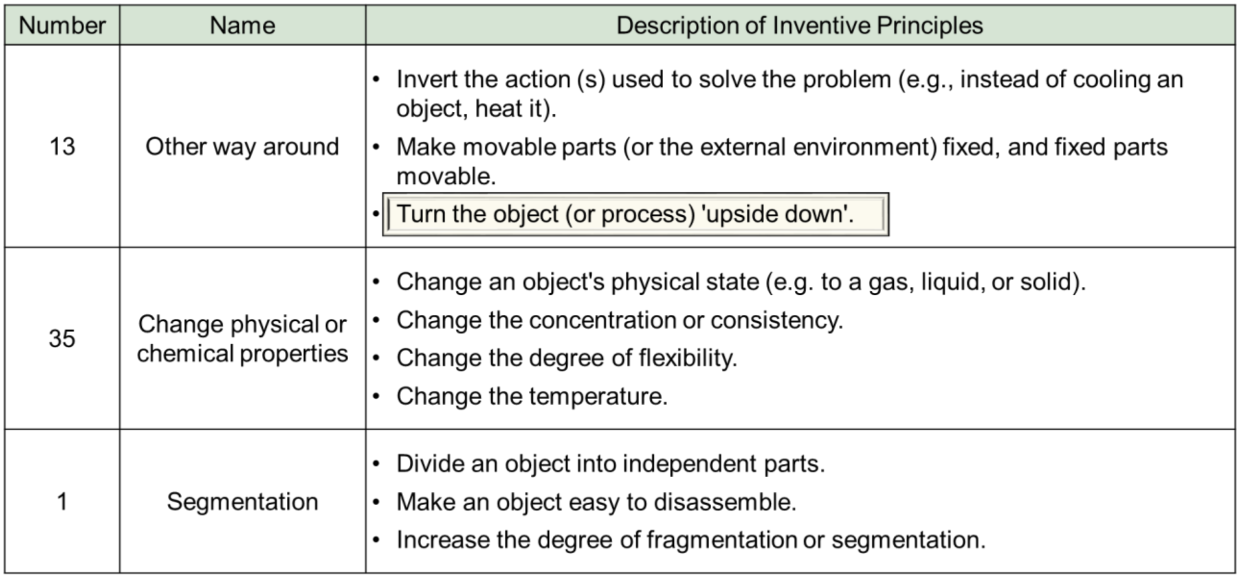
5. Enter these parameters in the respective columns and identify recommended Inventive Principles (Figure 31):



	Adaptability	Complexity of device	Complexity of control	Level of automation
Waste of time	35,28	6,29	18,28,32,10	24,28,35,30
Amount of substance	15, 3, 29	3, 13, 27, 10	3, 27, 29, 18	8, 35
Reliability	13, 35, 8, 24	13, 35, 1	7, 40, 28	11, 13, 27
Accuracy of measurement	13, 35, 22	27, 35, 10, 34	26, 24, 32, 28	28, 2, 10, 34
Accuracy of manufacturing	-	26, 2, 18	-	26, 28, 18, 23

Figure 31. **Inventive Principles for Turning Machine**

6. Read description of the recommended Inventive Principles and select the most suitable ones (Figure 32):



Number	Name	Description of Inventive Principles
13	Other way around	• Invert the action (s) used to solve the problem (e.g., instead of cooling an object, heat it). • Make movable parts (or the external environment) fixed, and fixed parts movable. • Turn the object (or process) 'upside down'.
35	Change physical or chemical properties	• Change an object's physical state (e.g. to a gas, liquid, or solid). • Change the concentration or consistency. • Change the degree of flexibility. • Change the temperature.
1	Segmentation	• Divide an object into independent parts. • Make an object easy to disassemble. • Increase the degree of fragmentation or segmentation.

Figure 32. **Description of recommended Inventive Principles**

7. Develop specific solutions

Apply selected Inventive Principles to resolve the Engineering Contradiction (Figure 33):

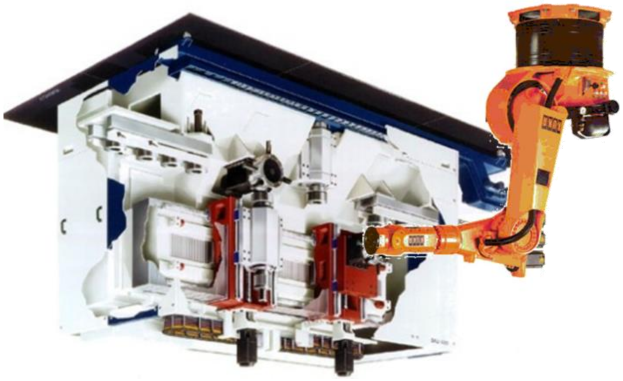


Figure 33. **Solution**

Inventive Principle 13: “Other way around”

Turn the object (or the process) “upside down”

Solution:

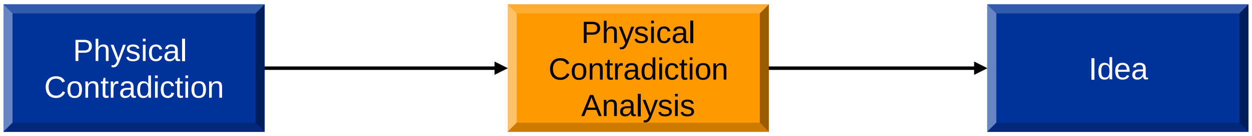
Locate the turning machines and serving robots in an 'upside down' position. By doing so, the shavings will fall down from the machine by themselves without any additional effort. Fully automatic unmanned turning machines and serving robots can work in such position without any problems.

This solution was developed and implemented in Japan.

Summary

In this chapter, we learned application Altshuller's Matrix and Inventive Principles to resolve Engineering Contradictions that lead to true breakthrough solutions.

Resolving Physical Contradictions



Key Terms

Physical Contradiction

Separation in Time

Separation in Space

Separation in Relation

Separation in System Level

Introduction

As described in this manual, an engineering problem can be modeled in several ways. For example, in the previous chapter we learned how a problem could be modeled as an Engineering Contradiction. A Physical Contradiction is another way of modeling a problem.

A Physical Contradiction is a situation in which two justified opposite requirements are placed upon a single parameter of a single object.

For example, to improve the quality of nail penetration, a hammer should be heavy, but to improve the performance and handling of the hammer, the hammer should be light. Therefore, to improve the performance and handling of the hammer, its parameter "weight" has contradictory requirements, i.e., to be light and heavy at the same time. This situation is caused by the conflicting requirements of an Engineering Contradiction.

It is important to understand the difference between a Physical Contradiction and an Engineering Contradiction: the former deals with a single parameter (e.g., weight), whereas the latter always deals with two parameters (e.g., weight and strength). In a sense, Physical Contradictions represent a deeper level of problem formulation, and a deeper level of abstraction, than Engineering Contradictions. Because of that, the innovations with the most impact often come from resolving Physical Contradictions.

If a problem is formulated as a Physical Contradiction, Inventive Principles can be used to solve the problem (though not in the form of Altshuller's Matrix, which requires specification of two parameters). This chapter describes in detail how problems can be modeled as Physical Contradictions and how Inventive Principles can be used to resolve them.

Resolving Physical Contradictions

There are three ways to resolve Physical Contradictions. For each of these ways and their sub-directions, a set of Inventive Principles are recommended. The three ways to resolve Physical Contradictions are as follows:

1. Separating Contradictory Demands

The first way of resolving Physical Contradictions is to separate the contradictory demands. As shown in the following illustration, separation removes the contradiction and enables each demand to be met.

For example, the blade of a knife has to be sharp to cut a bread, yet it has to be smooth for us to be able to hold it. You can separate the blade into two parts, where the cutting part is sharp and the holding part is smooth.

Contradictory demands can be separated using the following directions. These directions are discussed in detail later in this chapter.

A. Separation in Space
B. Separation in Time
C. Separation in Relation (Affiliation)
D. Separation in Direction
E. Separation in System Level (Hierarchy)

A. Separation in Space

Separate the contradictory demands using the Separation in Space method if the two contradictory demands are required at different locations within an Engineering System.

