MATRIZ – Level 1 Training Manual

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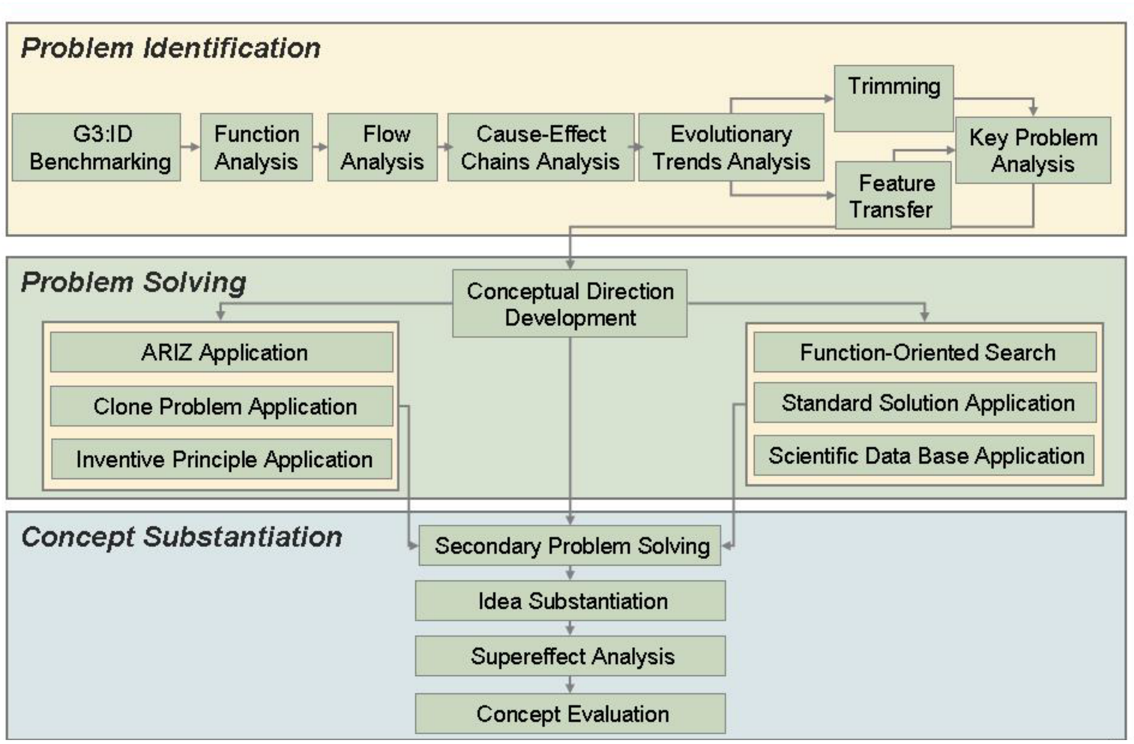
Organization of this Training Manual

This Level 1 Course provides an overview of the following tools that constitute TRIZ Product Innovation:

- Function Analysis: An analytical tool that identifies functions, their characteristics, and the cost of the System and Supersystem 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 Supersystem.
- 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.
- Standard Inventive Solutions introduction: a set of 76 typical solutions, in the form of Substance-Field Models, to typical problems that are also expressed in the form of Substance-Field Models.
- Trends of Engineering System Evolution Introduction: Statistically proven directions of Engineering System development that describe the natural transitions of Engineering Systems from one state to another.

Figure 1 illustrates all tools and methods included in G3:ID Product Innovation (some tools will be covered in the Advanced Course).

Figure 1 Product Innovation Roadmap



The previous figure can also be viewed as a typical roadmap for a product 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). 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.

FUNCTION ANALYSIS FOR DEVICES

Key Terms

Function	Component	Object of the Function	Useful Function
Function Analysis	Main Function	Parameter	Function Model
Component Analysis	Substance	Basic Function	Performance Level
Interaction Analysis	Field	Basic Function	Absolute Cost Function
Modeling	Interaction Matrix	Additional Function	Relative Cost
Engineering System	Function Carrier	Auxiliary Function	Cost Disadvantage
Supersystem	Action	Function Rank	Target
Cost	Harmful Function		

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 Supersystem. 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 in TRIZ 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 around 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 Supersystem are identified. The Supersystem 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 Supersystem).

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

Function Modeling: The functions performed by the Components of the Engineering System and its Supersystem 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 G3:ID problem statement and problem-solving tools. The learning and 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 course, we will only discuss Function Analysis for products. Function Analysis for processes is discussed in the Advanced course.

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 Supersystem. 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 Supersystem. 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 are always material objects. A material object could be a substance, a field, or a combination of both. Substances, such as water, an automobile, and a toothbrush, have resting mass. On the other hand, fields, such as an electric field, magnetic field, and thermal field, do not have resting mass. Fields enable interactions between two 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:

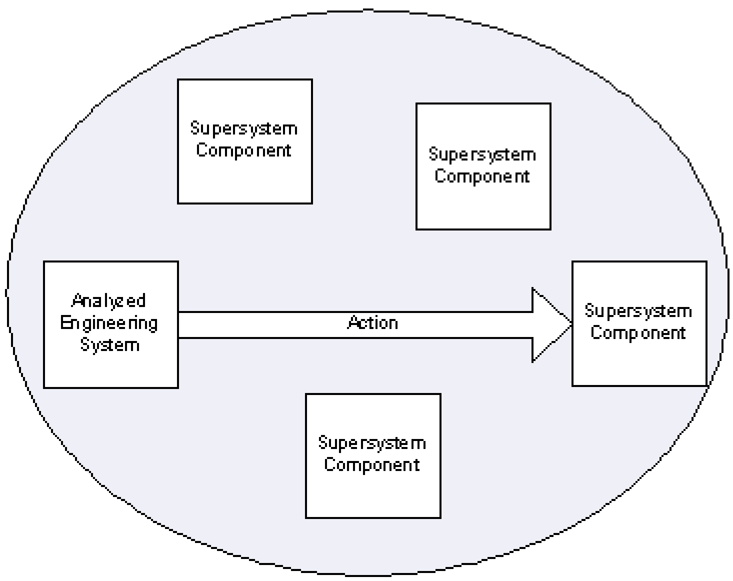
- Selecting a very low level may result in a component model having too many components. This will increase the analysis effort significantly at subsequent stages without commensurate benefits.
- Component Analysis at too high a level may generate a component model that is too generalized and have insufficient 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 constructing a model with five to seven components at each hierarchical level delivers the most useful information for analysis. 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 Supersystem

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 Supersystem. For the purpose of Component Analysis, the Supersystem components are everything that the Engineering System interacts with. For example, if a wheel of a car is the analyzed Engineering System, then the Supersystem components include the other parts of the car as well as the road, gasoline, air, water, etc.

Figure 2 Components of the Supersystem



Include all the components of the Supersystem with which the analyzed Engineering System interacts. You may also include those components of the Supersystem 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 Supersystem that neither interact with the Engineering System nor are potential resources for it.

Note: The Supersystems 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 Supersystem for the car; while the car is driving, the street may be considered as a Supersystem for the car.

Identifying the Target

Each Engineering System is built to perform some 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 Supersystem. 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 Supersystem 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 shown in the following table.

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 Supersystem's components that interact with the Engineering System or are located close to it.

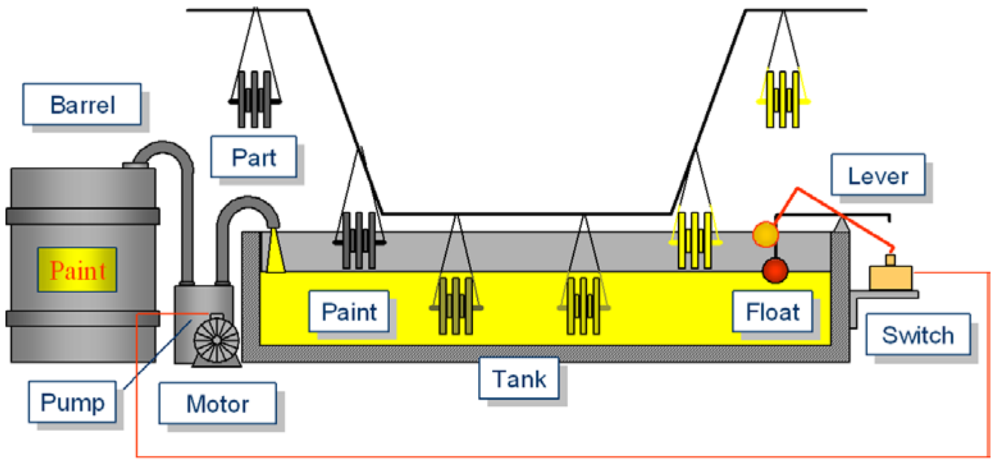
Table 1 Component Model Template

Engineering System	Engineering System Components	Supersystem Components
Name, or ES for...	Component 1 Component 2 Component 3	Component 4 Component 5

Example: Paint Filling System

To illustrate the various procedures in Component Analysis, we shall use the example of the Paint Filling System Engineering System, as shown in the following figure.

Figure 3 Example: 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

The following table shows the component model for the Paint Filling System.

Table 2 Component Model for the Paint Filling System

Engineering System	Components	Supersystem Components
Paint Filling System	Float Lever Switch Motor Pump Barrel	Paint (Target) Tank Parts Air

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 Supersystem 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, it is necessary to first 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 Supersystem. 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 Supersystem. 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.

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 those 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.

Table 3 Interaction Matrix Template

	Component 1	Component 2	Component 3	Component 4	Component 5
Component 1		-	+	-	+
Component 2	-		+	-	+
Component 3	+	+		-	+
Component 4	-	-	-		+
Component 5	+	+	+	+	

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 Supersystem 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 Supersystem.

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.

The following table shows the Interaction Matrix for the Paint Filling System.

Table 4 Interaction Matrix for the Paint Filling System

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

Paint	+	-	-	-	+	+		+	+	+
Tank	-	+	+	-	-	-	+		-	+
Parts	-	-	-	-	-	-	+	-		+
Air	+	+	+	+	+	+	+	+	+	

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.

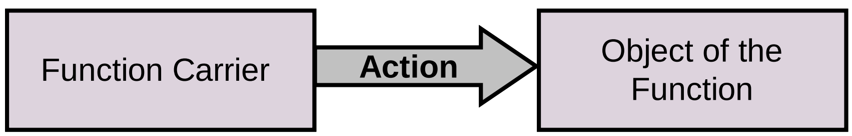
Outcome of Function Modeling

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

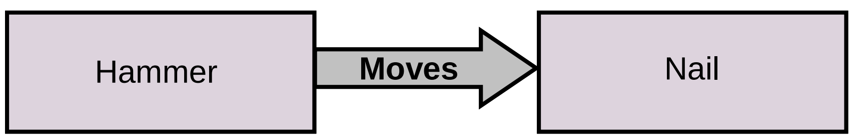
Function Model is used as input in the subsequent stages of problem identification and solution of the Engineering System.

Defining a Function

Function is an action performed by one material object to change or maintain a parameter of another material object. 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.



For example, a hammer (Function Carrier) moves a nail (Object of the Function) leading to a change in the physical position of the nail (change in the parameter value).



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

1. Both the Function Carrier and the Object of the Function must be material objects.
2. There must be interaction between the Function Carrier and the Object of the Function.
3. There must be a result in the form of a changed parameter of one of the objects (including maintaining a parameter value).

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. 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 Supersystem. 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 Supersystem 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.

Table 5 Identifying Functions of the Paint Filling System

Function	Category	Rank	Performance Level	Cost
Float				
Moves Lever	Useful		Insufficient	
Holds Paint	Harmful			

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 the change introduced in the value of a parameter.

First, a range is established for the parameter values. The change in the parameter value introduced by a function is then compared with this range to determine the performance of that function.

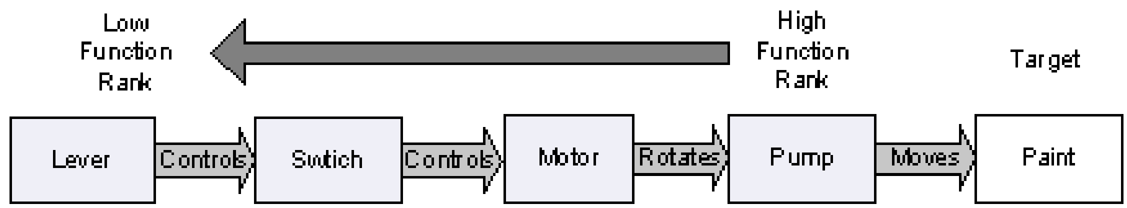
Classifying the Levels of Performance

The level of useful function performance is a comparison between the actual value of the change caused and the required values. Both insufficient and excessive levels of function performance are disadvantages.

Ranking Useful Functions

Functions in the Engineering System that are closer to the Target are more significant and, therefore, ranked higher than those away from it. For example, in the Paint Filling System example, the Pump is ranked higher because it moves the Paint (Target), the Motor is ranked lower than the Pump, and the Lever is ranked lower than the Motor as shown in the following illustration.

Figure 4 Ranking Useful Functions

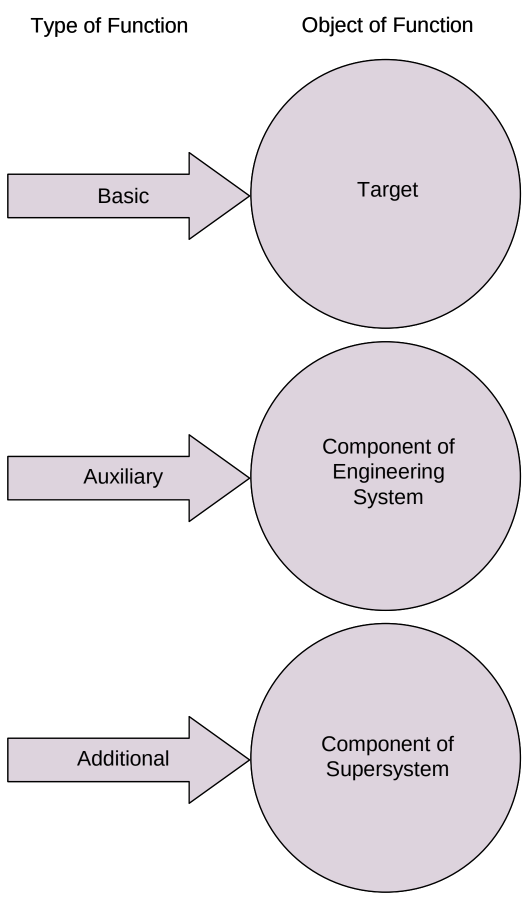


Determining Function Ranks

The rank of the function is determined as follows:

1. A function directed at the Target is a basic function and has the highest rank.
2. A function directed at a Supersystem component other than the Target is an additional function.
3. A function directed at a component of the Engineering System is an auxiliary function. Auxiliary functions are ranked in the following way:
   - If the Object of the Function performs at least one basic function then the function is ranked 1.
   - If the Object of the Function performs an auxiliary function of rank `n', then the function is ranked `n+1'.

Figure 5 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, on the basis of 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).

Table 6 Function Model Template

Function	Category	Rank	Performance level	Cost
Function Carrier 1 (Absolute Cost, Relative Cost)				
To /verb/ Object of the Function X		B, An, Ad, or H	I, E, or N	
To /verb/ Object of the Function Y		B, An, Ad, or H	I, E, or N	
Function Carrier 2 (Absolute Cost, Relative Cost)				
To /verb/ Object of the Function X		B, An, Ad, or H	I, E, or N	
To /verb/ Object of the Function Z		B, An, Ad, or H	I, E, or N	

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

Example: Paint Filling System

The following table shows the Function Model of the Paint Filling System. The main Function of the Paint Filling System is to fill (add) paint to the tank when the paint level is low and to stop the flow of paint when it reaches the desired level.

Table 7 Function Model of the Paint Filling System

Function	Category	Rank	Performance Level	Cost
Float				
Moves Lever		A4	Insufficient	
Holds Paint		H		
Lever				
Holds Float		A5	Normal	
Controls Switch		A3	Insufficient	
Switch				
Controls Motor		A2	Insufficient	
Motor				
Rotates Pump		A1	Excessive	
Pump				
Moves Paint		B	Excessive	
Barrel				
Contains Paint		B	Normal	

Paint				
Moves Float		A4	NA	
Tank				
Contains Paint		B	NA	
Air				
Solidifies Paint		H	NA	

Identifying Functions

To identify the functions:

1. Write down the components of the Engineering System as well as those of the Supersystem 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 Supersystem.

Determining the Performance Level of Functions

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

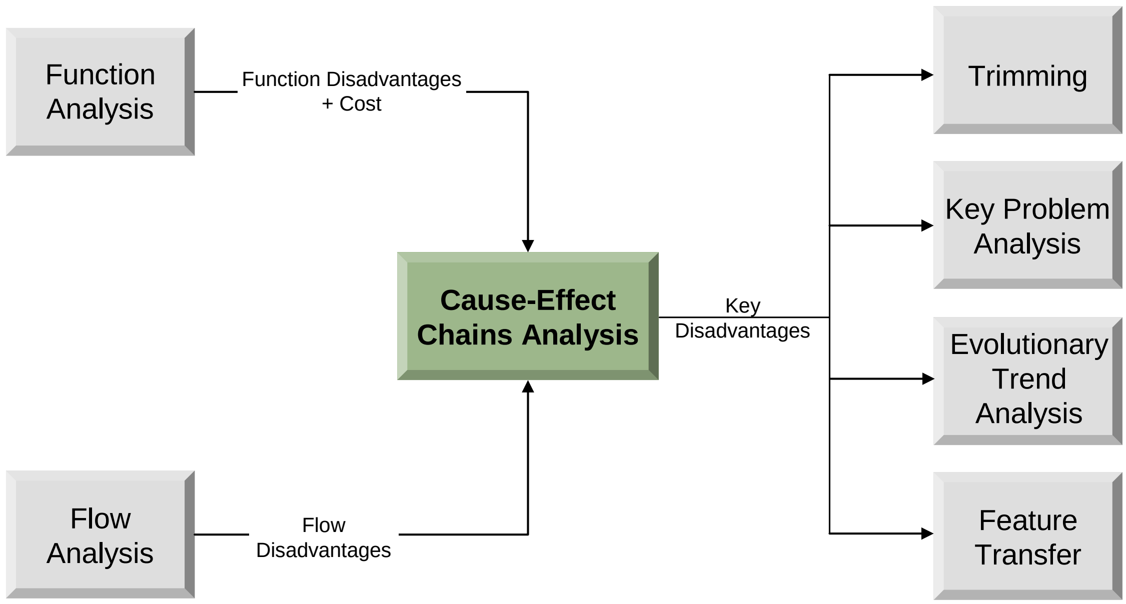
- For the component Float, the performance level of the function `Moves Lever' is insufficient because Float cannot move the lever normally as it gains weight.
- For the component Pump, the performance level of the function `Moves Paint' is excessive because the pump continues to move paint into the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

Summary

This chapter described one of the most important and powerful tools in the G3:ID 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 G3:ID tools for Problem Identification: Trimming, Flow Analysis, and Cause-Effect Chains Analysis. All of these tools will be described in the subsequent chapters of this manual.

CAUSE-EFFECR CHAIN ANALYSIS



Key Terms

Target Disadvantage

Key Disadvantage

Cause-Effect Chains

Intermediate Disadvantage

Cause Disadvantage

Effect Disadvantage

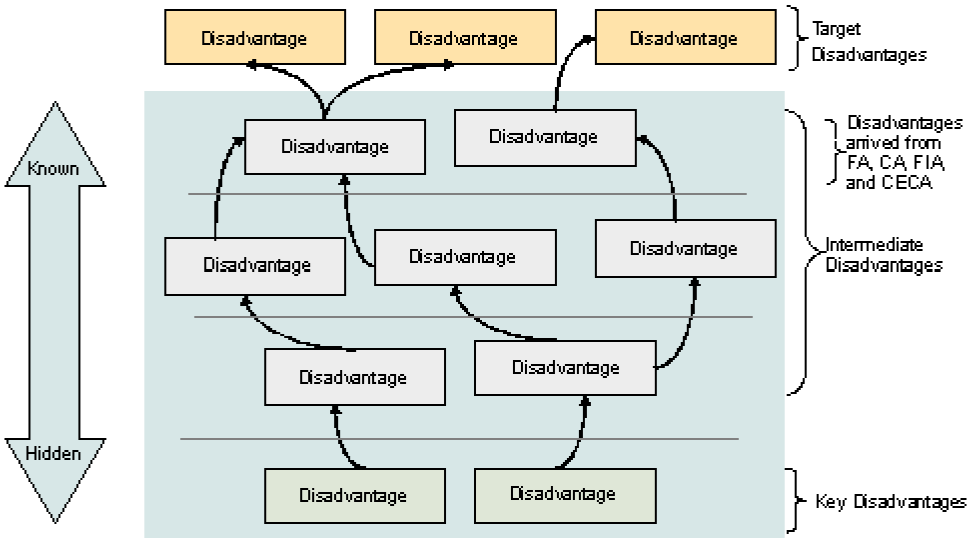
Introduction

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 Initial or Target Disadvantages) or from 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 almost always determined by physical, chemical, biological, or geometrical limits. Such disadvantages cannot be further broken down into underlying causes and are called Key Disadvantages. Importantly, CECA encompass all disadvantages of the analyzed Engineering System as it receives inputs from all 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 Initial 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 Initial Disadvantages). Additionally, the Key Disadvantages are typically formulated at the level of basic sciences and, therefore, are more easily resolved compared to, say, Initial Disadvantages. Finally, in the typical innovation initiative situation, Key Disadvantages have never been addressed prior to the application of the TRIZ methodology while Initial Disadvantages have been worked on extensively with unsatisfactory results.

6 Types of Disadvantages



Note: **Initial or** Target Disadvantages are defined by the goals and requirements of the innovation initiative.

It is always best to eliminate Key Disadvantages. These are the furthest from the Initial 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. However, if it is not possible to address the Key Disadvantage(s), proceed with Intermediate Disadvantages.

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, 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. This in turn is a result of excessive cell membrane conductivity to ions. We have now reached a Key Disadvantage as this is fundamental biological cause.

Identifying Key Disadvantages

As you keep building a Cause-Effect Chain by adding links of cause and effect, you may come to a stage where a disadvantage may not have any underlying cause. This disadvantage ends a Cause-Effect Chain and is called a Key Disadvantage.

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. 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 Initial 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.

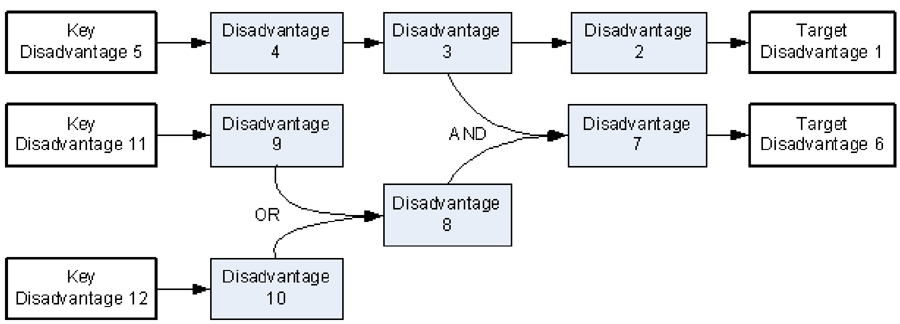
- Use a scientific formula. For example, if the Key Disadvantage is distance, D=SxT. The causes could be found in speed and time.
- Ask experts.

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 Initial Disadvantages.

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

Figure 7 Cause-Effect Chains Analysis Model



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 8 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.

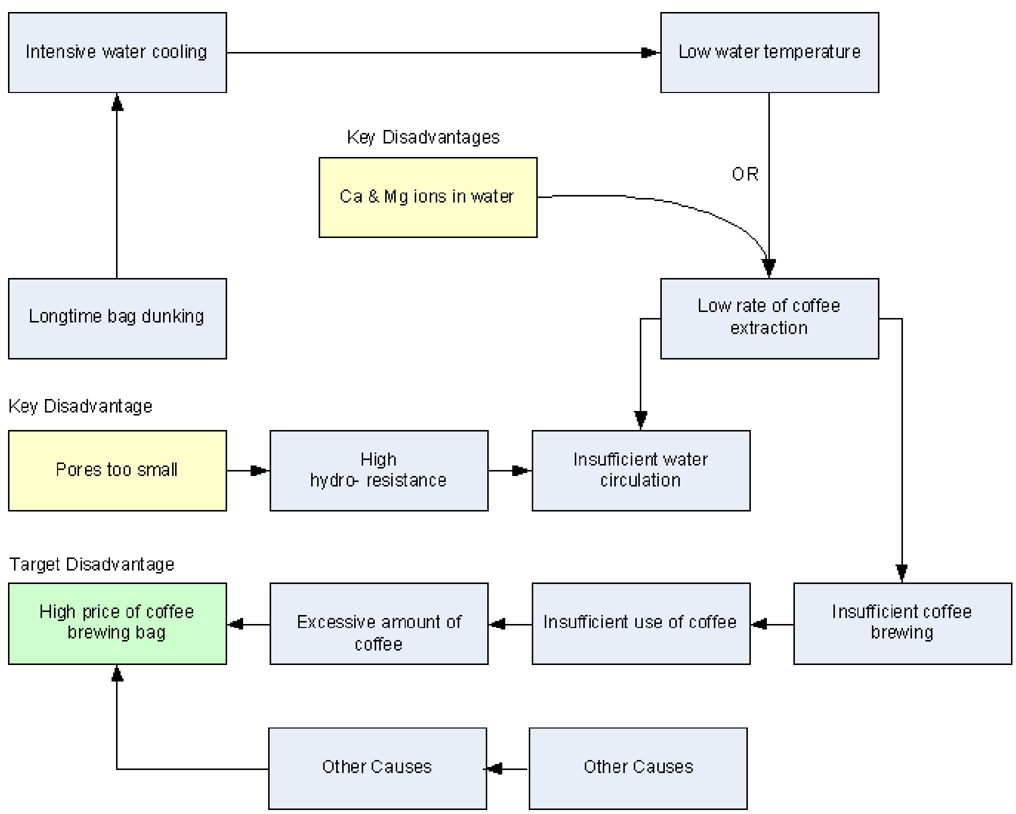
To construct the coffee bag Cause-Effect Chains Analysis model:

1. Write the Target (Initial) 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.

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

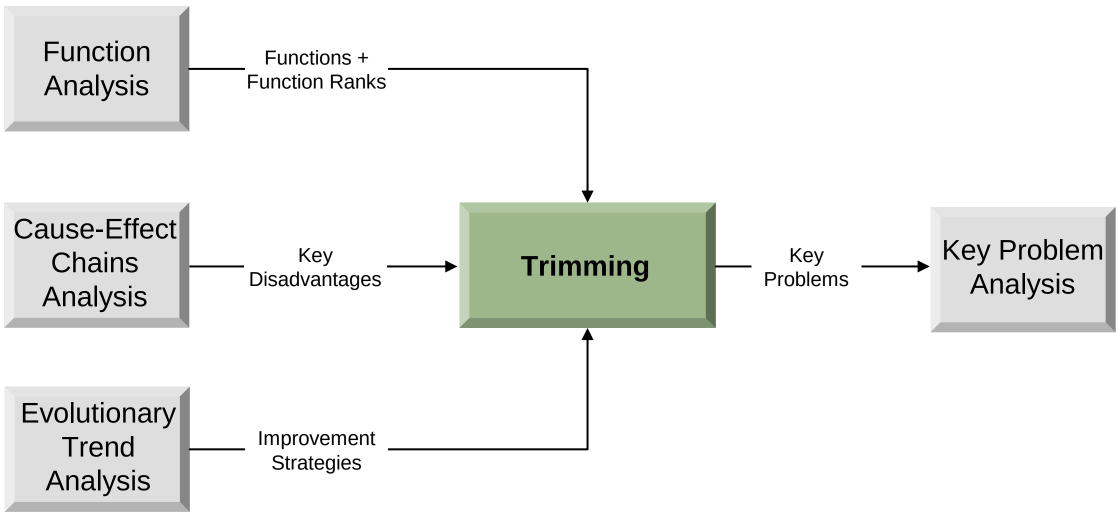
Figure 9 Cause-Effect Chains Analysis Model of Coffee Bag



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 TRIZ Problem Identification phase. Often, identified Key Disadvantages are outside of the expertise of professionals working on the System. If this is the case, TRIZ Problem Solving tools are used to find the solution in a different area or discipline. These tools will be described in subsequent chapters of this manual.

TRIMMING FOR DEVICES



Key Terms

Trimming Model

Trimming Problem

Trimming Rule

Function Redistribution

Similar Action

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 TRIZ methodology that handles removing (trimming) certain components and redistributing their Useful Functions among the remaining components of the Engineering System or its Supersystem. In other words, trimming ensures that the functionality of the System is preserved by "teaching" other components of the System or its Supersystem 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 can to be trimmed and how. The decisions about what can be trimmed are made based on the output of other 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 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

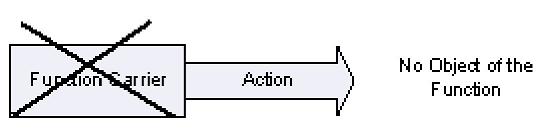
The following figure shows the typical situation where a Function Carrier performs a useful function on an object.

Figure 10 Performing of Function by a Function Carrier

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

Rule A: Object of the Function does not exist (the most radical trimming)

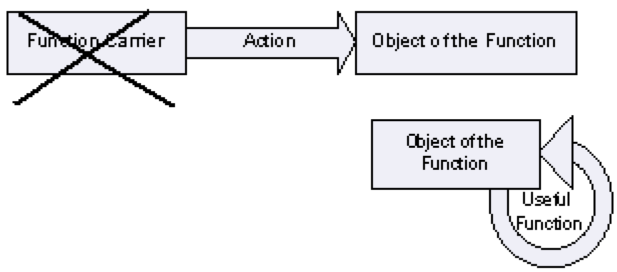
Figure 11 Rule A of Trimming



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 also can be trimmed.

Rule B: Object of the Function performs the function itself

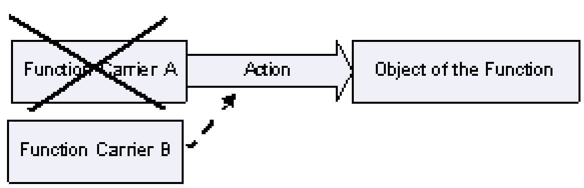
Figure 12 Rule B of Trimming



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 can be made to move by itself, the pump has no use and, therefore, can be trimmed.

Rule C: Another Component of the Engineering System or Supersystem performs the useful function of the Function Carrier

Figure 13 Rule C of Trimming



If another component of the Engineering System or the Supersystem 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, if air can be made to move the lever, the float can be trimmed.

Selecting Components for Function Redistribution

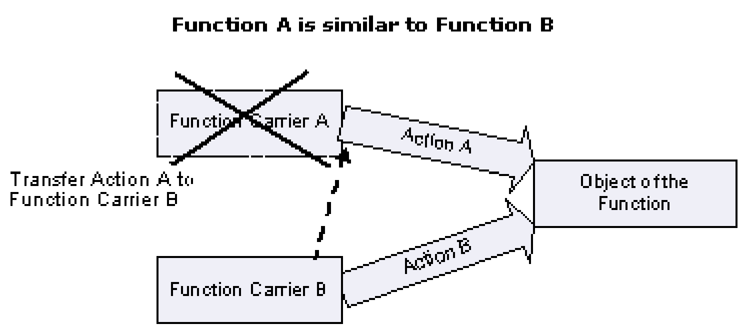
The useful functions of the trimmed components can be redistributed to the remaining components of the Engineering System or the Supersystem. You can select a component as a Function Carrier if it satisfies at least one of the following four conditions.

Condition 1

A component already performs a similar action on the Object of the Function. As shown in the following figure, Action A is similar to Action B and both are directed towards the same Object of the Function.