Example: Ship and Cart

To move a newly built ship in shallow seawater, special carts are used (Figure 34):

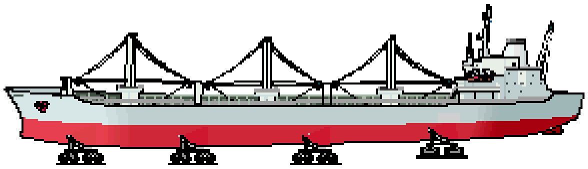


Figure 34**. Example: Ship and Cart**

The water near the shore is very dirty, so dirt gets into the bearings (Figure 35):

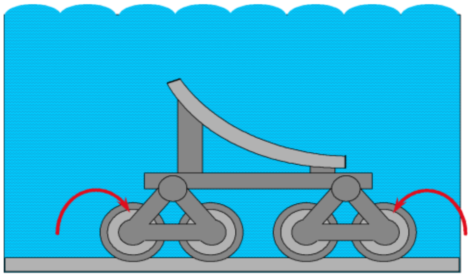


Figure 35**. Cart in Water**

Therefore, after returning to the shore, the carts have to be disassembled and washed, and then assembled again. The wheels are large, there are many carts, so the process is long, complicated and expensive.

- **The Physical Contradiction:**

The cart has to be above the water level to prevent contamination of bearings, BUT

The cart has to be below the water level to in order to move the ship into the water.

- **Inventive Principles for Separation in Space**

It is recommended to use the following Inventive Principles for resolving Physical Contradictions using the Separation in Space method:

- Segmentation
- Separation
- Local quality
- "Nested doll"
- Symmetry change
- Dimensionality change

- **Identifying the Inventive Principle**

After analyzing the different Inventive Principles recommended for resolving Physical Contradictions using the Separation in Space method, the Inventive Principle “Local Quality” is identified as the most appropriate.

- **Inventive Principle “Local Quality”:**

A. Change an object's structure from uniform to non-uniform; change the external environment (or external influence) from uniform to non-uniform

B. *Make each part of an object function in conditions most suitable for its operation*
C. Make each part of an object fulfill a different and useful function

- **Applying the Inventive Principle**

Inventive Principle “Local Quality” recommends to “…make each part of an object function in conditions most suitable for its operation”. The ideal conditions for wheels are when they are are surrounded by air. Therefore, try to provide air around the wheels even when the cart is inside water.

As shown in the following figure, air can be provided around the wheels by putting a container around the wheels and filling it with air (Figure 36):

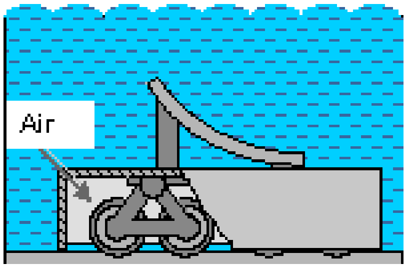


Figure 36. Applying Inventive Principle “Local Quality”

B. **Separation in Time**

Separate the contradictory demands using the Separation in Time method if the contradictory demands are required at different times.

Example: Eye of the Needle

A sewing needle gas a needle eye through which to put the thread (Figure 37):

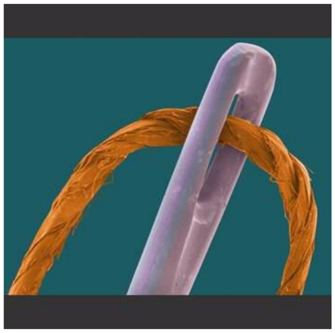


Figure 37**. Example: Eye of the Needle**

- **Physical Contradiction:**

The eye of the needle should be large for directing the thread easily into it, BUT

The hole should be small to avoid damage to the clothes

- **Identifying the Separation Directions**

Separation in Space cannot be applied because the location of the contradictory demands is the same (i.e., the hole of the needle).

Separation in Time can be applied because the demand "the eye of the needle should be large" is required before you start sewing, while the contradictory demand "the eye of the needle should be small" is required when you start sewing. Since the contradictory demands are for different times, this Physical Contradiction can be separated using Separation in Time.

- **Inventive Principles for Separation in Time**

It is recommended to use the following Inventive Principles for resolving Physical Contradictions using the Separation in Time method:

- Dynamization
- Discarding and recovering
- Preliminary action
- Preliminary counteraction
- Prior compensation

- **Identifying the Inventive Principle**

After analyzing the different Inventive Principles recommended for resolving Physical Contradictions using the Separation in Time method, the Inventive Principle "Dynamization" is identified as the most appropriate.

- **Inventive Principle "Dynamization":**

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.*
B. *Divide an object into parts capable of movement relative to each other.*
C. *If an object (or process) is rigid or inflexible, make it movable or adaptive.*

- **Applying the Inventive Principle**

To apply the Inventive Principle `Dynamization', construct a needle by interweaving two thin strands of metal and joining their two ends. This allows the two strands of the needle to move relative to each other and provides flexibility to the needle.

Before directing the thread into the needle hole, just twist and hold one end of the needle and a big hole is formed. Put the thread into the hole and release the hold. The hole disappears and the needle is ready for sewing with no hole. Hence, both the contradictory requirements are met by separating them in time (Figure 38):

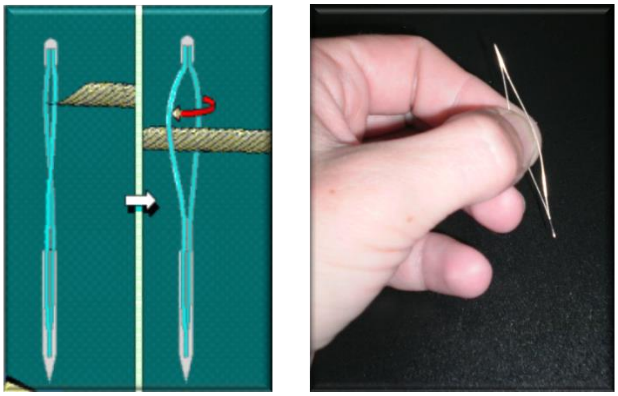


Figure 38**. Eye of the needle (solution)**

C. Separation in Relation

Separate the contradictory demands using the Separation in Relation method if the contradictory demands are required for different systems.

Example: Headlights

- **Physical Contradiction:**

The headlights should be bright to provide a good visibility of road objects for the driver, BUT

The headlights should be dim to avoid blinding of other drivers

- **Identifying the Separation Method**

Separation in Space cannot be applied because both requirements apply to the same area of space**.**

Separation in Time cannot be applied because both requirements apply to the same moment of time.

Separation in Relation can be applied because both requirements apply to different objects (the car driver and opposite drivers).

- **Inventive Principles for Separation in Relation**

It is recommended to use the following Inventive Principles for resolving Physical Contradictions using the Separation in Relation method:

- Composite material
- Porous materials
- Optical properties changes
- Local quality
- Periodic action
- Dimensionality change

- **Identifying the applicable Inventive Principle**

After analyzing the different Inventive Principles recommended for resolving Physical Contradictions using the Separation in Relation method, the Inventive Principle 32: “Optical properties changes” was selected as the most appropriate.

- **Inventive Principle 32: “Optical properties changes”**

D. Change the color of an object or its external environment
E. Change the transparency of an object or its external environment
F. Use well-visible additives

- **Applying the Inventive Principle**

There was suggested to detect live objects (humans or animals) by using infrared (IR) light invisible for drivers (Figure 39):

Figure 39**. Headlights (solution)**

Use an IR illuminator and compatible IR detector or camera configured to detect IR light reflected from objects in front of the car. The IR camera can output a video signal to a display, such as a head-up display, to provide an enhanced view of the approaching environment to the driver.
US Patent 7,217,020 “Headlamp assembly with integrated infrared illuminator” by General Motors Corporation.

D. **Separation in Directions**

Separate the contradictory demands using the Separation in Directions method if the contradictory demands are required for different directions.

Example: A wrench

Requirements that a wrench should rotate a nut clockwise but should not rotate it counterclockwise (or vice versa) contradict to each other.

- **Physical Contradiction:**

The wrench head should be retaining to rotate a nut, BUT

The wrench head should not be retaining to release a nut

- **Identifying the Separation Method**

Separation in Space cannot be applied because the contradictory demands are required for the same place.

Separation in Time can be applied because holding and releasing the nut should take place in different moments => a dynamized wrench (e.g. a channel lock) is applicable, but it is quite complex and expensive.