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

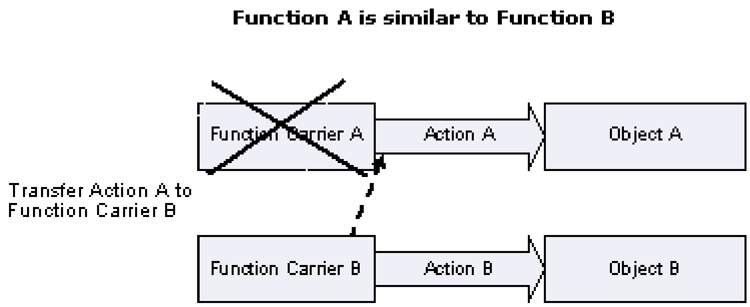
Figure 14 Condition 1 for Selecting Components



Condition 2

A component already performs a similar action on another object. As shown in the following figure, Action A is similar to Action B though both actions are directed on different objects.

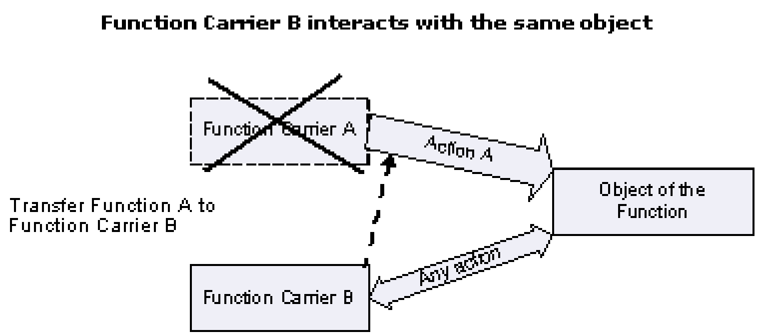
Figure 15 Condition 2 for Selecting Components



Condition 3

A component performs any other Function on the Object of the Function. As shown in the following figure, Function Carrier A simply interacts with the Object of the Function, but does not perform any function on it. However, Function Carrier B can be made to perform Action A.

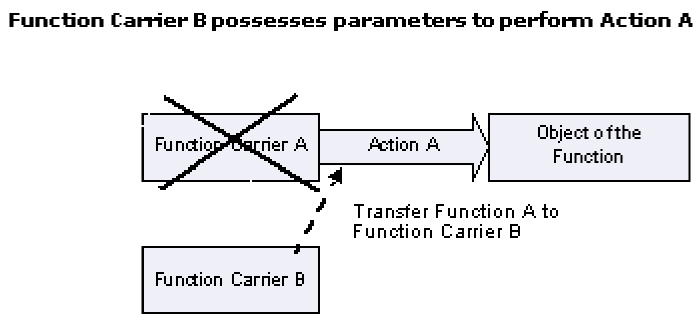
Figure 16 Condition 3 for Selecting Components



Condition 4

A component possesses a set of resources necessary to perform the analyzed Action A as shown in the following figure.

Figure 17 Condition 4 for Selecting Components



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.

Table 8 Trimming Model

Components	Functions	Rank	Trimming Rules	New Carrier	Trimming Problems
Component 1	Function X	Basic	Trimming Rule C	Component 3	How to make Component 2 perform Function X?
	Function Y	Basic	Trimming Rule B	Component 4	How to make Component 3 perform Function Y by itself?
Component 2	Function Z	Basic	Trimming Rule C	Component 5	How to make Component 5 perform Function Z?

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'.

Table 9 Trimming Model for Paint Filling System

Components	Functions	Rank	Trimming Rules	New Carrier	Trimming Problems
Float	Moves lever	A4	Trimming Rule A		
Lever	Controls switch	A3	Trimming Rule C	Air	How to make air control the switch
Lever	Holds Float	A5	Trimming Rule A		

Note: As shown above, sometimes there may be no Trimming Problems associated with a component.

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 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 TRIZ Patent Strategies, and, in particular, in Competitive Patent Circumvention.

ENGINEERING (TECHNICAL, SYSTEM) CONTRADICTIONS AND USING THE CONTRADICTION MATRIX TO RESOLVE THEM.

40 INVENTIVE PRINCIPLES.

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's 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.

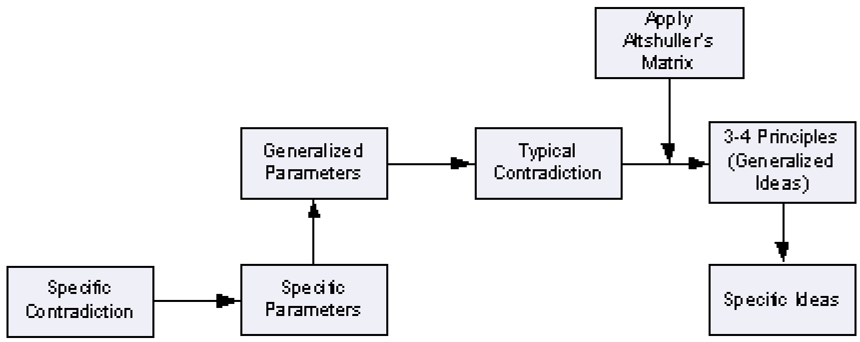
Altshuller's Matrix is a problem-solving tool that recommends Inventive Principles for resolving Engineering Contradictions. Inventive Principles are a set of 40 generalized recommendations for modifying a System to resolve an Engineering Contradiction formulated using a set of 39 generalized parameters. 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 G3:ID methodology. These Key Problems have to be re-formulated 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: (1) there are only 39 generalized parameters that can be used to formulate any Engineering Contradiction, and (2) there are only 40 typical ways, called Inventive Principles, that 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 24 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 an airplane wing can be formulated as shown in the following table.

Table 12 Formulating the Engineering Contradiction for Airplane Wing

	Engineering Contradiction for the Airplane Wing	Alternate Engineering Contradiction for the Airplane Wing
IF	one adds more steel to the airplane wing	one reduces the quantity of steel in the wing
THEN	the wing becomes more rigid	the wing becomes lighter
BUT	the weight of the wing increases	but its rigidity 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 airplane wing problem, the improving parameter is strength of the wing and the worsening parameter is weight of the wing.

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.

Table 13 Altshuller's Matrix

		Weight of a moving object	Weight of a stationary object	Length of a moving object	Length of a stationary object	Area of a moving object
		1	2	3	4	5
1	Weight of a moving object	+	–	15,8 29,34	–	29, 17 38, 34
2	Weight of a stationary object	–	+	–	10, 1 29, 35	–
3	Length of a moving object	8, 15 29, 34	–	+	–	15, 17 4
4	Length of a stationary object	35, 28 40, 29	–	–	+	17, 7 10, 40
5	Area of a moving object	2, 17 29, 4	–	14, 15 18, 4	–	+

Until 39 (columns)

Until 39 (rows)

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 judgement 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 suitable for resolving the Engineering Contradiction.

Table 14 Algorithm for Resolving the Engineering Contradiction

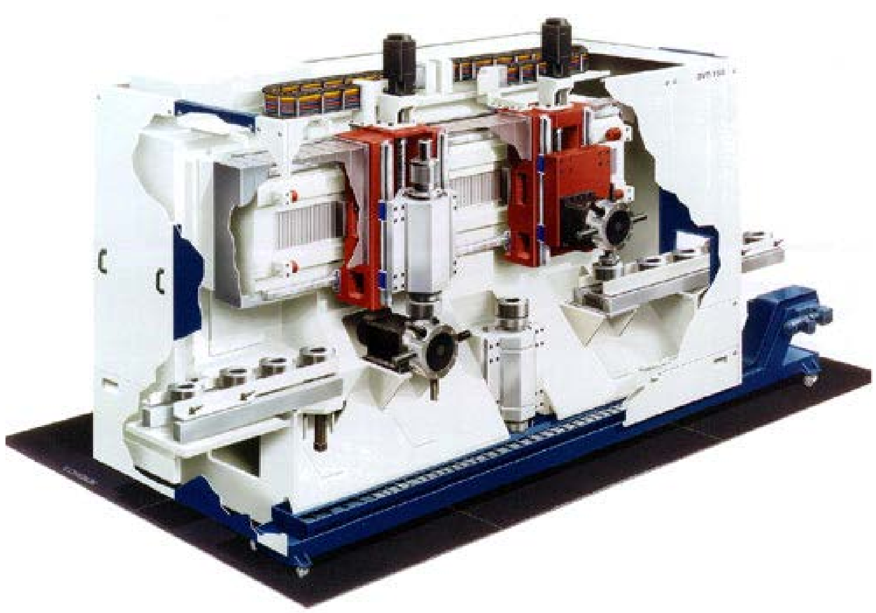
Problem	Engineering Contradiction	EC selection	Typical EC	Inventive Principles	Solutions
/describe/	EC1: If...then...but EC2: If...then...but	EC=ECx	Improving Typical Parameter; Worsening Typical Parameter/	Principle X Principle Y	describe/

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 is how to increase the process stability by constantly (and instantly) removing the shavings of scrap material that otherwise can jam the cutter and damage a work part.

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 25 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 terms of Engineering Contradictions as shown in the following table.

Table 15 Engineering Contradiction of Turning Machine

Engineering Contradiction		
EC1	If	one were to use special robot for image recognition,
	then	the facing would be removed and the process would be stable,
	but	the applied equipment would be extremely complex (and expensive)

3. Identify the parameters in the Engineering Contradiction.

   The problem is to provide stability of the process. Therefore, the process stability is one parameter in the Engineering Contradiction.

   The process stability can be provided by the special robot that is very complex. Therefore, the robot complexity is another parameter.

4. 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. Also, the complexity of the auxiliary robot gets worsened and, hence, it is the worsening parameter. The following table shows the improving and worsening parameters.

Table 16 Improving and Worsening Parameters of Turning Machine

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

5. Identify the Typical Parameters.

   a. Search the Contradiction Matrix, and identify the parameter in the rows that is closest in meaning to the improving parameter that you identified.

      'Process stability' is closest to the Typical Parameter 'Reliability'. Similarly, 'Robot complexity' is closest to the Typical Parameter 'Complexity of Device'.

b. Enter these parameters in the respective columns (Specific Parameter and Typical Parameter) as shown in the following table.

Table 17 Specific and Typical Parameters of Turning Machine

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

6. Identify the Inventive Principles.

To identify the Inventive Principles to resolve the Engineering Contradiction:

a. Identify the improving parameter 'Reliability' in the rows of Altshuller's Matrix. Similarly, identify the worsening parameter 'Complexity of Device' in the columns of Altshuller's Matrix.

The improving parameter 'Reliability' is in the 27th row and the worsening parameter 'Complexity of Device' is in the 36th column.

b. Identify the cell at the intersection of the row 27 and column 36 as shown in the following matrix. The cell shows the numbers 13, 35, and 1. Each number in the cell is a number of an Inventive Principle in Altshuller's list of 40 Inventive Principles.

Table 18 Inventive Principles for Turning Machine

		Adaptability	Complexity of device	Complexity of control	Level of automation
		35	36	37	38
25	Waste of time	35, 28	6, 29	18, 28, 32, 10	24, 28, 35, 30
26	Amount of substance	15, 3, 29	3, 13, 27, 10	3, 27, 29, 18	8, 35
27	Reliability	13, 35, 8, 24	13, 35, 1	7, 40, 28	11, 13, 27
28	Accuracy of measurement	13, 35, 22	27, 35, 10, 34	26, 24, 32, 28	28, 2, 10, 34
29	Accuracy of manufacturing	–	26, 2, 18	–	26, 28, 18, 23

1. Identify the Inventive Principles from the list of Altshuller's Inventive Principles as shown in the following table.

19 Altshuller's Inventive Principles

Inventive Principle Number	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.

Identify Specific Solutions.

7. Identify specific solutions by using the Inventive Principles identified in the previous step. The following table shows the Inventive Principles and the identified specific solutions to resolve the Engineering Contradiction.

Table 20 Specific Solutions for Turning Machine

Inventive Principle: Other way around	Specific Solution
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'	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 to apply 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 can 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 opposite requirements are placed upon a single parameter of an Engineering System. 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.

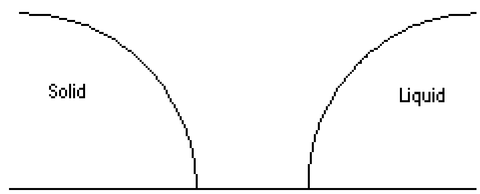
If a problem is formulated as a Physical Contradiction, Inventive Principles can be used to solve the problem (though not in the form of Altshuller's Matrix, which requires specification of two parameters). This chapter describes in detail how problems can be modeled as Physical Contradictions and how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

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

One 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.

Figure 26 Separating Contradictory Demands



For example, the blade of a knife has to be sharp to cut, 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

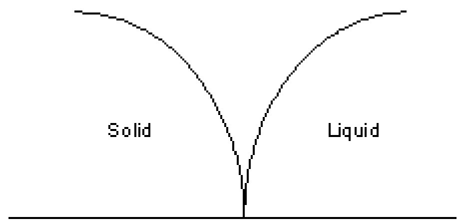
C. Separation in Relation (Affiliation)

D. Separation in System Level (Hierarchy)

2. Satisfying Contradictory Demands

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

Figure 27 Satisfying Contradictory Demands

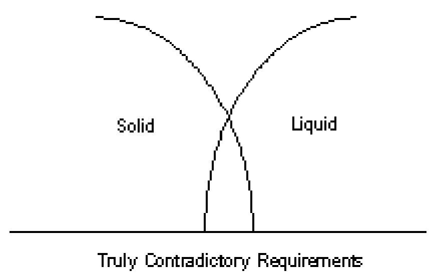


For example, consider a Physical Contradiction where the requirement is that water should be solid and water should be liquid. The contradictory demands can be satisfied by freezing the water and making it ice. Now it is both solid and liquid.

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.

Figure 28 Bypassing Contradictory Demands

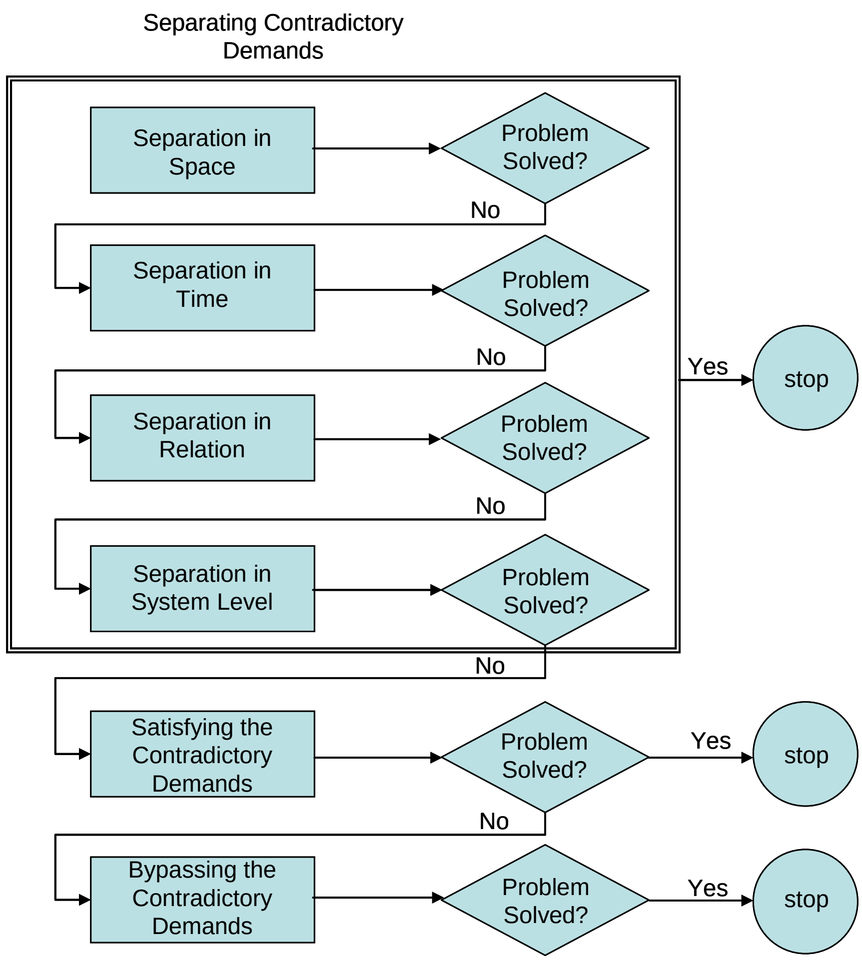


For example, consider a Physical Contradiction where a boat should be thin to move fast in water, but the boat should be broad to increase balance and seating capacity. In this problem, instead of trying to resolve the contradictory demands by solving problems of water resistance and boat design, you 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.