Separation in Relation cannot be applied because the contradictory demands are required for the same nut and the same wrench.

Separation in Direction can be applied because the wrench should hold the nut in one direction, and it should not hold it in opposite direction

- **Inventive Principles for Separation in Direction**

It is recommended to use the following Inventive Principles for resolving Physical Contradictions using the Separation in Direction method:

- Asymmetry
- Composite Materials
- Parameter Changes
- Curvature
- Another Dimension
- Color Changes

- **Identifying the Inventive Principle**

After analyzing the different Inventive Principles recommended for resolving Physical Contradictions using the Separation in Direction method, the Inventive Principle “Asymmetry” was identified as the most appropriate.

- **Applying the Inventive Principle**

Applying this principle, the asymmetrical wrench was invented: due to special shape of the head, it can rotate a nut in one direction and slide around it in opposite direction (Figure 40):

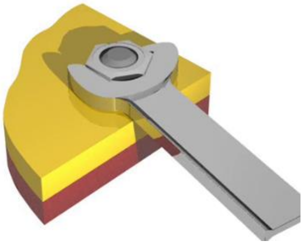


Figure 40**. Asymmetrical Wrench**

E. Separation in System Level

Separate the contradictory demands using the Separation in System Level method if one of the contradictory demands is required at the Subsystem or Super-system level.

Example: Cast Iron Cable

The engineering problem is to produce a cable made of cast iron. The cable must be flexible enough to be folded and stored in a small place.

- **Physical Contradiction:**

The cable should be made of a cast iron to be strong, BUT

The cable should not be made of a cast iron to be flexible

- **Identifying the Separation Method**

Separation in Space cannot be applied because the contradictory demands (i.e., flexibility and rigidity) must be present in the same place.

Separation in Time cannot be applied because the contradictory demands must be present at the same time.

Separation in Relation cannot be applied because the contradictory demands are required for every user of the cable.

Separation in System Level can be applied.

- **Inventive Principles for Separation in System Level**

It is recommended to use the following Inventive Principles for resolving Physical Contradictions using the Separation in System Level method:

- Segmentation
- Merging
- Homogeneity
- Equipotentiality

- **Identifying the Inventive Principle**

After analyzing the different Inventive Principles recommended for resolving Physical Contradictions using the Separation in System Level method, the Inventive Principle “Segmentation” is identified as the most appropriate.

- **Inventive Principle “Segmentation”:**

A. *Divide an object into independent parts*
B. *Make an object easy to disassemble*
C. *Increase the degree of fragmentation or segmentation*

- **Applying the Inventive Principle**

To resolve the Physical Contradiction, construct a chain of cast iron (Figure 41):

Figure 41. **Cast Iron Chain (solution)**

The components of the chain are made of cast iron and are rigid, but the whole chain is flexible and can be folded for storage purposes.

2. Satisfying Contradictory Demands

If you cannot separate the contradictory demands, try to satisfy both the demands. This is usually done by making changes in the physical or chemical parameters of the Engineering System.

Example: Swimming pool

- **Physical Contradiction:**

The swimming pool should be long to avoid frequent turns, BUT

The swimming pool should be short to have a compact infrastructure

- **Comments:**

Any turns are not allowed, therefore a ring-shaped swimming pool is not a solution

- **Resolving Method:**

No any types of separation are applicable. It means that we need to develop a very long but quite compact swimming pool

- **Inventive Principles for Satisfying Contradictory Demands:**

- Phase transition
- Thermal expansion
- Mechanical interaction substitution
- Parameter change
- Strong oxidation
- Inert atmosphere

- **Identifying the Inventive Principle**

After analyzing the different Inventive Principles recommended for resolving Physical Contradictions by satisfying the contradictory demands, the Inventive Principle 13: “The other way around” was identified as the most appropriate.

- **Inventive Principle 13: “The other way around”**

A. Invert the action used to solve the problem (e.g. instead of cooling an object, heat it)
B. Make movable parts (or the external environment) fixed, and fixed parts movable
C. Turn the object (or process) “upside down”

- **Applying the Inventive Principle**

By analogy to a treadmill, the water is moved against the swimmer. Thus, the athlete can swim long distances without actually moving forward (Figure 42):

Figure 42**. Swimming pool (solution)**

3. Bypassing Contradictory Demands

You can solve the engineering problem by completely bypassing the Physical Contradiction. As shown in the following illustration, the new solution may make the Physical Contradiction irrelevant.

Example: A boat

- **Physical Contradiction:**

The boat must be narrow to reduce the hydrodynamic resistance, BUT

The boat must be wide to be stable

- **Resolving Method:**

Let us assume that neither the separation of opposite requirements nor their simultaneous satisfaction is possible. Therefore, we should try to get around the problem by radically changing the object.

- **Applying Bypass**

Instead of trying to resolve the contradictory demands by solving problems of water resistance and boat design, we can completely bypass them by introducing a hovercraft. Since a hovercraft moves on a layer of air above the water surface, the problems of water resistance and boat design are eliminated, and the engineering problem is solved (Figure 43):

Figure 43. **Hovercraft**

Algorithm for Resolving Physical Contradictions

1. Identify the value of the parameter that the Engineering System must have to satisfy the requirement of system improvement.
2. Select the opposite value of the parameter. Analyze if this opposite state is required for improving the Engineering System.
3. If the opposite value is not required for improving the Engineering System, there is no Physical Contradiction and, hence, try to solve the problem by addressing the single parameter.
4. If the opposite value identified in step 2 is needed for improving (or not deteriorating) the Engineering System, there is a Physical Contradiction. Solve the problem by applying the directions of resolving Physical Contradictions.

Summary

This chapter demonstrated how a problem can be resolved by formulating it as a Physical Contradiction, an approach used in the classical TRIZ application to solve Engineering Problems. As mentioned previously, this is just one of several possible ways to model a problem as part of creating a comprehensive picture of the problem. In the following chapter, yet another approach to modeling of Engineering Problems, the Standard Inventive Solutions, will be introduced.

Competitive Patent Circumvention

The Goal of Competitive Patent Circumvention is to legally circumvent the constraints imposed by competitive patents, i.e., to obtain the freedom to operate

For Competitive Patent Circumvention, at least one component must be removed from each independent claim of the competitive patent

Algorithm of Competitive Patent Circumvention

1. Create a Function Model of each independent claim
2. Identify the component to be trimmed - one that:
    - Performs auxiliary functions of the lowest rank
    - Would be easier to trim without major design changes
3. Perform Trimming — remove the identified component mentioned in the independent claim, and redistribute its functions among other components
4. Solve Trimming problems

Example: The Ionic Toothbrush

The Independent claim of the patent formula:

- A toothbrush consists of a head containing bristles, and a handle that holds the head
- The handle and the head also hold an electrode that is powered by a battery inside the handle
- The electrode ionizes air for easy plaque removal (Figure 44):