Order of Applying the Directions

The three methods of solving engineering problems that have Physical Contradictions are applied in the order shown in the following figure. Attempt a subsequent method only if the previous method cannot be applied to solve the problem.

Figure 29 Order of Applying the Directions



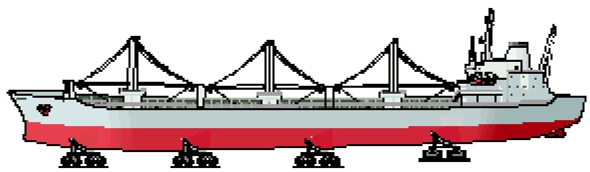
Separation in Space

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

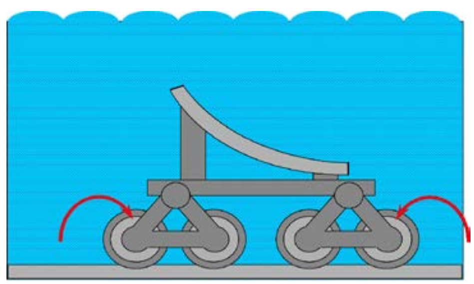
To move a newly built ship in shallow sea water, special carts are used as shown in the following figure.

Figure 30 Example: Ship and Cart.



The carts move well while outside the water but when they enter the water, the water enters the bearings and, eventually, the bearings have to be cleaned. This process requires disassembling the carts which is complex and expensive. Therefore, the engineering problem is to move the carts carrying the ship as easily inside the sea water as they move outside the water.

Figure 31 Cart in Water



The Physical Contradiction can be stated as:

> The cart must be above water to prevent the wheels from clogging
>
> BUT
>
> The cart must be under water to transport the ship

Inventive Principles for Separation in Space

TRIZ recommends 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.

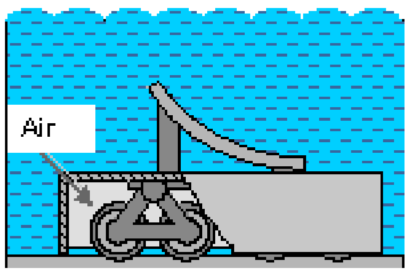
C. Make each part of an object fulfill a different and useful function.

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 the cart to function is when the wheels 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 32 Applying Inventive Principle `Local Quality'



Separation in Time

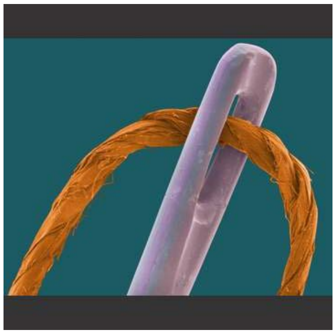
Separate the contradictory demands using the Separation in Time method if the contradictory demands are required at different times.

Example: Eye of a Needle

A sewing needle contains a hole through which to put the thread as shown in the following figure. The hole, however, has a Physical Contradiction, which can be stated as follows:

> The hole should be big for directing the thread easily into it
>
> BUT
>
> The hole should be small to avoid damage to the clothes

Figure 33 Example: Eye of the Needle



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 `hole should be large' is required before you start sewing, while the contradictory demand `hole 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

TRIZ recommends the following Inventive Principles for resolving Physical Contradictions using the Separation in Time method:

- Dynamics
- Discarding and recovering
- Preliminary action
- Preliminary anti-action
- In-advance "cushioning"

Identifying the Inventive Principle

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

Inventive Principle `Dynamics':

A. Allow (or design) the characteristics of an object, external environment, or process to change to be optimal or to find an optimal operating condition.

B. Divide an object into parts capable of movement relative to each other.

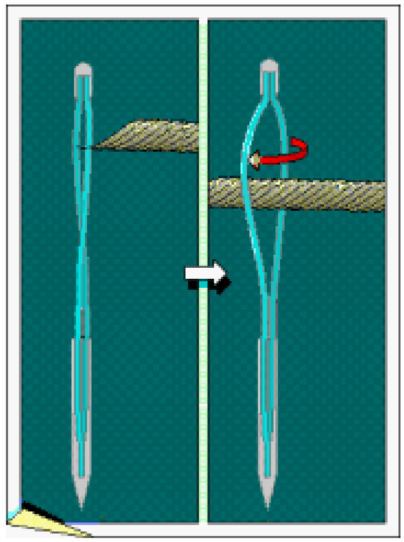
C. If an object (or process) is rigid or inflexible, make it movable or adaptive.

Applying the Inventive Principle

To apply the Inventive Principle `Dynamics', 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 also 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 34 Example of Separation in Time



Separation in Relation

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

Example: Window

A requirement that air should enter a room but that sun rays should not enter the same room has a Physical Contradiction. The Physical Contradiction can be stated as follows:

> The window should be open to allow air to come in
>
> BUT
>
> The window should be closed to prevent the sun rays from coming in

Identifying the Separation Method

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

Separation in Time cannot be applied because `allowing in air' and `not allowing sunlight' must happen at the same time.

Separation in Relation can be applied because the demand `window should be open' is required for air and the contradictory demand `window should be closed' is required for sunlight. Sunlight and air are two different systems.

Inventive Principles for Separation in Relation

TRIZ recommends 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
- Another dimension

Identifying the Inventive Principle

After analyzing the different Inventive Principles recommended for resolving Physical Contradictions using the Separation in Relation method, the Inventive Principle `Dimentionality' is identified as the most appropriate.

Inventive Principle `Dimentionality':

A. Move an object in two- or three-dimensional space.

B. Use a multi-story arrangement of objects instead of a single-story arrangement.

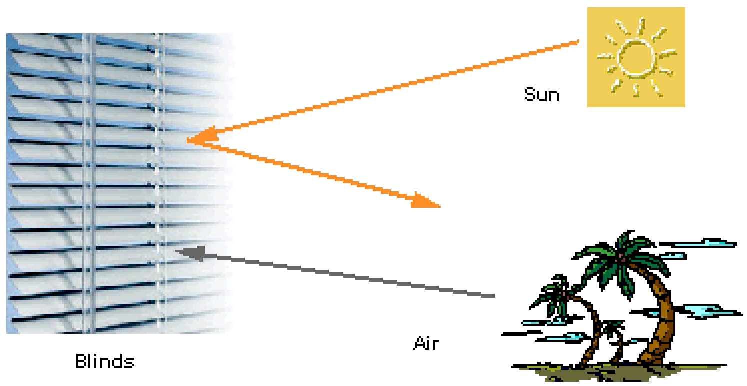
C. Tilt or re-orient the object, lay it on its side.

D. Use 'another side' of a given area.

Applying the Inventive Principle

By taking the ideas from the Inventive Principle `Dimentionality', window blinds are identified. Blinds do not allow sunlight to enter the room and at the same time allow air to enter the room as shown in the following figure.

Figure 35 Example: Window Blinds



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 Supersystem level.

Example: Cast Iron Rope

The engineering problem is to produce a rope made of cast iron. The rope must be flexible enough to be folded and stored in a small place. The Physical Contradiction can be stated as follows:

> The rope must be flexible to be folded during storage
>
> BUT
>
> The rope must be rigid because it is made of cast-iron

Identifying the Separation Method

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

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 rope.

Separation in System Level can be applied because the contradictory demands `rope must be flexible' is needed at the system level while the contradictory demand `rope must be rigid' can be delegated to the Subsystem level.

Inventive Principles for Separation in System Level

TRIZ recommends 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 as shown in the following figure.

Figure 36 Example: Cast Iron Chain

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.

Satisfying Contradictory Demands

If the Physical Contradiction cannot be resolved using separation, it may be possible to satisfy both demands simultaneously.

Example: Teredo Worm Research

Teredo worms live inside wood; therefore, to conduct any research on their natural behavior, they must be observed while they are inside the wood (i.e., their natural habitat). However, because the wood is opaque, it is not possible to observe the Teredo worms in their natural habitat. The Physical Contradiction can be stated as follows:

> The research sample must be opaque to keep Teredo worms alive
>
> BUT
>
> The research sample must be transparent to observe the Teredo worms

Inventive Principles for Satisfying Contradictory Demands

Altshuller recommended the following Inventive Principles for resolving the engineering problem by satisfying the 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 `Parameter Change' is identified as the most appropriate.

Inventive Principle `Parameter Change':

A. Change an object's physical state.

B. Change the concentration or consistency.

C. Change the degree of flexibility.

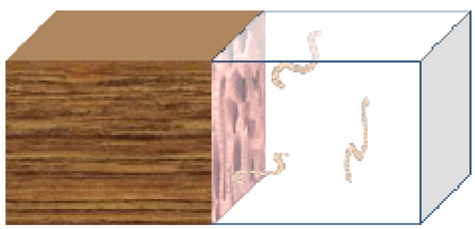
D. Change the temperature.

Applying the Inventive Principle

On analyzing the problem, it is found that Teredo worms live in wood because they need cellulose, one of the components of the wood. By applying the idea of the Inventive Principle `Parameter Change', identify another substance that contains cellulose but is also transparent. The substance identified is cellophane.

By using cellophane, the contradictory demands are satisfied. Cellophane provides the same function as wood because it contains cellulose. Since cellophane is transparent, it also satisfies the demand of transparency.

Figure 37 Example: Teredo Worm Research



Bypassing Contradictory Demands

If the Physical Contradiction cannot be resolved using separation or by satisfying both the demands, it may be possible to bypass the contradictory demands.

Example: Coffee Bags

Coffee bags containing coffee particles need to be dipped in hot water to prepare instant coffee. As shown in the following figure, the engineering problem is that the pores in the bags are too small for the water to quickly get inside the bag and mix with the coffee particles in order to make the coffee quickly. However, the pores cannot be made larger because the coffee particles in the bag will flow out. Also, if you use bigger coffee particles, the surface area decreases, and more coffee is needed per bag.

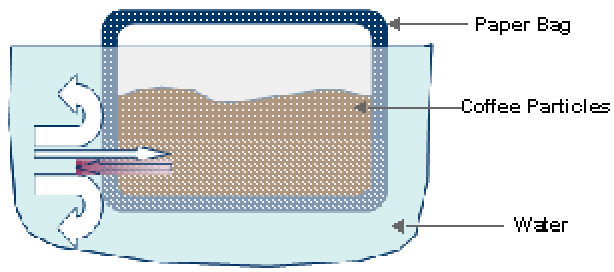
The Physical Contradiction can be stated as follows:

Paper pores must be large to provide water circulation

BUT

Paper pores must be small to hold small coffee particles

Figure 38 Example of Bypassing Contradictory Demands



Inventive Principles for Bypassing Contradictory Demands

Altshuller recommended the following Inventive Principles for resolving the engineering problem by bypassing the contradictory demands:

- Self-service
- Multi-functionality
- `The Other Way Around'

Identifying the Inventive Principle

After analyzing the different Inventive Principles recommended for resolving Physical Contradictions by bypassing contradictory demands, the Inventive Principle `The Other Way Around' is identified as the most appropriate.

Inventive Principle 'The Other Way Around':

A. Invert the action(s) used to solve the problem.

B. Make movable parts (or the external environment) fixed, and fixed parts movable.

C. Rotate the part instead of the tool.

D. Turn the object (or process) 'upside down'.

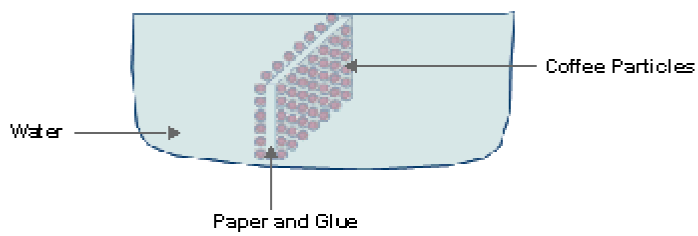
Applying the Inventive Principle

Instead of trying to resolve the contradictory demands, try to bypass them by applying the Inventive Principle most suitable for bypassing the contradictory demands.

The Inventive Principle `The Other Way Around' states `Turn the object upside down'. Taking this idea, make the bag `inside out'. The coffee particles now come outside the bag and the paper goes in. Stick the coffee particles to the paper using glue as shown in the following figure.

By doing this, the issue of `size of the pores' is no longer relevant. The engineering problem is also solved because very small coffee particles can be used and, therefore, the quantity of coffee used per bag is decreased. Also, the water comes in contact with the coffee particles instantly and, hence, instant coffee gets prepared.

Figure 39 Applying Inventive Principle `Bypassing Contradictory Demands'



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.

INTRODUCTIONS TO THE SYSTEM OF STANDARD INVENTIVE SOLUTIONS

Key Terms

Standard Inventive Solution

Substance-Field Model (Su-Field Model)

Substance

Field

Standard Problem Model

Introduction

As mentioned in previous chapters of this manual, modeling a given Engineering Problem in several different ways provides a comprehensive view of what it is we are trying to solve. For example, we introduced Engineering and Physical Contradictions as ways to understand - and resolve - an Engineering Problem. This chapter will introduce yet another powerful way to resolve engineering problems by modeling them as Substance-Field Models, and then using Standard Inventive Solutions to create a model of the solution. Just as with Engineering and Physical Contradictions, Altshuller's Matrix, and Inventive Principles, this chapter belongs to the tools of classical TRIZ originated by Genrich Altshuller and his disciples.

In order to understand Standard Inventive Solutions, we must introduce several new definitions. A "Substance", in TRIZ, is any object with rest mass. In other words, a cat can be considered a Substance, under certain circumstances, as much as, say, a chemical can. Field, in TRIZ, is an entity without rest mass that transmits an interaction between Substances. This includes what is typically understood by "field" (e.g., magnetic and electric), as well as other types of interactions (e.g., thermal and acoustic).

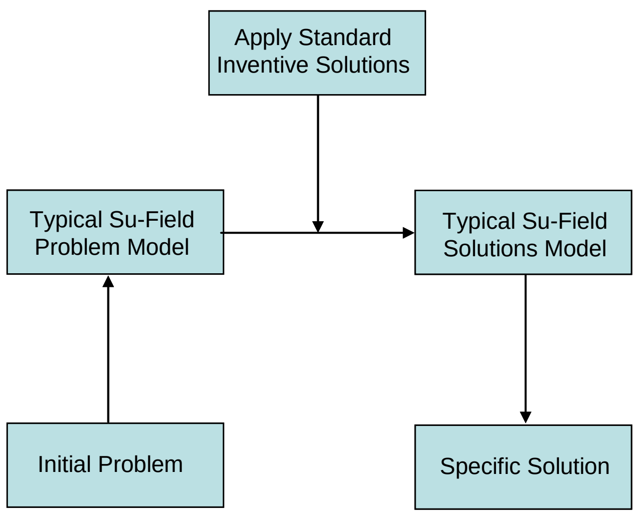
The analysis of millions of patents showed that almost all engineering problems can be modeled by a limited number of generalized Substance-Field structures (Su-Field Models) categorized by Altshuller into several specific types. Altshuller further identified Standard Inventive Solutions, also in the form of Su-Field Models, that are effective in solving most engineering problems. Thus, Standard Inventive Solutions are a set of 76 generalized models of solutions to engineering problems. The distinctive characteristic of this application is that both the engineering problems and the solutions are formulated as Substance-Field interactions (i.e., interactions between Substances and Fields).

As with other TRIZ applications, both the Su-Field Model of the problem and the Su-Field Model of the solution are highly abstract and, therefore, require skills of generalization (for the problem) and interpretation (for the solution) from the user.

Standard Inventive Solutions follows the general pattern of problem solving that is represented in the following diagram.

1. Start with "Specific Engineering Problem or Initial Problem".
2. Climb up to "Typical Substance-Field Problem Model".
3. Move right to "Typical Solution Model" by applying Standard Inventive Solutions.
4. Move down to "Specific Solution to Initial Problem".

Figure 40 Problem Solving by Standard Inventive Solutions



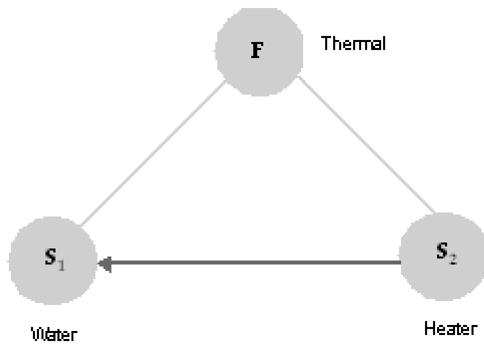
Substance-Field Model (Su-Field Model)

An effective Engineering System must have at least two Substances and one Field to perform a useful function. The Field establishes interaction between the Substances. For example, if you want to heat water using a heater, the two Substances are heater and water, and the Field is thermal energy.

The interaction among the Substances and Fields of an Engineering System can be shown in a graphical manner using the Su-Field Model. In the Su-Field Model, the

Substances and Fields are shown as circles and the interactions are shown as arrows. For example, in the following Su-Field Model, Heater boils water (a useful interaction):

Figure 41 Example of Su-Field Model



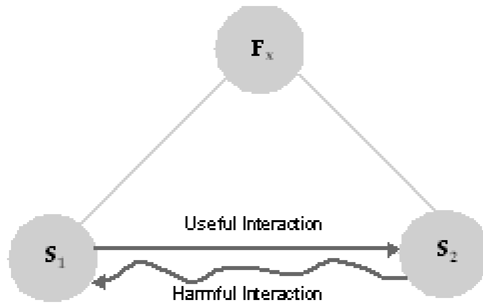
The relationship between the elements in the Su-Field Model are depicted by three different connecting lines, as shown in the following table:

Table 21 Connecting Lines

Useful Interaction	
Insufficient Useful Interaction	
Harmful Interaction	

The following figure shows a Su-Field Model with both harmful and useful interactions.

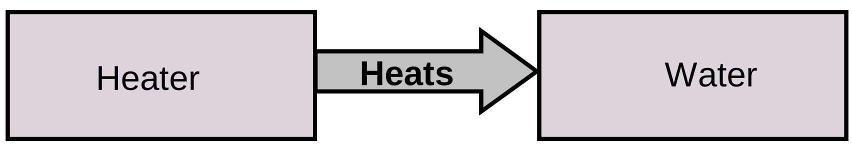
42 Su-Field Model with Harmful and Useful Interactions



Function Model vs. Substance-Field Model

The Function Model of the example `Heater heats water' is shown in the following figure:

Figure 43 Example of Function Model



This is a model of the function being performed. Performance of the function is measured as adequate, insufficient, or excessive. Function Analysis deals with the entity "component" that is a material object and can be both a Substance or a Field.

The Su-Field model is a model of the problem related to the Engineering System, but not of the Engineering System itself. Also, the Substances and Fields are clearly differentiated.

Goal of Standard Inventive Solutions

The main goal of Standard Inventive Solutions is to provide a model of the problem solution in terms of Substance and Field structure for solving engineering problems.

Classifying Standard Inventive Solutions

Altshuller divided the 76 Standard Inventive Solutions into five main classes and various sub-classes according to the type of typical engineering problems they solve. The complete list of Standard Inventive Solutions will be discussed in the Advanced Course. A summary of the classification of Standard Inventive Solutions is as follows:

Class 1 Building and Destruction of Substance-Field Models

This class of Standard Inventive Solutions solves problems by constructing or destroying the Su-Field Model, if it is incomplete or has harmful functions. This class contains 2 sub-classes and 13 Standard Inventive Solutions.

Class 2 Development of Substance-Field Models

This class of Standard Inventive Solutions is used for improving the efficiency of the Engineering System by introducing minor modifications. This class contains 4 sub-classes and 23 Standard Inventive Solutions.

Class 3 Transition to Supersystem and Microlevel

This class of Standard Inventive Solutions is used for solving problems by developing solutions on the level of the Supersystem or Subsystem. This class contains 2 sub-classes and 6 Standard Inventive Solutions.

Class 4 Standards for Detection and Measuring

This class of Standard Inventive Solutions is used for solving `measuring or detection' problems of the Engineering System. This class contains 5 sub-classes and 17 Standard Inventive Solutions.

Class 5 Standards on Application of Standards

This class of Standard Inventive Solutions gives recommendations as to how to introduce new Substances or Fields or scientific effects more effectively in applying the Standard Inventive Solutions in the four previous classes. This class contains 5 sub-classes and 17 Standard Inventive Solutions.

Algorithm for Applying Standard Inventive Solutions

To identify and apply the Standard Inventive Solutions:

1. In the first column, describe the Key Problem to be solved.

2. In the second column, list all the Substances and Fields involved in the interactions related to the problem.

3. In the third column, create a Su-Field Model of the engineering problem using the components from second column.

4. In the fourth column, write the Standard Inventive Solution applicable for solving the problem.
5. In the fifth column, create the Su-Field Model of the possible solution by applying the recommendation of the Standard Inventive Solution identified in step 4.
6. In the sixth column, describe the solution for implementing the Su-Field Model created in step 5.
7. Evaluate the solution in step 6 and, if it is not found to be effective, repeat from step 5.

Table 22 Algorithm for Applying the Standard Inventive Solutions

Key Problem	Interacting Components	Model	Standard Inventive Solution	New Su-Field Model	Solution
Describe	Substance 1 Substance 2 Field 1	F_1 / \\ S_1 ~~ S_2	Introduction of a new substance	F_1 / \\ S_1 -|- S_2 S_3	Describe
F- Field S - Substance					

Example: Mousetrap

The mousetrap is an Engineering System whose main function is to trap a mouse, as shown in the following figure:

Figure 44 Example: Mousetrap

Mouse

Mouse Trap

This system has the following disadvantages:

- It is potentially harmful to children and pets.
- It is traumatic for the mouse (a lot customers do not like to kill the mouse, just trap it).

The key cause of both of these disadvantages is the component `spring' and, hence, it is desirable to trim or remove it from the Engineering System.

Creating a Su-Field Model of the Problem

The Su-Field Model of the problem, after removal of the spring, is shown in the following figure:

Figure 45 Su-Field Model for the Mousetrap Problem

The Su-Field Model is incomplete because there is no interaction between the mousetrap and the mouse. The mouse can come near the mousetrap and even eat the morsel of food from it, but the mousetrap cannot perform any action because the mechanical field supplied by the spring is no longer available.

Identifying the Standard Inventive Solution

Since the objective is to complete the interaction between the components, look for a Standard Inventive Solution in Class 1 `Creation and Destruction of Substance-Field Models'.

The following Standard Inventive Solution is identified:

Standard Inventive Solution `Complete the Su-Field Model'

If an Su-Field Model is incomplete

THEN

Complete the Su-Field Model by adding, if needed, the Substance or Field

AND

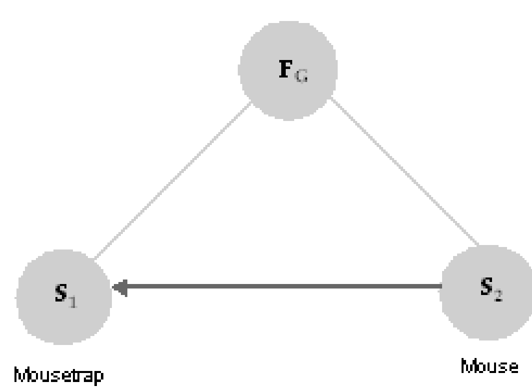
Organize the interaction among the Substances and Fields

Note: The detailed discussion on the 76 Standard Inventive Solutions will be provided in the Advance Course. Only after such a discussion will it be possible to identify the appropriate Standard Inventive Solution for a problem. For the purpose of this course, an appropriate Standard Inventive Solution has been selected to demonstrate its usage.

Creating a Su-Field Model of the Solution

Since the Field is missing from the Su-Field Model, introduce a Field. Gravitational Field is introduced because it is already available. Now that two Substances and a Field are available in the Su-Field Model, create a new Model by organizing the interaction between the Substances and the Field as shown in the following figure:

Figure 46 Su-Field Model for the Mousetrap Solution

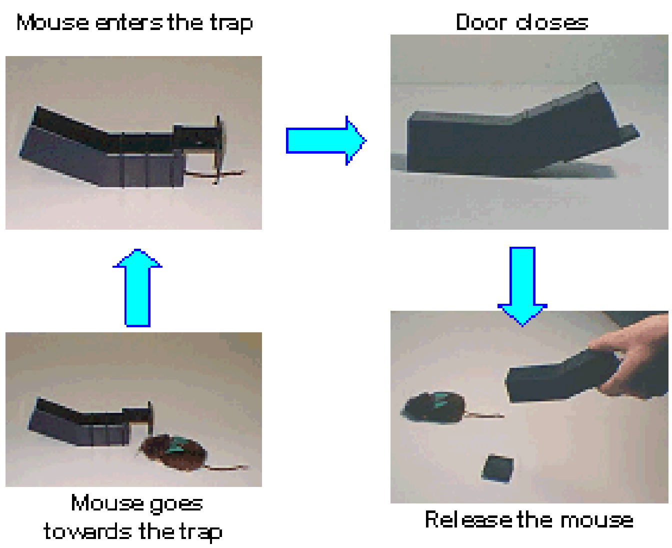


Implementing the Su-Field Model of the Solution

The improved mousetrap system is shown in the following figure. This system has two doors: one is closed and the other is kept open. Food is kept inside the mousetrap to attract the mouse.

As the mouse enters the trap and travels inside. The weight of the mouse tilts the trap and the door closes due to gravity. The mouse gets trapped. It can be released later by opening the door on the other end of the trap.

Figure 47 Implementing the Su-Field Model for the Mousetrap Solution



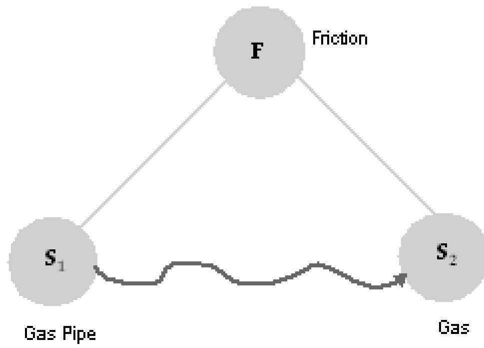
Example: Ultra-Clean Gas Delivery System

The ultra-clean gas delivery system transmits compressed gas through a delivery pipe. The system must transmit the gas without contaminating it. However, as the compressed gas moves through the delivery pipe, it extracts some particles from the surface of the pipe and gets contaminated. The engineering problem is to avoid the contamination of the gas.

Creating a Su-Field Model of the Problem

Create the Su-Field Model of the problem as shown in the following figure:

Figure 48 Su-Field Model for Ultra-Clean Gas Delivery System Problem



Identifying the Standard Inventive Solution

Since the objective is to destroy the harmful interaction between the gas and the gas pipe, look for a Standard Inventive Solution in Class 1, Sub-class 2 `Destruction of Substance-Field Models'.

No new substance can be added between the gas and the gas pipe because the particles from the new Substance may contaminate the gas.

The following Standard Inventive Solution is identified:

Standard Inventive Solution `Introduce modified substances'

If there is harmful interaction between components in the Substance-Field

AND

No new Substance can be introduced between them to destroy the interaction

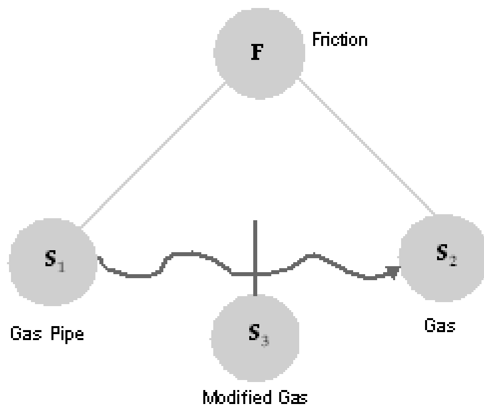
THEN

Introduce a modified version of the existing component between the two components to destroy their harmful interaction

Creating a Su-Field Model of the Solution

Create a Su-Field Model of the solution based on the recommendation of the identified Standard Inventive Solution, as shown in the following figure:

Figure 49 Su-Field Model for Ultra-Clean Gas Delivery System Solution

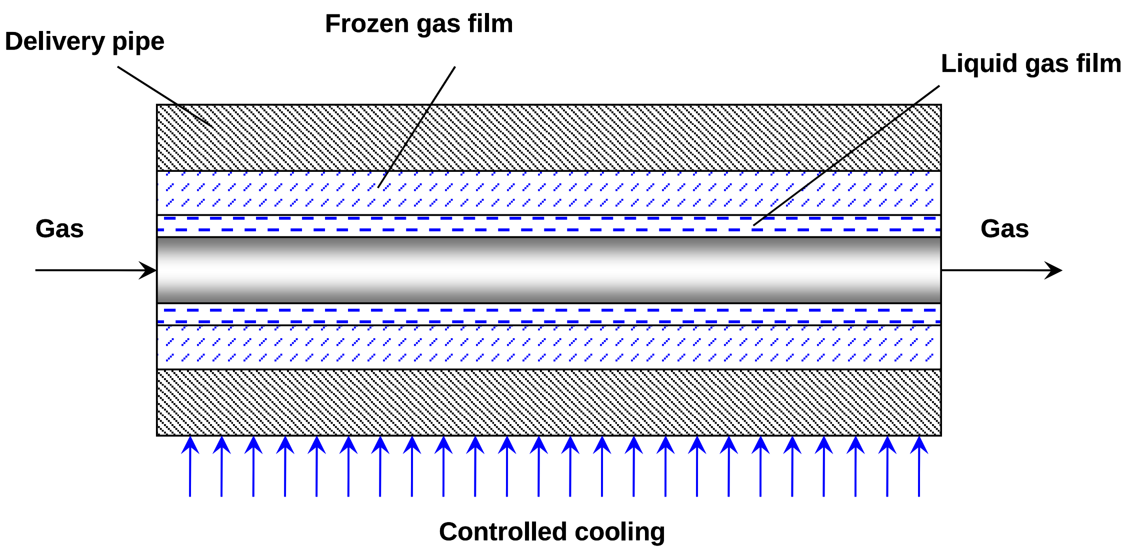


Implementing the Su-Field Model of the Solution

The identified Standard Inventive Solution recommends the introduction of a modified form of the existing component between the two interacting components. Liquid gas is identified as the modified component because if the gas rubs against the liquid gas instead of the delivery pipe, it will extract only the particles of the liquid gas. Since the particles of the liquid gas are the same as those of the gas, the gas will not be contaminated.

As shown in the following figure, the Su-Field Model of the solution is implemented by controlled cooling of the delivery pipe. This leads to freezing of the gas that comes in contact with the pipe, while the gas that is further inside the pipe remains in the liquid form. This liquid form of the gas comes in contact with the compressed gas and, hence, there is no contamination of the gas.

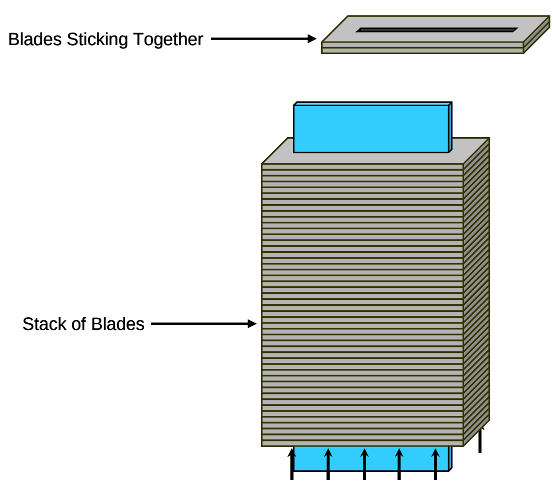
Figure 50 Implementing the Su-Field Model for Ultra-Clean Gas Delivery System Solution



Example: Razor Blade Stack

This Engineering System holds a stack of razor blades and delivers one blade at a time. These blades have a thin film of oil on them to avoid corrosion, but this makes the blades stick to each other. The problem is that sometimes more than one blade pops up instead of just one, as shown in the following figure:

Figure 51 Example: Razor Blade Stack

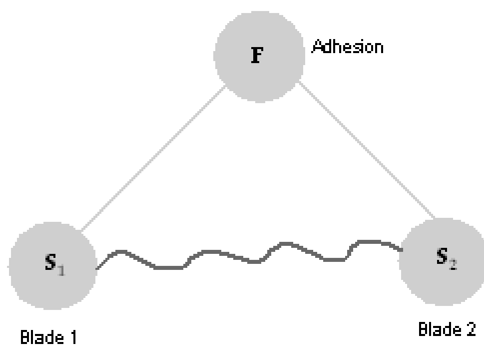


There is harmful interaction between the blades. You cannot add a new component or a modified component in the System because the blades come pre-stacked in the Engineering System.