Figure 44. **Ionic toothbrush**

- **Function model of the independent claim (Figure 45):**

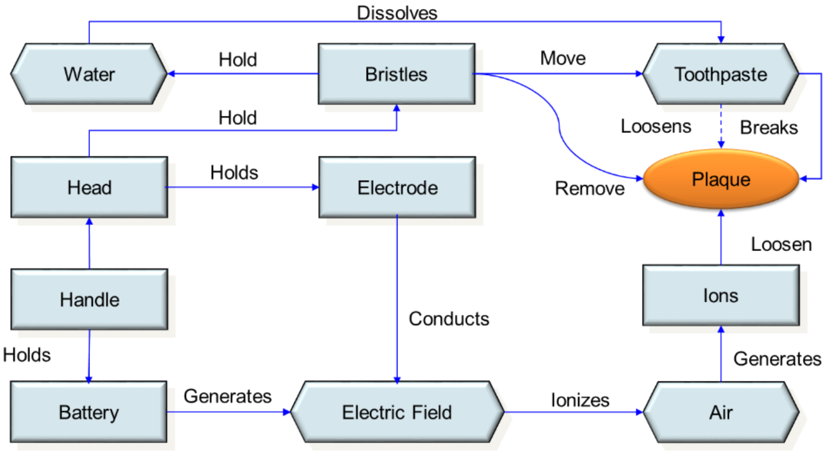


Figure 45. **Function model of the independent claim**

- **Trimming model of the independent claim (Figure 46):**

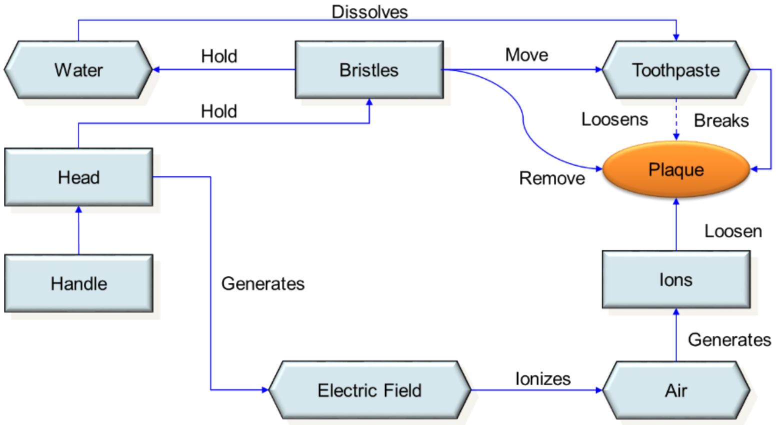


Figure 46. **Trimming model of the independent claim**

- **Trimming problem:**

How to make the Head generate Electric Field?

- **Solution:**

The toothbrush head surface is covered with an alloy that, when in contact with toothpaste and water, works as an active couple and generates voltage. As a result, the head itself ionizes the air near the plaque (Figure 47):

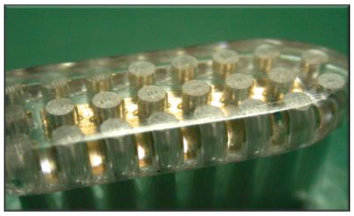


Figure 47. **Ionic toothbrush (solution)**

Afterword

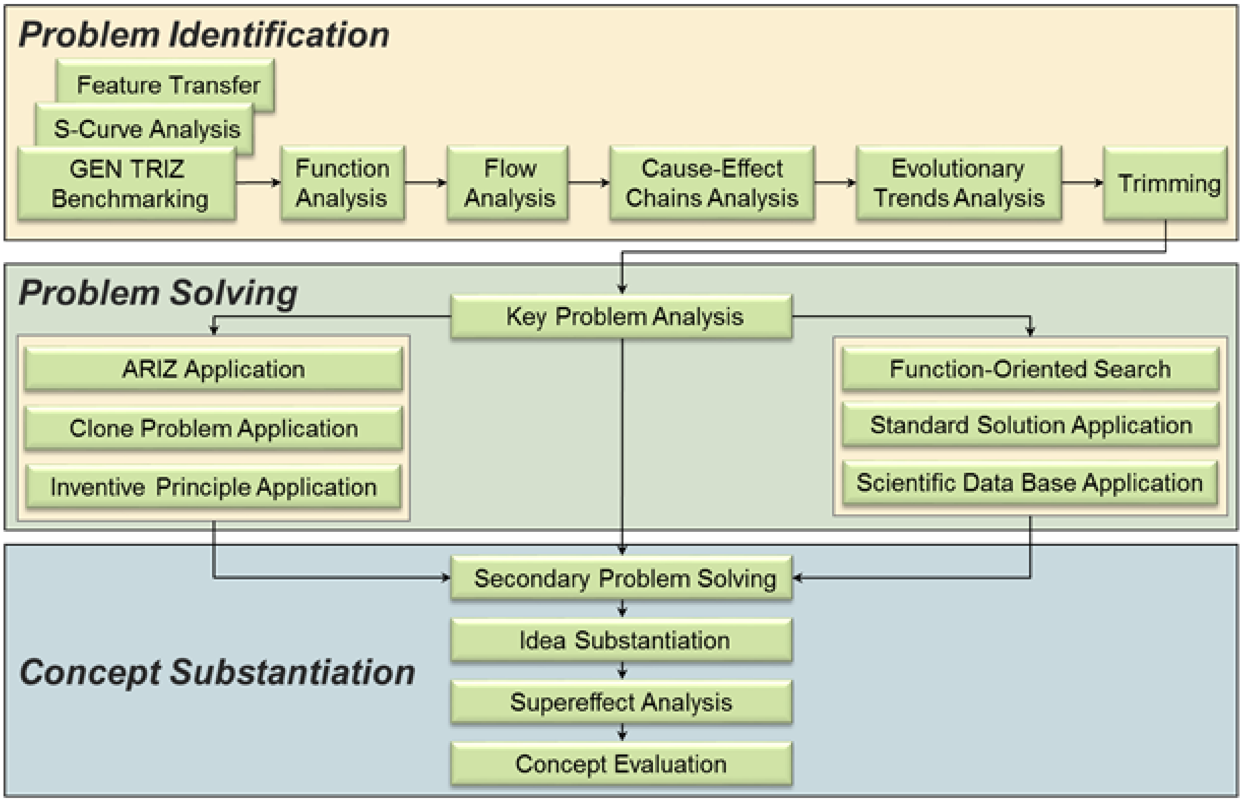
The goal of the Basic Module in GEN TRIZ Product Innovation was to provide the detailed knowledge and hands-on experience on the fundamental tools used for Problem Identification and Problem Solving. In particular, you were introduced to Function Analysis, Cause-Effect Chains Analysis, Trimming, and Inventive Principles. These powerful tools make it possible to circumvent psychological inertia, enable "out of the box" thinking, escape the limits of a specific discipline, and provide means to forecast the technological future. As a result, the process of innovation becomes a low risk, high gain investment with minimal waste of time, money, and resources.

While all the tools described in this manual focused on improving products, GEN TRIZ Product Innovation is also well suited for improving processes. The Advanced Module in GEN TRIZ Product Innovation focuses on how to use Problem Identification tools to improve processes. In addition, the Advanced Module also covers some problem solving tools not covered in the Basic Module (e.g., ARIZ). Thus, after the completion of both the Basic and Advanced Modules, all problem identification and problem solving tools of the GEN TRIZ methodology will be covered and you will be able to apply these tools to improve both products and processes.

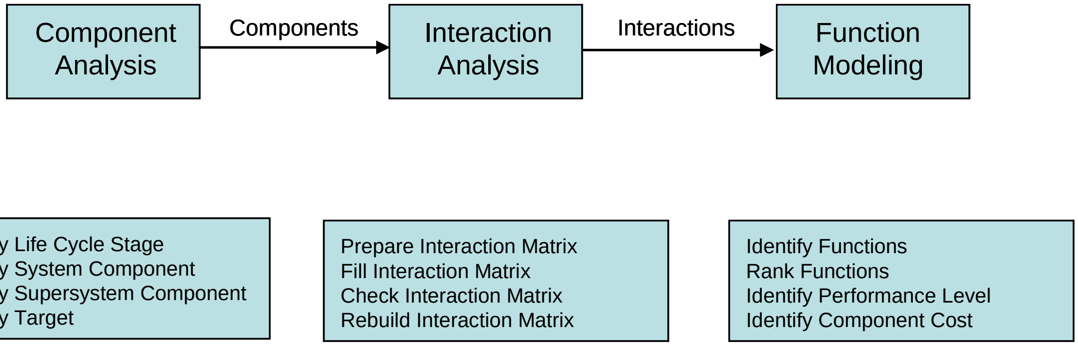
Wherever your innovation future takes you, we hope this course provided you with new and exciting approaches to solve problems, helped develop universal and effective innovation vocabulary, and, most importantly, fundamentally changed how you think about technology and innovation.

Appendix A — Product Innovation Roadmap and Tools

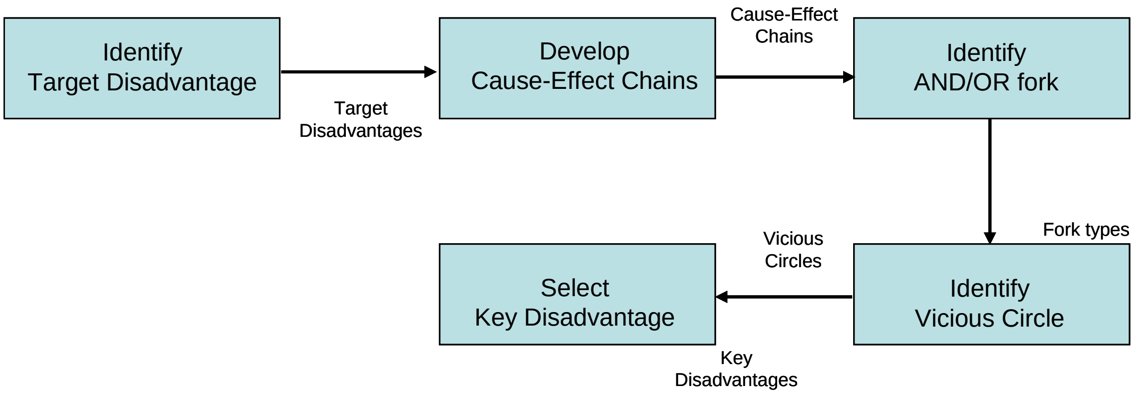
Product Innovation Roadmap



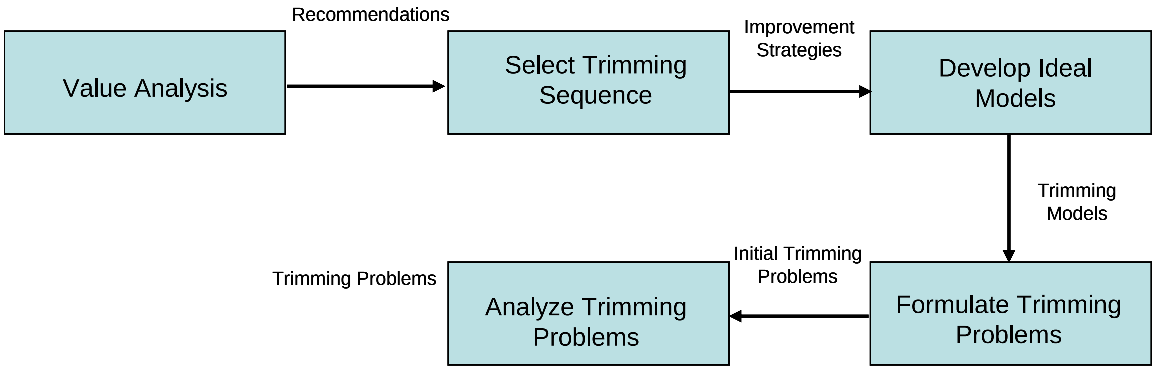
Function Analysis



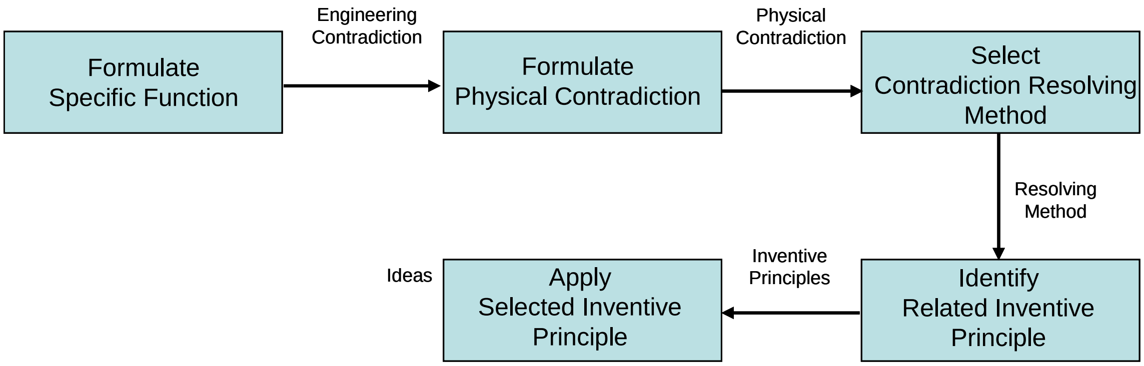
Cause-Effect Chains Analysis



Trimming



Inventive Principles Application: Engineering Contradictions and Altshuller’s Matrix



Appendix B — 40 Inventive Principles with Examples[1]

Principle 1. Segmentation

A. Divide an object into independent parts.

Replace a mainframe computer with personal computers.

Replace a large truck with 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 a rod to get better penetration of the joint.

Principle 2. Taking Out

A. 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.

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[1] Reprinted from the original article in the July 1997 issue of the TRIZ Journal with permission of the author, Ellen Domb. See: http://www.triz-journal.com/archives/1997/07/b/index.html and http://www.triz-journal.com/matrix/index.htm

Principle 3. Local Quality

A. 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.

B. Make each part of an object function in conditions most suitable for its operation.

Lunch box with special compartments for hot and cold foods and liquids

C. 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, and also functions as pliers, a wire stripper, a flat-blade screwdriver, a Phillips screwdriver, a manicure set, etc.

Principle 4. Asymmetry

A. 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, for improved sealing.

Use astigmatic optics to merge colors.

Principle 5. Merging

Bring closer together (or merge) identical or similar objects, assemble identical or similar parts to perform parallel operations.

A. 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.

Slats linked 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 "nesting" 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).

An aircraft's wing shape reduces air density above the wing, and 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 to control harmful effects.

Buffer a solution to prevent harm from extremes of pH.

B. Create stresses in an object in advance, which will oppose known undesirable working stresses later on.

Pre-stress rebar before pouring concrete.

Mask 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 wallpaper

Sterilization of 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 delivery system for parts in a factory

Locks in a channel between two bodies of water (Panama Canal)

"Skillets" in an automobile plant that bring all the 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.

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 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 cube-shaped (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.

Ballpoint 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 the act of wringing clothes to remove water, with spinning the 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, become optimal, or achieve optimal operating conditions.

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 borescope for examining engines

The flexible sigmoidoscope, for medical examinations

Principle 16. Partial or Excessive Actions

A. If 100% of a task or object is hard to achieve using a given solution method then, by using 'slightly less' or 'slightly more' of the same method, the problem may be considerably easier to solve.

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 six CDs 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 level of ultrasound).

Distribute powder with vibration.

C. Use an object's resonant frequency.

Destroy gallstones 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.

Hit 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)

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 of it (e.g., destructible, harmful or hazardous operations) at high speed.

Use a high-speed dentist's drill to avoid the issue of heat.

Cut plastic faster than heat can propagate in the material, to avoid deforming the shape.

Principle 22. “Blessing in disguise”

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, crosschecking) 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.

A carpenter's nail set, 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 that is 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 redeposited.

To weld steel to aluminum, create an interface from alternating thin strips of the two 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 audio tape 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 expensive object with a multiple of inexpensive ones, 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, gustatory, or olfactory) 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 two powders, electrostatically charge one as 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 omni-directional broadcasting. We now use antennae 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 a 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 silkscreen 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 a diamond-cutting tool out of diamonds.

Principle 34. Discarding and Recovering

A. Remove portions of an object that have fulfilled their functions (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 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 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, which 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 used, use multiple materials with different coefficients of thermal expansion.

The basic leaf spring thermostat: (two metals with different coefficients of expansion are linked, to bend 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. Same for airplane parts.

Fiberglass surfboards are lighter and more controllable and easier to form into a variety of shapes than wooden ones.

Contradiction Matrix

Explanation of Some Features

1. Length of stationary (moving object) - any linear dimension: radius, diameter, width, depth.
2. Area or volume of stationary object - any parameter associated with it: porosity, absorbency (volume of pores), etc.
3. Volume of moving object - flow rate, any physical volume, absorbency (volume of absorbed liquid), etc.
4. Stability of object's composition - desirable / undesirable changes of the state of aggregate, chemical stability / decomposition, volatile compounds, etc.
5. Use of energy of moving object - effective (net) efficiency, losses of energy, using secondary power resources, etc.
6. Loss of energy - heat losses, friction, etc.
7. Loss of time - anything associated with low productivity, speed, etc.
8. Object-affected harmful factors - a very generic feature that can be applied to nearly any case when there is a harmful effect, a worsening of any parameter: low quality, any harmful interaction, etc.
9. Adaptability or versatility - when changes of any parameter are required (in time or in space); one of the most generic features
10. Quantity of substance - flow rate, parameters associated with volume, density, etc.
11. Loss of information - problems with feedback, detection, etc.