Creating a Su-Field Model of the Problem

Create the Su-Field Model of the problem as shown in the following figure:

Figure 52 Su-Field Model for Razor Blade Stack Problem



Identifying the Standard Inventive Solution

Since the objective is to destroy the harmful interaction between the two blades, look for a Standard Inventive Solution in Class 1, Sub-class 2 `Destruction of Substance-Field Models'.

No new or modified substance can be added between the blades because the blades come pre-stacked into the system.

The following Standard Inventive Solution is identified:

Standard Inventive Solution `Introduce a new field'

If there is harmful interaction between components in the Substance-Field

AND

No new or modified Substance can be introduced between them to destroy the interaction

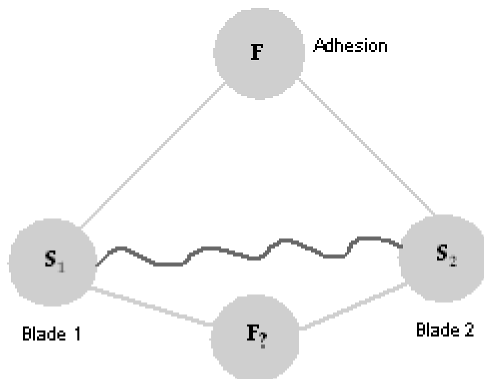
THEN

Introduce a new Field between the two components to destroy their harmful interaction

Creating a Su-Field Model of the Solution

Create a Su-Field Model of the solution based on the recommendation of the identified Standard Inventive Solution, as shown in the following figure:

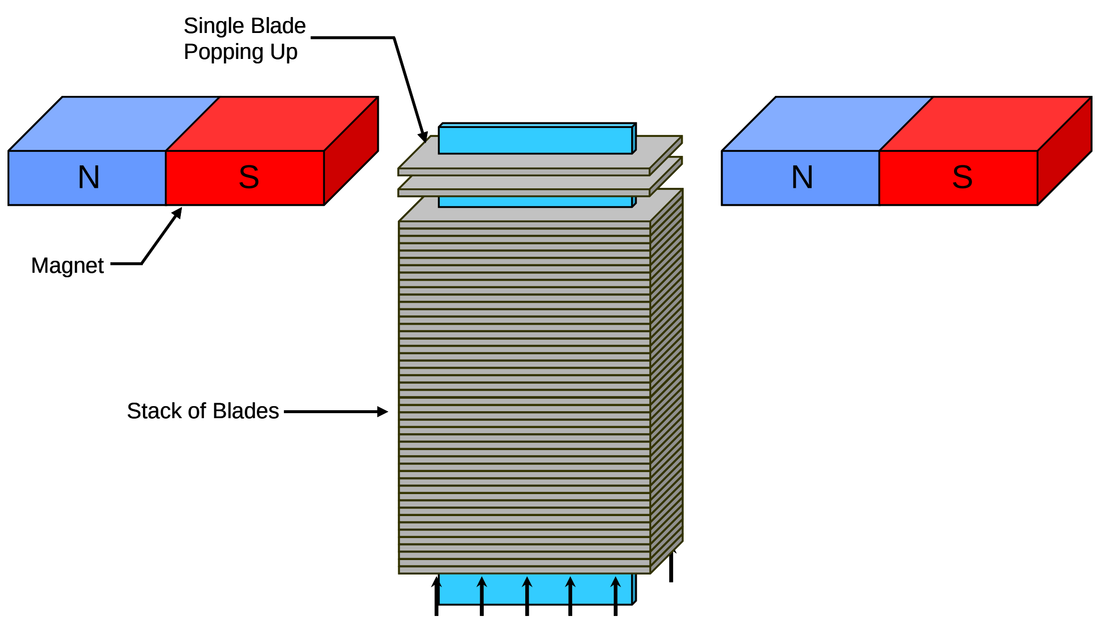
Figure 53 Su-Field Model for Razor Blade Stack Solution



Implementing the New Su-Field Model

Since the blades are metallic, a magnetic field is introduced in the Su-Field Model as shown in the following figure. The magnetic field magnetizes the sticking blades with the same polarity. Since same poles repel each other, the blades passing through the magnetic field repel each other and get separated from each other. This ensures that only one blade pops out.

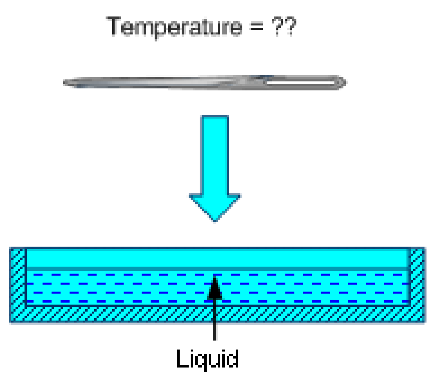
54 Implementing Su-Field Model for Razor Blade Stack Solution



Example: Needle Temperature

A needle is hardened by heating it to a high temperature and then immediately cooling it. The hardness of the needle depends on the precision of measuring the temperature and on cooling it exactly after a certain temperature is attained. The problem is to measure the temperature of the needle precisely because it has very low mass and the surface area is large, as shown in the following figure:

Figure 55 Example: Needle Temperature



Identifying the Standard Inventive Solution

Since the objective is to measure the temperature of the needle, look for a Standard Inventive Solution in Main 4 `Standards for Detection and Measuring'.

Measurement of the needle temperature is required to switch the process step from heating to cooling. Hence, it is not essential to know the temperature of the needle provided the process step is switched at the right temperature.

The following Standard Inventive Solution is identified:

Standard Inventive Solution `Try not to measure or detect'

If there is a task requiring detection of measurement

THEN

Change the task so that it is not necessary to measure or detect

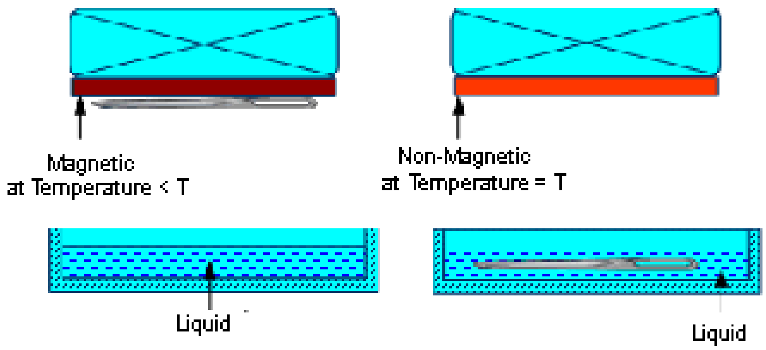
Implementing the Standard Inventive Solution

Organize the system as shown in the following figure. Identify a magnetic component that loses its magnetic property at the same temperature as required to heat the needle. Keep a container of cold liquid below the magnetic material.

The metallic needle attaches to the surface of the magnetic component. Now heat the magnetic material. On reaching the required temperature, the magnetic component loses its magnetic properties and the needle drops into the cold liquid and gets cooled.

In the whole process, there is no need to measure the temperature of any component, yet the needle gets hardened.

Figure 56 Implementing Standard Inventive Solution for Needle Temperature



Example: Snake Length

The requirement is to measure the length of a live poisonous snake. This situation poses problems of measurement because the snake is difficult to catch and dangerous to hold.

Figure 57 Example: Snake Length

Identifying the Standard Inventive Solution

Since the objective is to measure the length of the snake, look for a Standard Inventive Solution in Class 4 `Standards for Detection and Measuring'. Since measurement of the snake is the main task, it cannot be avoided by changing the task.

The following Standard Inventive Solution is identified:

Standard Inventive Solution `Work with a copy or picture'

If there is a problem in measuring or detecting a parameter of an object

THEN

Measure the same parameter in the object's copy or picture

PROVIDED

The copy or picture contains the same parameter to be measured

Implementing the Standard Inventive Solution

Take a photograph of the snake and a ruler using a camera and measure the length of the snake in the picture. Observe the length of the snake compared to the ruler and estimate the length of the snake.

Example: Electric Bulb Pressure

An electric bulb contains an inert gas at low pressure and is sealed to prevent the oxidation of the bulb filament by oxygen in the air. The pressure inside the bulb is lower than the atmospheric pressure.

Due to errors in the manufacturing process, some bulbs may have micro-cracks. These cracks are difficult to detect but allow gases like oxygen from the atmosphere to gradually enter in the bulb and oxidize the filament. The bulb stops functioning after a certain period due to oxidation of the filament.

The problem is to detect the glass bulbs that have micro-cracks. The existing solution is to select the bulbs using random sampling and apply tests that destroy the bulbs. The disadvantage of the existing solution is that it is an approximation and also that it destroys the bulb.

Identifying the Standard Inventive Solution

Since the objective is to measure the pressure inside the bulb, look for a Standard Inventive Solution in Class 4 `Standards for Detection and Measuring'.

Since the measurement task is essential, it cannot be bypassed by changing the task. Also, the micro-cracks are not available in the copy or picture of the bulb, hence it cannot be measured using a copy or picture of the bulb.

The following Standard Inventive Solution is identified:

Standard Inventive Solution `Create a measurable Substance-Field'

Create a measurable Su-Field Model by introducing new Fields

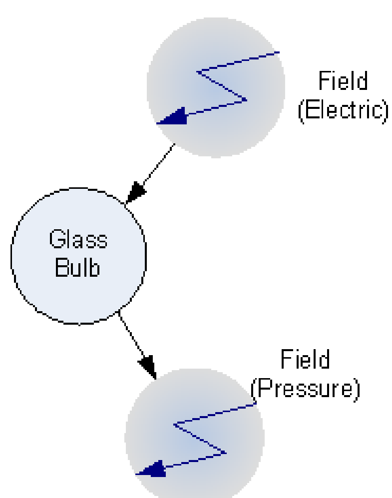
Creating a Su-Field Model of the Solution

One of the fields identified for the Su-Field Model is the pressure of the gas inside the bulb because the pressure within a bulb directly relates to the absence or presence of the micro-cracks in the bulb.

If the bulb has micro-cracks, the air from the atmosphere starts entering the bulb and the pressure inside the bulb increases. Therefore, if the pressure inside the bulb is high, the presence of micro-cracks could be assumed.

Since a bulb is an electrical system, electric field is identified as the second Field as shown in the following figure:

Figure 58 Su-Field Model for Electric Bulb Pressure Solution

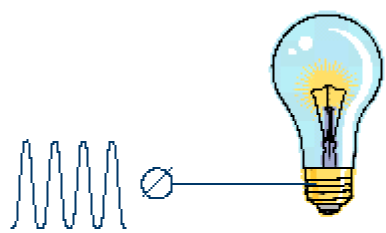


Implementing the Su-Field Model of the Solution

Identify the relation between the electric field that can be applied to the bulb and the pressure inside the bulb. The gas particles get ionized in the presence of an electric field. As shown in the following figure, if the electric field is gradually increased, the charged particles show corona discharge, which can be easily detected. It is easy to predict the time of corona discharge inside a bulb under fixed voltage and pressure values.

If the corona discharge takes place earlier than expected, the pressure of the gas inside the bulb is more than required and, hence, the bulb has micro-cracks.

Figure 59 Implementing the Su-Field Model for Electric Bulb Pressure Solution



Summary

The goal of Standard Inventive Solutions, like that of other problem solving tools, is to solve Key Problems discovered during the Problem Identification stage of the TRIZ methodology. This chapter concludes the part of the TRIZ methodology that deals with problem solving using classical TRIZ tools developed by Altshuller and his school. Additional tools, such as ARIZ and Scientific Effects, will be presented in the Advanced Course.

TRENDS OF ENGINEERING SYSTEM EVOLUTION

Key Terms

Evolutionary Stage

Trends

Value

S-Curve Evolution

Ideal Engineering System

S-Curve Evolution

Ideal Engineering System

S-Curve Analysis

Typical Indicator

Typical Recommendation

Introduction

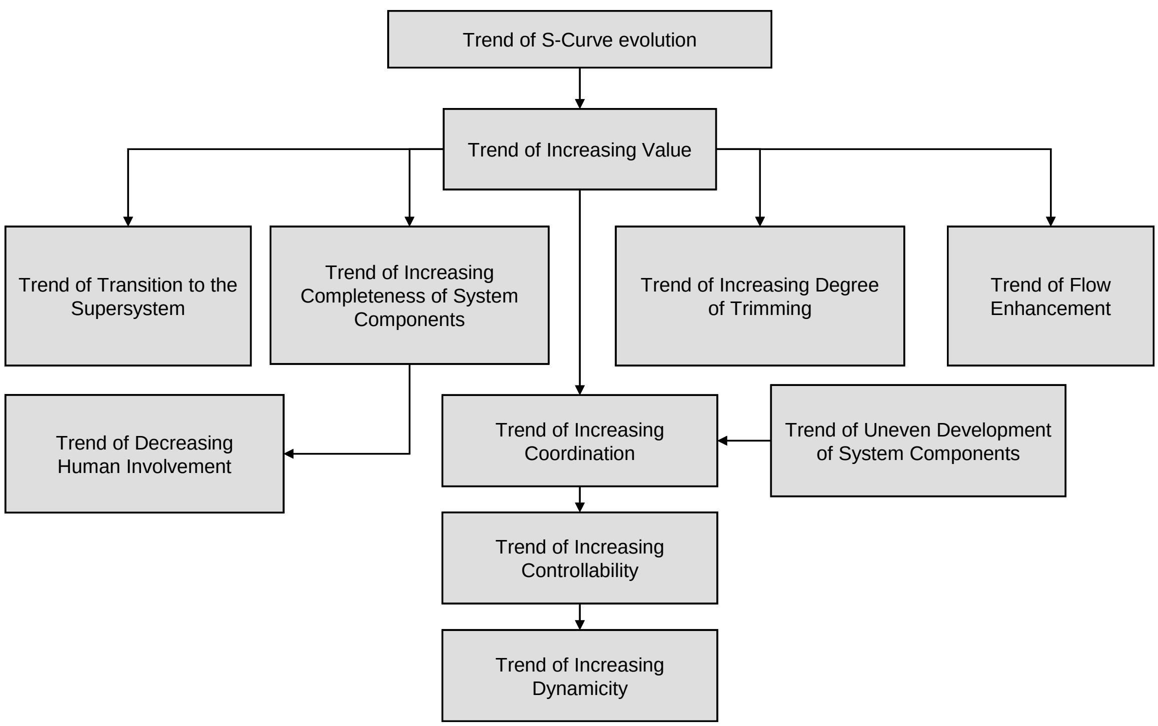
In the extensive methodology of TRIZ, Trends of Engineering System Evolution (TESE) occupy a very special place: they provide an unprecedented view in the usually obscure window of the technological future.

As Altshuller defined them, TESE are statistically proven, and thus, objective, directions of Engineering System development. They describe the natural transitions of Engineering Systems from one state to another and are statistically true for all categories of Engineering Systems. A number of TESE were identified based on historical patterns of Engineering System evolution and analysis of the world's patent collection (see Figure 60). All trends are not considered to be of equal importance and have a hierarchical taxonomy: the Trend of S-Curve Evolution occupies the very top level of the trend tree, with the Trend of Increasing Value following at the second layer of hierarchy.

TESE are the foundation of TRIZ Technology Forecasting. Unlike typical methods for technology forecasting (e.g., normative, extrapolation, etc.), TESE allow long-term forecasting of true disruptions in technology. Furthermore, TESE also has a power to predict solutions to problems that will arise from implementing these new technologies. It is important to keep in mind that, while TESE points, with very high probability, towards what should happen in the future, it does not say when it will happen. "When" depends on several non-technological factors such as market trends and consumer readiness to change behavior.