CHARACTERISTIC THAT IS GETTING WORSE

CHARACTERISTICS TO BE IMPROVED

	CHARACTERISTICS	1 Weight of a mobile object	2 Weight of a stationary object	3 Length of a mobile object	4 Length of a stationary object	5 Area of a mobile object	6 Area of a stationary object	7 Volume of a mobile object	8 Volume of a stationary object	9 Speed	10 Force	11 Tensioin / Pressure	12 Shape	13 Stability of the compostion	14 Strength	15 Time of action of a moving object	16 Time of action of a stationary object	17 Temperature	18 Brightness	19 Energy spent by a moving object	20 Energy spent by a stationary object
1	Weight of a mobile object		—	15, 8 29,34	—	29, 17 34, 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, 29 4, 38	19, 1 32	35, 12 34, 31	—
2	Weight of a stationary object	—		—	10, 1 29, 35	—	35, 30 13, 2	—	5, 35 14, 2	—	8, 10 19, 35	13, 29 10, 18	13, 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 a mobile 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 a stationary 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 a mobile 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, 18	19, 32	—
6	Area of a stationary 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 a mobile object	2, 26 29, 40	—	1, 7 4, 35	—	1, 7 4, 17	—		—	29, 4 38, 34	15, 35 36, 37	6, 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 a stationary object	—	35, 10 19, 14	19, 14	35, 8 2, 14	—	—	—		—	2, 18 3	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, 19 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, 22	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, 28	10, 15 36, 37	6, 35 10	35, 24	6, 35 36	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 composition	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, 35	40, 26 27, 1	1, 15 8, 35	15, 14 28, 26	3, 34 40, 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	Time of action of a 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, 14	—
16	Time of action of a stationary object	—	6, 27 19, 16	—	1, 40 35	—	—	151	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, 2	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, 35 1, 15
19	Energy spent by a moving object	12, 18 28, 33	—	12, 28	—	15, 19 25	—	35, 13 18	—	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 a stationary object	—	19, 9 6, 27	—	—	—	—	—	—	—	36, 37	—	—	27, 4 29, 18	35	—	—	—	19, 2 35, 32	—	
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	Loss of energy	15, 6 19, 28	19, 6 18, 9	7, 2 6, 13	6, 38 7	15, 26 17, 30	17, 7 30, 16	7, 18 23	7	16, 35 38	36, 38	—	—	14, 2 39, 6	26	—	—	19, 38 7	1, 13 32, 15	—	—
23	Loss of a 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	Loss 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, 3	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	3, 27 40	—	19, 26	3, 32	32, 2	—
30	Harmful factor acting on an object from	22, 21 27, 19	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 factors developed by an	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, 11	—
36	Complexity of a device	26, 30 34, 36	2, 26 35, 39	1, 19 26, 24	26	14, 1 13, 16	6, 36	34, 26 6	1, 16	34, 10 28	26, 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 18, 17	2, 39 30, 16	29, 1 4, 16	2, 18 26, 31	3, 4 16, 35	30, 28 40, 19	35, 36 37, 32	27, 13 1, 39	11, 22 39, 30	27, 3 15, 28	19, 29 39, 25	25, 34 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	Capacity / 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

CHARACTERISTIC THAT IS GETTING WORSE																				
21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	CHARACTERISTICS	CHARACTERISTICS TO BE IMPROVED
Power	Loss of energy	Loss of a substance	Loss of information	Loss of time	Amount of substance	Reliability	Accuracy of measurement	Accuracy of manufacturing	Harmful factors acting on an object from outside	Harmful factors developed by an object	Manufacturability	Convenience of use	Repairability	Adaptability	Complexity of a device	Complexity of control	Level of automation	Capacity / Productivity	CHARACTERISTICS	
12, 16 18, 31	6, 2 34, 19	5, 35 3, 31	10, 24 35	10, 35 20, 28	3, 26 18, 31	1, 3 11, 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	Weight of a mobile object	1
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 12, 11	19, 15 29	1, 10 26, 39	25, 28 17, 15	2, 26 35	1, 28 15, 35	Weight of a stationary object	2
1, 35	7, 2 35, 39	4, 29 23, 10	1, 24	15, 2 29	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	Length of a mobile object	3
12, 8	6, 28	10, 28 24, 35	24, 26	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	Length of a stationary object	4
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	Area of a mobile object	5
17, 32	17, 7 30	10, 14 18, 39	30, 16	10, 35 4, 18	2, 18 40, 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	Area of a stationary object	6
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	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	29, 26 4	35, 34 16, 24	10, 6 2, 34	Volume of a mobile object	7
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	Volume of a stationary object	8
19, 35 38, 2	14, 20 19, 35	10, 13 28, 38	13, 26	—	10, 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	—	Speed	9
19, 35 18, 37	14, 15	8, 35 40, 5	—	10, 37 36	14, 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	Force	10
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	Tension / Pressure	11
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	Shape	12
23, 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	Stability of composition	13
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 25, 2	27, 11 3	15, 3 32	2, 13 25, 28	27, 3 15, 40	15	29, 35 10, 14	Strength	14
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	Time of action of a moving object	15
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	20, 10 16, 38	Time of action of a stationary object	16
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	Temperature	17
32	13, 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, 1 19	6, 32 13	32, 15	2, 26 10	2, 25 16	Brightness	18
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	Energy spent by a moving object	19
—	—	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	Energy spent by a stationary object	20
	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	Power	21
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, 32 1	2, 19	—	7, 23	35, 3 15, 23	2	28, 10 29, 35	Loss of energy	22
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	Loss of a substance	23
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	Loss of information	24
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	—	Loss of time	25
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	Amount of substance	26
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	Reliability	27
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	Accuracy of measurement	28
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	Accuracy of manufacturing	29
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	Harmful factor acting on an	30
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, 14 34, 26	—		—	—	—	—	19, 1 31	2, 21 27, 1	2	22, 35 18, 39	Harmful factors developed by an	31
27, 1 12, 24	19, 35	15, 34 33	32, 24 18, 16	35, 28 35, 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	Manufacturability	32
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	Convenience of use	33
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	Repairability	34
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 31	15, 34 1, 16	1, 16 7, 4		15, 29 37, 28	1	27, 34 35	35, 28 6, 37	Adaptability	35
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	Complexity of a device	36
19, 1 16, 10	35, 3 15, 19	1, 18 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 37, 28		34, 21	35, 18	Complexity of control	37
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			Level of Automation	38
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	5, 12 35, 26		Capacity / Productivity	39

Glossary

A

Absolute Cost (Cost): The monetary cost of the Engineering System or its Component.

Activity Analysis: Analysis conducted through observation of how consumers actually use the product in the marketplace by building a model of user activities.

Additional Function: A Useful Function that acts on a Component of the Super-system that is not a Target.

Adjacent Market: Markets with important similarities and large differences in cost structure, competitors, customers, and requisite capabilities.

Alternative Engineering System: A Competing Engineering System that has a complementary pair of advantages and disadvantages to the Base ES.

Altshullers's Matrix: A problem solving tool that recommends Inventive Principles for solving Engineering Contradictions.

ARIZ: A problem-solving tool that transforms a complex engineering situation into a well defined model of the problem, which can be solved effectively using a wide spectrum of TRIZ tools. ARIZ is the Russian acronym for "Algorithm for Inventive Problem Solving".

Attribute: A fundamental quality of a Component that characterizes its interaction with other Components. Examples include electrical conductivity, viscosity, or strength. (Note that a parameter is a measurable value of an Attribute. Examples of parameters include specific level of conductivity measured in ohms or specific level of viscosity measured in Pascal seconds.)

Auxiliary Function: A Useful Function that acts on a component of the Analyzed Engineering System.

B

Base Engineering System: A System to which features from the Alternative System is transferred. The Base System is the Alternative System selected for improvement.

Basic Function: A Useful Function directed toward a Target Component of the Analyzed Engineering System.

Bottleneck: A place in a flow channel that significantly increases resistance to flow. A Bottleneck is a typical disadvantage identified by Flow Analysis.

Business Case: An analysis that establishes the justification to implement an innovation initiative.

C

Cause Disadvantage: A disadvantage in the Cause-Effect Chain that is a direct cause of a given disadvantage.

Cause-Effect Chain: A graphical model of the Analyzed Engineering System that reflects the inter-dependence of its disadvantages.