Applying TESE enables innovation to be more predictable, and thus less risky: an enormous value proposition for the typically risk-averse corporate cultures. An important advantage of TESE-based innovation is that it is also significantly more productive. The present chapter describes the trends, their internal taxonomy, and recommendations on how to use them.

Figure 60 Trends of Engineering System Evolution



The Basic Course provides an introduction to the following trends:

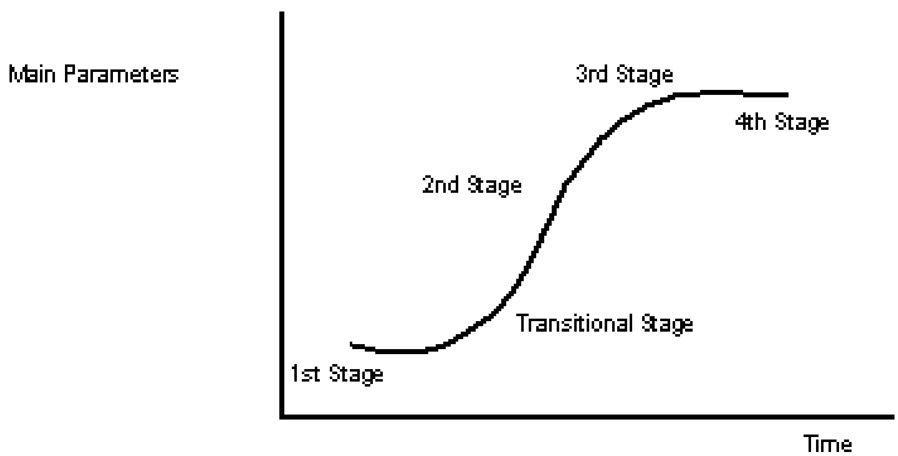
- Trend of S-Curve Evolution
- Trend of Increasing Value
- Trend of Transition to the Supersystem
- Trend of Increasing Dynamicity

Trend of S-Curve Evolution

Another important trend is the Trend of S-Curve Evolution. This trend states that Engineering Systems evolve in such a way that their main parameters follow S-shaped curves toward increasing value. Application of the S-Curve Trend enables effective forecasting for Engineering Systems.

It is common knowledge in the business world that the inception, growth, maturity, and decline of most systems follow an S-shaped curve. S-Curves are frequently used in contemporary business language to represent the evolutionary state of a product or system. The following diagram shows the S-Curve Evolution of an Engineering System. Typically the S-Curve is represented by four stages. TRIZ also identifies a fifth stage called the Transitional stage. This stage has its own characteristics and warrants a separate analysis and treatment.

Figure 61 Trend of S-Curve Evolution



G3:ID S-Curve Analysis

Unlike commonly known S-Curve usage and representation, TRIZ S-Curve Analysis can be used to forecast and make strategic decisions about where to spend innovation dollars. It provides actionable recommendations for each stage of the S-Curve. Further details are provided in the Professional Course.

Assessing the Evolutionary Stage

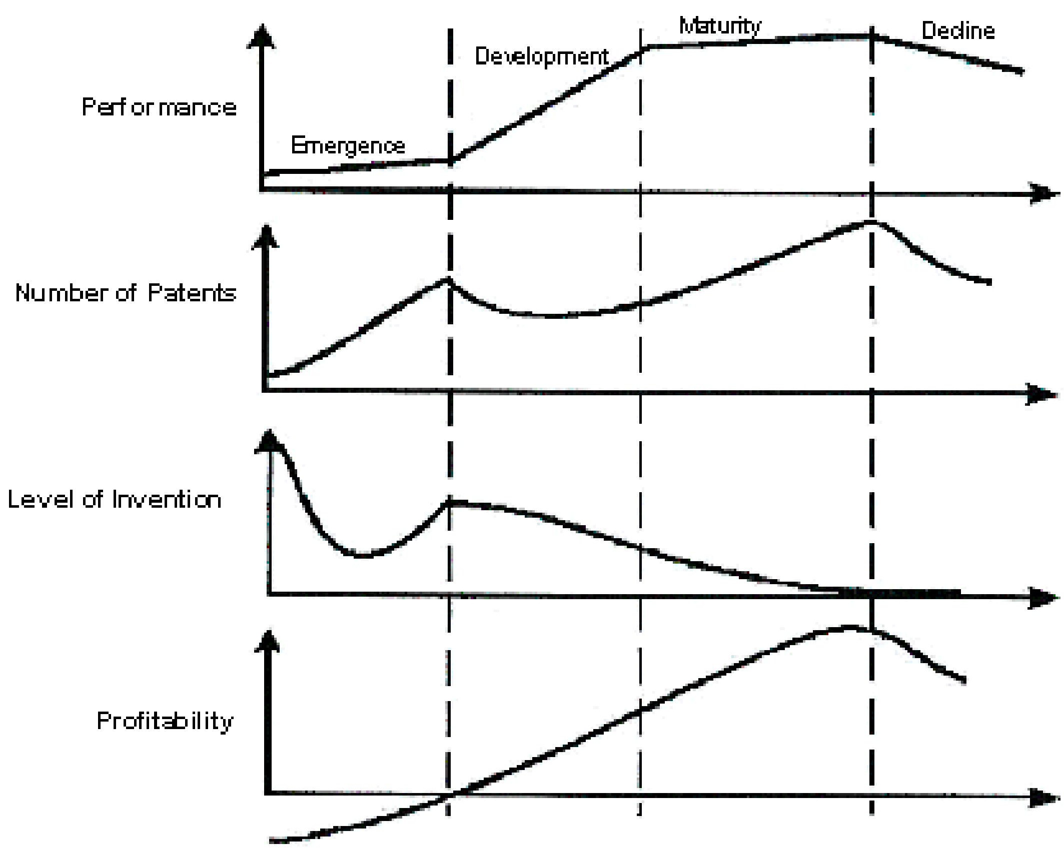
It is not easy to determine the exact evolutionary stage of an Engineering System. G3:ID provides Typical Indicators to identify the evolutionary stage of the System for each Main Parameter of Value being analyzed.

There are two major indicators that determine the stage of the S-Curve: Number of Patents and Level of Invention:

1. Number of Patents: Analyze the number of patents issued, as a function of time, for improving the performance parameter of your Engineering System
2. Level of Invention: Classify the Level of Invention of your Engineering System

The following figure shows the observed trends in parameters that effectively characterize the evolution of an Engineering System: Performance, Number of Patents, Level of Invention, and Profitability.

Figure 62 Observed Trends in Parameters



The Number of Patents issued for advancements in a particular system varies with the S-Curve stages as follows:

- When an Engineering System is in its Infancy stage, there are very few inventions associated with its development.

- When the System enters its Growth stage, the demand for technology that supports its industrial implementation increases dramatically. This leads to a greater Number of Patents being issued for the technology that directly supports the implementation process of the System.
- At the Maturity stage, engineers work toward prolonging the life of the System so that it continues to be profitable - the Number of Patents related to this System continues to increase, albeit at a slower rate.

In the automobile industry, for example, millions of dollars are invested in research and development, and thousands of cars are manufactured every month. Although it is no longer desirable to work toward increasing the speed of cars, the natural tendency is to continue revitalize a declining System. However, experience shows that even small improvements in the performance of a System can lead to significant financial gains!

In addition, the Level of Invention parameter can be used to assess the S-Curve stage of your System. Genrich Altshuller, the founder of the TRIZ methodology, outlined five innovation levels:

Level 1 - Simple Invention

This level incorporates inventions that do not resolve any engineering contradictions. A typical engineer can easily solve the problems associated with such inventions using his/her own personal knowledge and common sense.

Level 2 - Minor System Modifications

At this level, small improvements are made to the original technology, system, or method. Here, engineering contradictions do exist and the solutions usually involve compromises. A typical engineer must investigate dozens of variants within his/ her area of expertise in order to find a solution.

Level 3 - Major System Modification

Contradictions do exist at this level and, when solved, result in significant improvement of the original system or method. The improved system provides the same engineering function(s) as the old system. The engineer must investigate hundreds of variants to find a solution.

Level 4 - Modification Based on a New Principle

At this level, the optimized system or method uses a new physical principle to perform its original intended function. The engineer must investigate thousands of variants and look outside his/her discipline to find the solution. Typically, the solution at this Level of Invention must be sought in scientific knowledge, rather than in technology.

Level 5 - Discovery of New Phenomenon

This level encompasses inventions that, literally, change the world - once-in-a-lifetime discoveries. These inventions have a completely new function, which extends beyond the limits of contemporary science, and often mark the birth of a new industry.

Figure 62 shows the Level of Invention pattern at different S-Curve stages of the Engineering System. Most inventions at the Infancy stage correspond to a higher Level of Invention. However, when a Engineering System exhausts development resources and reaches its Maturity stage, a large number of patents are issued at a lower Level of Invention. These "Innovations" often involve minor, or even cosmetic, changes to an Engineering System.

In summary, you can use the Number of Patents and the Level of Invention criteria to determine the approximate S-Curve stage of your Engineering System.

Trend of Increasing Value

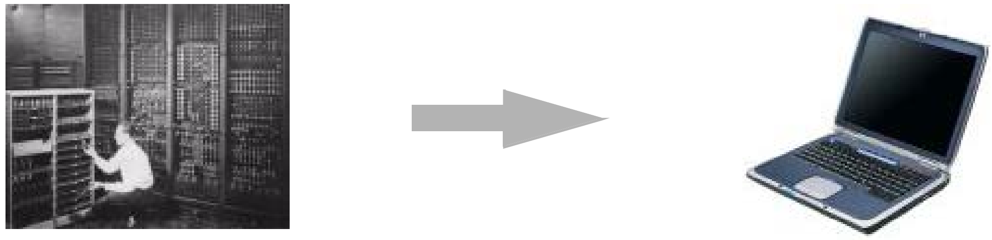
According to the Trend of Increasing Value, Engineering Systems evolve in the direction of increasing value. Value can be expressed as the ratio of the total functionality of the Engineering System and its cost. The following formula is used to express value:

$$V = \frac{\Sigma F}{\Sigma C}$$

The rationale behind this Trend is that in the world of limited resources and fierce competition, only those Engineering Systems survive that provide maximum functionality with minimum cost, and that can adapt quickly to the changing environment. In other words, the Trend of Increasing Value is necessary for the survival and growth of Engineering Systems.

Consider the evolution of a computer from the old mainframe to a modern laptop as shown in the following figure. The computer has followed the Trend of Increasing Value by increasing its functionality (processing power, mobility, ease of use) and decreasing its cost.

Figure 63 Example of Trend of Increasing Value



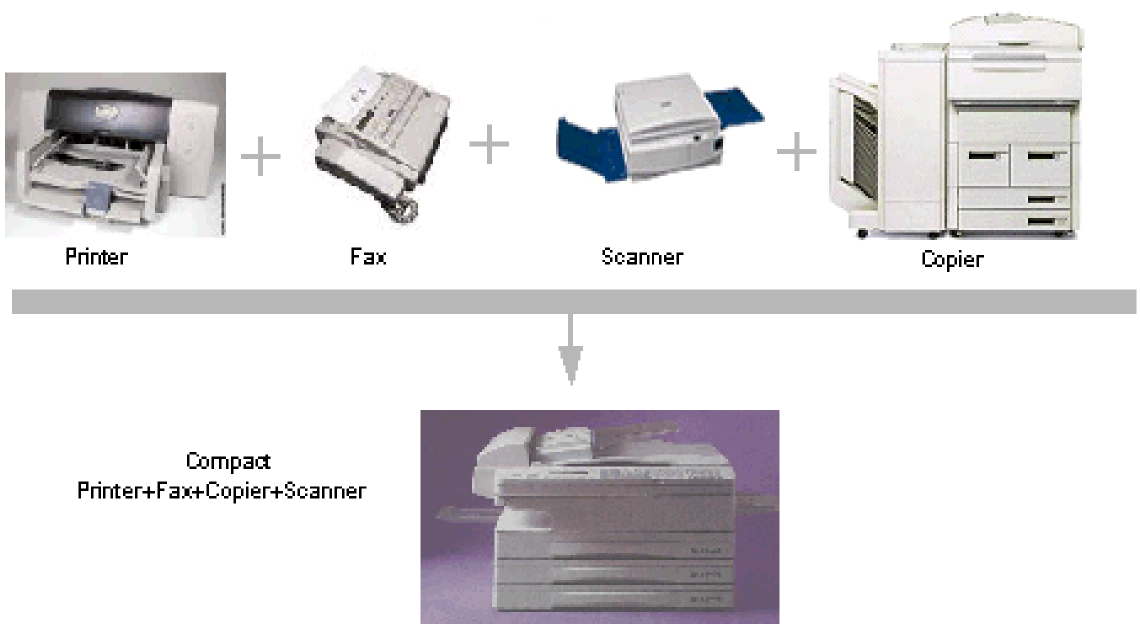
Old computer (ENIAC) Laptop

Trend of Transition to the Supersystem

According to the Trend of Transition to the Supersystem, as the inner resources of an Engineering System deplete during the process of evolution, the Engineering System integrates with other systems and continues its evolution.

For example, as shown in the following figure, the fax, printer, copier, and scanner machines evolved by integrating into one office machine having the features of all four machines.

Figure 64 Example of Trend of Transition to Supersystem



Trend of Increasing Dynamization

According to the Trend of Increasing Dynamization, as Engineering Systems evolve, they become more flexible, dynamic, and adaptable. This Trend is a mechanism of the Trend of Increasing Controllability.

For example, a simple ruler is an inflexible stick with measuring marks. It evolves into a folding ruler with multiple joints, then evolves into a measuring tape, which is very flexible, and next it evolves into the field-based laser device.

Figure 65 Example of Trend of Increasing Dynamization

Simple Ruler | Folding Ruler | Measuring Tape | Laser Device

Summary

This chapter introduced one of the most powerful tools of the TRIZ methodology: TESE. Applying TESE analysis to the Engineering System guarantees a supply of novel ideas, trimming recommendations, and conceptual directions. The art of using TESE, however, lies in deciding how to filter these ideas and recommendations: which recommendations should be considered for implementation presently and which ones need to wait for the future, which ideas make more sense from the perspective of the market and consumers. Given the power and importance of TESE, a significant portion of the Professional Course will be devoted to this tool.

AFTERWORD

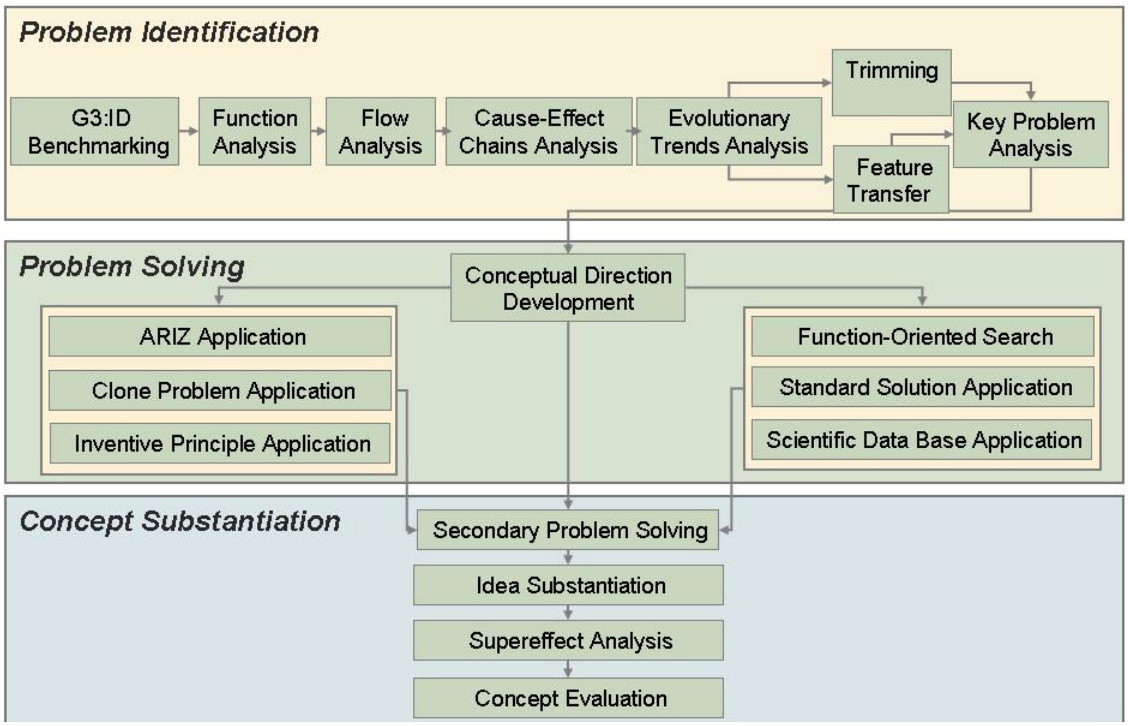
The goal of the Basic Course in TRIZ Product Innovation was to provide the detailed knowledge and hands-on experience on the fundamental tools used for Problem Identification and Problem Solving. In particular, you were introduced to Function Analysis, Cause-Effect Chains Analysis, Trimming, Inventive Principles, Standard Inventive Solutions, and Trends of Engineering System Evolution. 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, G3:ID is also well suited for improving processes. The Advanced Course in G3:ID Product Innovation focuses on how to use Problem Identification tools to improve processes. In addition, the Advanced Course also covers some problem-solving tools not covered in the Basic Course (e.g., ARIZ). Thus, after the completion of both the Basic and Advanced Courses, all problem identification and problem-solving tools of the G3:ID methodology will be covered and you will be able to apply these tools to improve both products and processes.