Cause-Effect Chains Analysis (CECA): An analytical tool that identifies the Key Disadvantages of the Analyzed Engineering System. This is accomplished by building cause-effect chains of disadvantages that link the Target Disadvantage to its fundamental causes.

Clone Problems: Different problems that have identical Physical Contradictions.

Commodity: A generic, non-differentiated product that is sold with a low margin, a price close to cost.

Commodity Price: When the price of the product is close to cost, yielding low profit margins.

Competency: A specific range of skill, knowledge, or ability.

Competing Engineering Systems: Engineering Systems with similar Main Functions.

Component (Sub-system): A part of the Engineering System or Super-system, consisting of a substance, a field, or substance-field combination.

Component Analysis: The step in Function Analysis that identifies Components of the analyzed Engineering System and its Super-system.

Component Cost: The monetary cost of the Component. Cost can be relative or absolute.

Component Functionality: The measure of a Component's contribution to the overall performance of the System.

Component Model: The set of Components belonging to the Analyzed Engineering System and its Super-system. The Component Model can be built in graphical form or as a table.

Concept: A feasible (Substantiated) idea.

Conceptual Direction: A specific method to achieve the project goals based on solving of a Key Problem.

Conceptual Sub-direction: A specific method of solving a Key Problem within the frame of the Conceptual Direction.

Conflict Components: Components that require an improvement in the interaction between them according to the formulation of the Mini-Problem.

Conjoint Analysis: A research technique used to measure the trade-offs people make in choosing between products and service providers. It is also used to predict their choices for future products and services.

Contradictory Demand: A demand that, when resolved, prevents from meeting the requirements of another demand.

Control System: A common functional part of the Engineering System that controls how the other parts function. For example, a thermostat in an air-conditioning system.

Cost (see Absolute Cost)

Cost Analysis: A step in Function Analysis that identifies the absolute and relative costs of Components that constitute the Analyzed Engineering System.

D

Defect: A Component or its part that impairs performance of a Useful Function or performs some Harmful Function.

Delay Zone: A location in a flow in which the integral flow speed is significantly lower than local flow speed. A Delay Zone is a typical disadvantage identified by Flow Analysis.

E

Effect (see Scientific Effect)

Effect Disadvantage: Disadvantage in the Cause-Effect Chain that is directly caused by a given disadvantage.

Energy Source: A common functional part of the Engineering System that generates energy to operate the system. For example, an engine in a car.

Engineering Contradiction (EC): A situation in which an attempt to improve one parameter of an Engineering System leads to the worsening of another parameter. For example, improving the strength of the airplane wing leads to the increased weight of the wing.

Engineering System: A System that has been assigned to perform a Function.

Evolutionary Trends Analysis: An analytical tool that predicts the development directions of an Engineering System based on the Trends of Engineering System Evolution.

F

Feature: A characteristic of an Alternative Engineering System to be transferred to the Base Engineering System to eliminate the disadvantage of the Base System (used in Feature Transfer).

Feature Providing Alternative Engineering System: An Alternative Engineering System chosen for Feature Transfer.

Feature Transfer: An analytical tool for improvement of the Base Engineering System by transferring relevant features from the Alternative Engineering System.

Field: An object with no rest mass that transmits interaction between Substances. Examples include magnetic, electric, thermal, and acoustic fields.

Flow Analysis: An analytical tool that identifies disadvantages in flows of energy, substances, and information in the Engineering System.

Flow Disadvantage: A disadvantage of the Analyzed Engineering System identified during Flow Analysis. These disadvantages include, for example, "Bottlenecks", "Gray Zones", "Stagnation Zones", etc.

Flow Partition Analysis: A part of Flow Analysis that identifies allocation of flows.

Function: An action performed by one Component (Function Carrier) to change or maintain a parameter of another Component (Object of the Function).

Function Analysis: An analytical tool that identifies Functions, their characteristics, and the cost of System and Super-system Components.

Function Carrier: A Component performing a Function.

Function Category: A characteristic of a Function that describes its usefulness. A Function can be Useful, Harmful, or Neutral.

Function Disadvantage: A disadvantage of the Analyzed Engineering System identified during Function Modeling. These disadvantages include Harmful Functions, as well as inadequately (i.e., excessively or insufficiently) performed Useful Functions.

Function Model: A model of the Engineering System that identifies and describes the Functions performed by the Components of the System and its Super-system. Functions are characterized by category (useful or harmful), quality of performance (insufficient, normal and excessive), cost level (insignificant, acceptable and unacceptable) and cost of corresponding components.

Function Modeling: A part of Function Analysis that builds a Function Model.

Function-Oriented Search (FOS): A problem solving tool based upon identifying existing technologies worldwide, using function criteria.

Function Parameter: A parameter that characterizes the performance of a function.

Function Rank: A characteristic that determines the importance of the useful function based on the type of its object (i.e., Target, component of the Analyzed Engineering System, or component of the Super-system).

Function Redistribution: Redistribution of useful functions of a trimmed component to other components of the Analyzed Engineering System, or its Super-system, done as a part of Trimming.

Functionality: A measure of a component's contribution to the overall performance of the System. Functionality depends on: the number of useful functions a component performs, importance of these functions, and how well these functions are performed

G

GEN TRIZ Benchmarking: An analytical tool that identifies the best Engineering System for improvement as well as possible candidates for Feature Transfer.

GEN TRIZ Product and Technology Forecasting: A method for predicting Engineering System evolution at the level of conceptual design. This is done based on analyzing of TESE and market trends, and applying other tools.

Generalized Function: A Function for which the specific object and associated action are reduced to universal terms. For example, the specific Function "remove water" can be generalized to "move liquid".

Gray Zone: A location in a flow whose parameters are difficult to predict. A Gray Zone is a typical disadvantage identified by Flow Analysis.

Gross Profit Potential: A measure of market attractiveness - market size adjusted by a market change rate and multiplied by gross profit margin.

H

Harmful Function: A Function that worsens the parameters of its object.

Hedonic Regression: Also known as Hedonic Demand theory, it is a method of estimating demand or prices by decomposing the item being researched into its constituent characteristics, and obtaining estimates of the value of each characteristic. In essence, it assumes that there is a separate market for each characteristic.

Hedonic Price Index: Using Hedonic Regression analysis, the assumption is that the price of a product is a function of its quality characteristics.

I

Idea: A potential solution to a Key Problem that has not yet been substantiated to determine its viability.

Ideal Engineering System: A System that has an infinite value. For example, it may have no components or associated costs, but still deliver the intended functionality.

Ideal Final Result: A model of the inventive problem solution formulated as a set of justified requirements towards the X-factor (part of ARIZ).

Initial Disadvantage: A disadvantage in the Analyzed Engineering System, the elimination of which is the goal of a project.

Innovation: Commercially available significant improvement along a Main Parameter of Value (MPV).

Innovation Agenda: Multi-year plan for innovation projects directly linked to the company's growth objectives.

Intermediate Disadvantage: A disadvantage in the Cause-Effect Chain that is not a Target or a Key Disadvantage.

Interaction Analysis (Structure Analysis): A part of Function Analysis that identifies interactions between the Components included in a Component Model.

Interaction Matrix: A table that identifies interactions between Components of an Analyzed Engineering System and its Super-system.

Inventive Principles (Principles): A problem-solving tool that provides generalized recommendations for modifying a System to solve a problem formulated as an Engineering or Physical Contradiction (an Inventive Principle is an abstract model of the solution to the problem).

K

Key Disadvantage: A disadvantage to be eliminated to achieve the project goal. Usually, Key Disadvantages appear at the root of a Cause-Effect Chain.

Key Problem: A problem to be solved to achieve project goals within the specified constraints.

Key Problem Analysis: An analytical tool that first eliminates redundant Key Problems from all the Key Problems identified during the Problem Identification stage, then identifies trivial Key Problems and, finally, classifies non-trivial Problems as function- or contradiction-based.

Knowledge Base: A function-based database of the Scientific Effects.

L

Leading Area: An area where a Function of interest is performed under more challenging conditions and/or is more important compared to the area from which the project originated.

Level of Useful Function Performance (Insufficient, Normal, Excessive): The ratio between the actual and required values of the function criterion. If the actual value (AV) > required value (RV), the level is excessive. If AV < RV, the level is insufficient. If AV = RV, the level is normal.

Landscape Mapping: A map where a large number of highly diverse products are positioned in terms of criteria such as value and gross profit potential. It allows the comparison of a large number of different products and enables companies to identify potential products to focus their Innovation Initiatives on.

M

Main Function: A Function for which an Engineering System is assigned.

Main Functional Parameters of Value (MFPVs): The objective technical (physical, chemical, geometrical, biological, etc.) characteristics that underlie the MPV.

Main Parameters of Value (MPV): Product characteristics that define customer behavior in the market.

Margin: Net sales minus the cost of goods and services sold.

Market Segment: A distinct groups of buyers who might require separate products or marketing mixes.

Material Object: *See Component*.

Measurement Function: A Providing Function that reveals information about Components.

Meta-Experts ("spiders"): Experts who can identify and manage subject matter experts in specific scientific or engineering areas.

Mini-Problem: A problem formulated as an Engineering Contradiction with a constraint against significant changes to the Analyzed Engineering System.

MPV Performance: An aggregate measure of how well a product fulfills market requirements.

MPV Value: The relationship between MPV performance and price.

MPV Relative Value: A dimensionless indicator of relative position. Reflects what is commonly referred to as our "Value Proposition."

N

Niche: A special area of demand for a product or service.

Non-recoverable investment: Investment that, once made, cannot be recovered.

Neutral Function: A Function that either has an insignificant influence on the parameter of its object, or changes it in a way that is irrelevant according to current requirements.

O

Object of Function: A Component, the parameter of which is changed as a result of performing a Function.

Operating Tool: A typical function part of an Engineering System that usually performs the most important Basic Functions.

Operation: An action within a Technological Process.

Operation Time: A time interval, during which one of the Contradiction requirements (either engineering or physical) must be met.

Operation Zone: A physical space, in which one of the Contradiction requirements (either engineering or physical) must be met.

P

Parameter: A comparable value of an Attribute.

Patent: A legal document that grants exclusive rights to make, use, or sell the invention described in the patent claims.

Patent Circumvention: The method to legally circumvent the constraints imposed by competitive patents, i.e., to obtain the freedom to operate without infringing on the patent owner's rights.

Performance Level (see Level of Useful Function Performance)

Physical Contradiction (PhC): Two justified opposite requirements placed upon a single physical parameter of a single object.

Physical Contradiction Analysis: A method for resolving Physical Contradictions based on selecting the typical approach for resolving a Physical Contradiction, and then identifying a set of applicable Inventive Principles relating to the selected approach.

Physical Parameters: Technological parameters of a System that underlie the given MPVs.

Portfolio Landscape: A landscape positioning of products in terms of their value and gross profit potential.

Primary Research: Information collected by interviews or questionnaires designed for a specific need.

Principles (see Inventive Principles)

Process: A model of an Engineering System built in the form of a sequence of actions.

Product: An Engineering System that is an object of Innovation.

Product (in ARIZ): A conflict component that is an object of the Function performed by the Tool (term originated in ARIZ; corresponds to Object of Function).

Productive Function: A Useful Function that irreversibly (permanently) changes a Parameter of the Product.

Providing Function: A Useful Function that temporaily changes parameter of the Object to help performing of other Useful Functions.

R

Relative Cost: A cost of the component expressed as a percentage of the overall cost of the entire Engineering System.

Relative Value: Ratio of product's value to the value of competitive products.

Return on Investment (ROI): A performance measurement used to evaluate the efficiency of an investment or to compare the efficiency of a number of different investments. To calculate

ROI, the benefit (return) of an investment is divided by the cost of the investment. The result is expressed as a percentage or a ratio.

S

S-Curve: An S-shaped curve that represents the typical dependence of a main functional parameter of an evolving Engineering System on time.

S-Curve Analysis: An analytical tool that determines the potential of an Engineering System based on its position on the S-Curve and Limits of Development. This tool is usually applied within GEN TRIZ Benchmarking and Trends of Engineering System Evolution Analysis.

Scenario Generation: To identify and analyze multiple situations on how external factors could influence and affect results.

Scientific Effect: A natural phenomenon or combination of such that could be used for problem solving. For example, Bernoulli's Principle is used to control pressure in fluids.

Secondary Problem: A problem that addresses a new disadvantage that arises from a proposed solution.

Secondary Research: Examining or reading about someone else's research (either primary or secondary), such as in a library or on the internet through web searches.

Segmentation: Identifying niches or subgroups within a market, generally with the aim of more targeted communication.

Similar Functions: Functions with similar objects and/or actions.

Stagnant Zone: A part of a flow in which the flow stops temporarily or permanently. A Stagnation Zone is a typical disadvantage identified by Flow Analysis.

Stakeholders: Any party that has an interest and/or involvement in the purchase decision-making process, both directly and indirectly.

Standard Inventive Solutions (SIS): A set of 76 typical solutions in the form of Substance-Field (Su-Field) Models, to typical problems that are also expressed in the form of Su-Field Models.

Standard Problem Model (see Substance-Field Model)

Standards (see Standard Inventive Solutions)

Structure Analysis (see Interaction Analysis)

Substance: An object with rest mass.

Substance-Field Analysis: A part of Standard Inventive Solution application that models a problem and potential solutions in the form of a Substance-Fields interaction.

Substance-Field Model (**Su-Field Model, Su-Field**): Symbolic model of a problem or solution formulated in terms of interactions between substances and fields (virtual, real, or improved).

Substance-Field Resources: Substances, fields, and their parameters that can be used to solve a problem.

Substantiation: A part of the GEN TRIZ Innovation process that determines the feasibility of developed Ideas.

Sub-system (see Component)

Super-system: The system that contains the Analyzed Engineering System as a component.

T

TRIZ: An applied scientific discipline that deals with directions of development and methods for improvement of Engineering Systems based on Trends of Engineering System Evolution. TRIZ is the Russian acronym for the Theory of Inventive Problem Solving.

Target: An object of the Main Function of the Analyzed Engineering System.

Target Disadvantage: *See Initial Disadvantage*.

Technological Process: A Process that uses Material Objects, such as raw materials, equipment, tools, energy, parts, assemblies, people, etc., to create a Product.

Tool: A conflict component that performs a function (term originated in ARIZ; corresponds to Function Carrier).

Transmission: A common functional part of an Engineering System and its Super-system that transfers a Field (energy) from an Energy Source to an Operational Device.

Transport Function: A Providing Function that changes a position of its Object in space.

Trends of Engineering System Evolution (TESE): Statistically proven directions of Engineering System development that describe the natural transitions of Engineering Systems from one state to another. These directions are statistically true for all categories of Engineering Systems.

Trends of Engineering System Evolution Analysis: An analytical tool that identifies the directions of development of the Engineering System related to the Trends of Engineering System Evolution.

Trimming: An analytical tool that formulates problems for improvement of the Engineering System, relating to removing (trimming) certain components and redistributing their useful functions among the remaining System or Super-system components.

Trimming Condition: An option for eliminating a Component of the Engineering System by either eliminating its Useful Functions or redistributing its Useful Functions to other Components.

Trimming Model: A model of an improved Engineering System developed through Trimming.

Trimming Problem: A problem that must be solved to realize the Trimming Model.

Trimming Rule (see Trimming Condition)

Typical Parameters: A limited set of the generalized parameters that typically need improvement in the Engineering Systems, listed in the Altshuller's Matrix.

U

Useful Function: A Function that changes the parameter of its object in the required direction.

V

Value (as in GEN TRIZ Product Innovation): A ratio between the Engineering System's (or System component's) functionality and cost: V = F/ C.

Value (as in GEN TRIZ Business Analysis; also Stakeholder Value): A ratio between the MPV performance and price.

Value Analysis: An analytical tool that compares the relative functionality and relative cost of System Components.

Value Analysis Model: System components distributed on the graph which plots component's functionality vs. its cost.

Value Chain: A high-level model of how businesses receive raw materials as input, add value to the raw materials through various processes, and sell finished products to customers.

Value Proposition: The unique added value an organization offers customers through their products/operations/services.

Verification: Process of establishing the validity and practical viability of the developed concepts.

X

X-factor: Any change in the Engineering System (e.g., change in its components, parameters, etc.) that should be incorporated into the System in order to solve a problem (used in ARIZ).