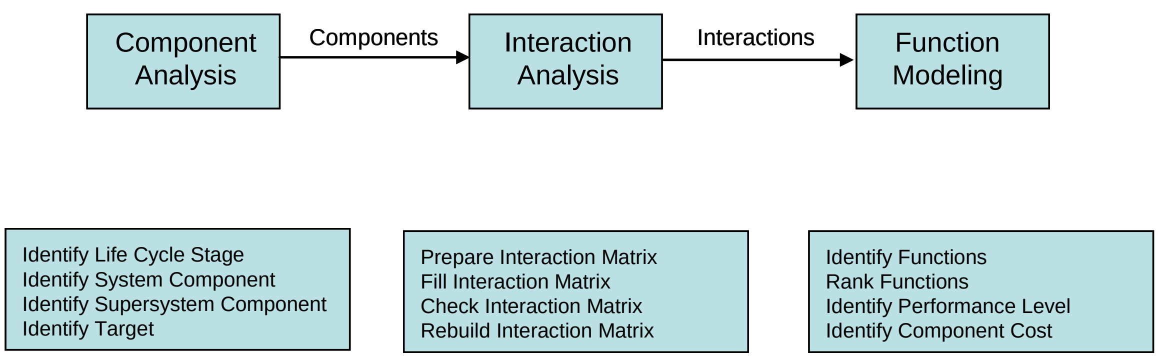
Wherever your innovation future takes you, we hope this course provided you with new and exciting approaches to solve problems, helped develop universal and effective innovation vocabulary, and, most importantly, fundamentally changed how you think about technology and innovation.

APPENDIX A – PRODUCT DEVELOPMENT TRIZ ROADMAP

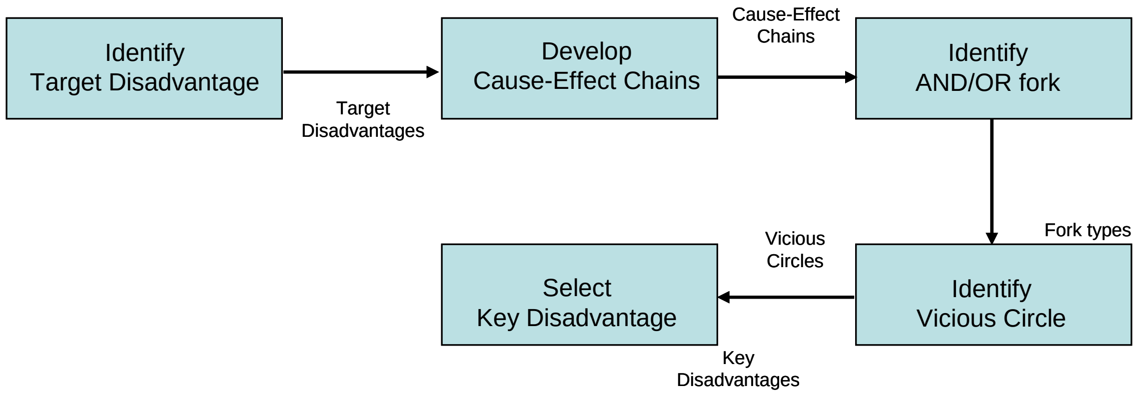
Product Innovation Roadmap



Function Analysis



Cause-Effect Chains Analysis



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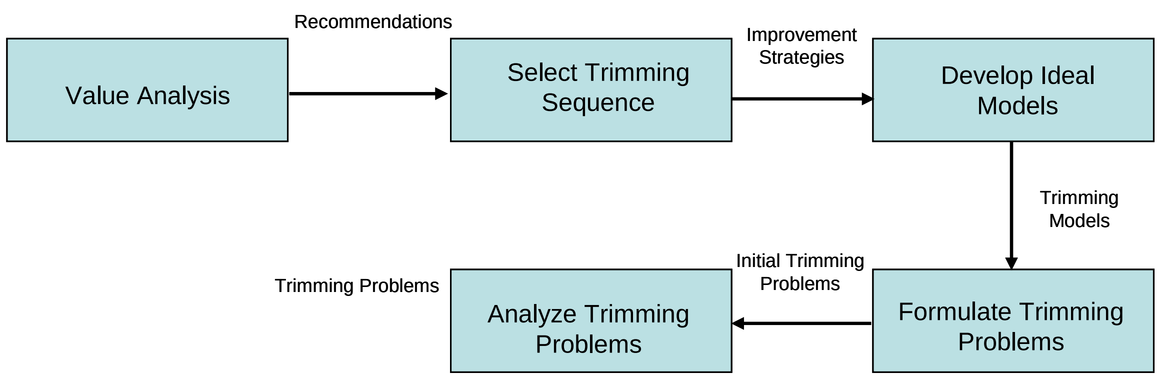
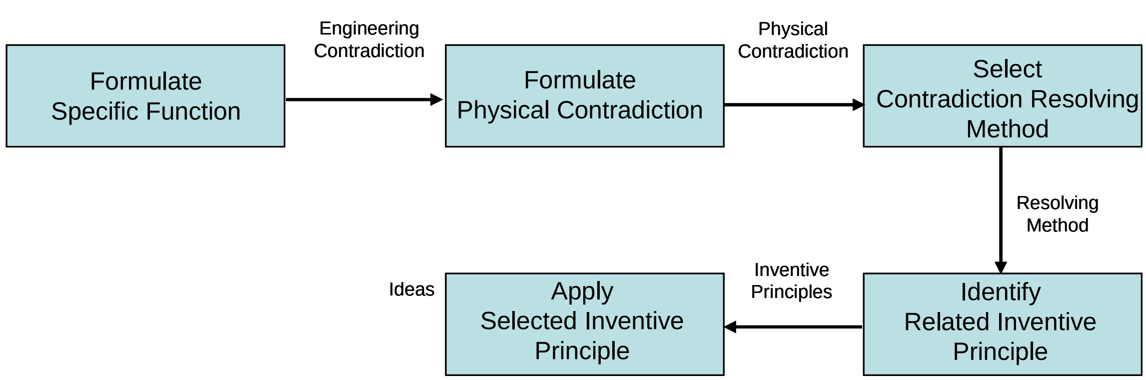
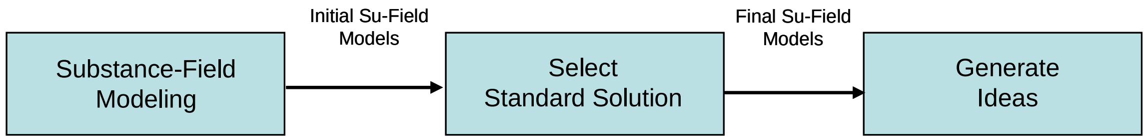


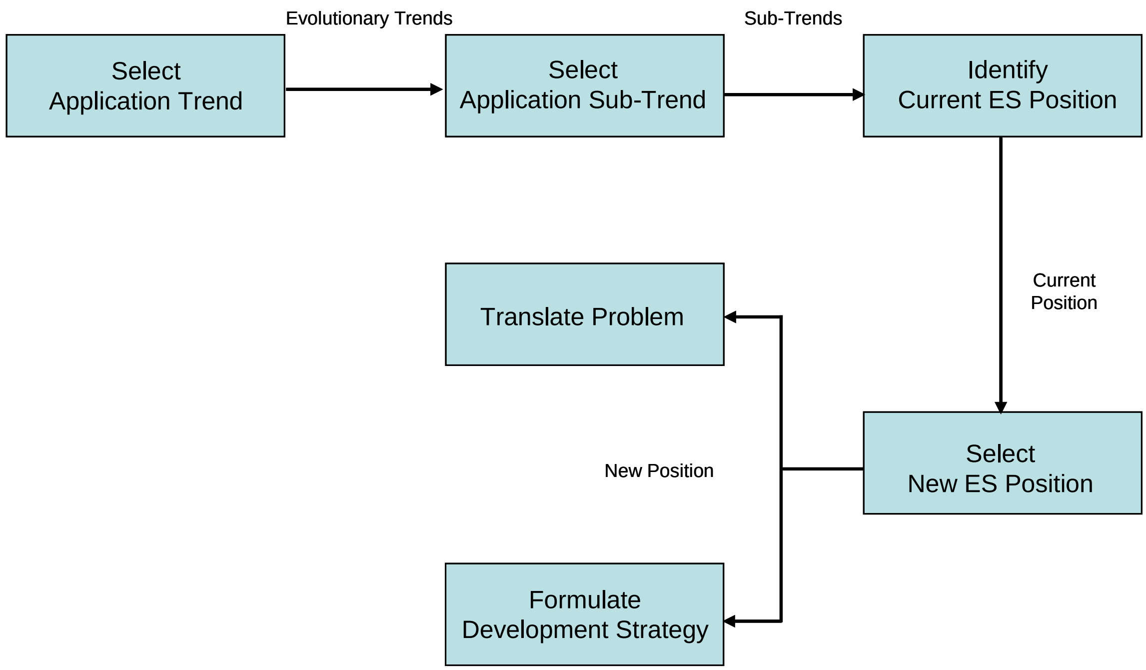
Inventive Principles Application: Engineering Contradictions and Altshuller's Matrix



Standard Inventive Solutions



Trends of Engineering System Evolution



APPENDIX B- 40 INVENTIVE PRINCIPLES WITH EXAMPLES

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.

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 wall paper

   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. In-advance 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 around

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.

   Ball point and roller point pens for smooth ink distribution

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

   Produce linear motion of the cursor on the computer screen using a mouse or a trackball.

   Replace 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 boroscope 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 6 CD's to increase music time and variety

Electronic chips on both sides of a printed circuit board

Employees "disappear" from the customers in a theme park, descend into a tunnel, and walk to their next assignment, where they return to the surface and magically "reappear."

C. Tilt or re-orient the object, lay it on its side.

Dump truck

D. Use 'another side' of a given area.

Stack microelectronic hybrid circuits to improve density.

Principle 18. Mechanical Vibration

A. Cause an object to oscillate or vibrate.

Electric carving knife with vibrating blades

B. Increase its frequency (even up to the level of ultrasound).

Distribute powder with vibration.

C. Use an object's resonant frequency.

Destroy gall stones or kidney stones using ultrasonic resonance.

D. Use piezoelectric vibrators instead of mechanical ones.

Quartz crystal oscillations drive high accuracy clocks.

E. Use combined ultrasonic and electromagnetic field oscillations.

Mixing alloys in an induction furnace

Principle 19. Periodic Action

A. Instead of continuous action, use periodic or pulsating actions.

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, cross-checking) to improve a process or action.

   Automatic volume control in audio circuits

   Signal from gyrocompass is used to control simple aircraft autopilots.

   Statistical Process Control (SPC) - Measurements are used to decide when to modify a process. (Not all feedback systems are automated!)

   Budgets - Measurements are used to decide when to modify a process.

B. If feedback is already used, change its magnitude or influence.

   Change sensitivity of an autopilot when within 5 miles of an airport.

   Change sensitivity of a thermostat when cooling vs. heating, since it uses energy less efficiently when cooling.

   Change a management measure from budget variance to customer satisfaction.

Principle 24. “Intermediary”

A. Use an intermediary carrier article or intermediary process.

   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 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 recycled.

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 silk screen processing.

Principle 33. Homogeneity

A. Make objects interacting with a given object of the same material (or material with identical properties).

   Make the container out of the same material as the contents, to reduce chemical reactions.

   Make 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.

APPENDIX C – PHYSICAL CONTRADICTION RESOLUTION

The following lists the Inventive Principles that should be used to resolve Physical Contradictions during certain situations.

Separating Contradictory Demands

The following principles should be used to separate contradictory demands:

Separation in Space:

- Principle 1 — Segmentation
- Principle 2 — Taking out
- Principle 3 — Local quality
- Principle 4 — “Nested doll”
- Principle 5 — Asymmetry
- Principle 17 — Another dimension

Separation in Time:

- Principle 9 — Preliminary anti-action
- Principle 10 — Preliminary action
- Principle 11 — In-advance “cushioning”
- Principle 15 — Dynamics
- Principle 34 — Discarding and recovering

Separation in Relation:

- Principle 3 — Local quality
- Principle 17 — Another dimension
- Principle 19 — Periodic action
- Principle 31 — Porous materials
- Principle 32 — Color changes
- Principle 40 — Composite material

Separation in the System Level

- Principle 1 — Segmentation

- Principle 5 — Merging
- Principle 12 — Equipotentiality
- Principle 33 — Homogeneity

Satisfying Contradictory Demands

The following principles should be used to satisfy contradictory demands:

- Principle 13 — The other way around
- Principle 24 — Intermediary
- Principle 28 — Mechanics substitution
- Principle 30 — Flexible shells and thin films
- Principle 35 — Parameter changes
- Principle 36 — Phase transition
- Principle 37 — Thermal expansion
- Principle 38 — Strong oxidation
- Principle 39 — Inert atmosphere

Bypassing Contradictory Demands

The following principles should be used to bypass contradictory demands:

- Principle 6 — Multi-functionality
- Principle 13 — The other way around
- Principle 25 — Self-service

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 Supersystem 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 Material Object that characterizes its interaction with other Material Objects. 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 Material Object (substance, field, or substance-field combination) that constitutes a part of the Engineering System or Supersystem.

Component Analysis: The step in Function Analysis that identifies components of the analyzed Engineering System and its Supersystem.

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 Supersystem. 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 entity without 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 Material Object (Function Carrier) to change or maintain a parameter of another Material Object (Object of the Function).

Function Analysis: An analytical tool that identifies functions, their characteristics, and the cost of System and Supersystem components.

Function Carrier: A Material Object 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 Supersystem. 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 Supersystem).

Function Redistribution: Redistribution of useful functions of a trimmed component to other components of the Analyzed Engineering System, or its Supersystem, 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

G3:ID Benchmarking: An analytical tool that identifies the best Engineering System for improvement as well as possible candidates for Feature Transfer.

G3:ID 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 G3:ID 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".

Global Knowledge Network (GKN): A global network of approximately 7,000 experts in multiple scientific disciplines around the world. GKN has a functional structure, and is tailored for Function-Oriented Search (FOS).

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 markefor 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).

Innovation: 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 Supersystem.

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 parameter. 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: A substance, a field, or combination of both.

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 Material Object, 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 opposite requirements placed upon a single physical parameter of an 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 helps perform 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 G3:ID 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.

Stagnation 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 G3:ID Innovation process that determines the feasibility of developed Ideas.

Sub-system (see Component)

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

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 Supersystem 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 for improvement of the Engineering System by removing (trimming) certain components and redistributing their useful functions among the remaining System or Supersystem components.

Trimming Condition: An option for eliminating a component of the Engineering System by either eliminating its useful function or redistributing its useful functions to other system 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 G3:ID Product Innovation): A ratio between the Engineering System's (or System component's) functionality and cost: V = F/ C.

Value (as in G3:ID 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).