TRIZ-based Systematic Device Trimming: Theory and Application

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ABSTRACT

This work developed a systematic Device Trimming Algorithm with theory and an application example. The method is based on TRIZ (Theory of Inventive Problem Solving) methodology and can be used to trim components of any physical devices/products with various benefits without compromising its performance. It can also be used to resolve process-machine problems by re-designing the problematic processing machines with fewer components and less cost. The trimming process is orchestrated by a trimming plan which consists of sequenced trimming tasks. Elements of each trimming task include function carrier, useful function, object, trimming rule, new carrier, trimming problem statement, and trimming method. A 2-loop depth-first recursive trimming process is proposed to maximize the trimming effect. Applied on a slit-valve failure of a piece of chemical vapor deposition equipment in one of major Taiwanese foundry companies, the proposed problem solving process successfully identified the critical key disadvantages of the problem and solved the slit-valve failure with breakthrough results. A number of solutions were generated by the integrated process which involves a number of TRIZ tools. This paper describes only the solution by the trimming process. The main contributions of this paper include:1) Establishing an integrated trimming process consistent with TRIZ problem-solving model and capable of breakthrough problem solving and cost savings; 2) Solving the slit-valve problem with 83.3% component count reduction, 95% component cost reduction, 99% operational energy reduction, and completely designed-out the original failure mode. The results have been converted into a patent pending approval.

Keywords: TRIZ, Trimming, Systematic Innovation,

1. Introduction

When facing engineering problems, the great majority of engineers tend to use “Addition” or “Substitution” methods to solve problems. For example, when an electronic component generates radio interference with other components, engineers almost always introduce a cap to block out the interference. When a river floods, civil engineers will build a dam to protect the lands from being flooded. This method of introducing additional elements to solve a problem constitutes the mind set of “Addition” to solve a problem. Some people may use “Substitution” to solve a problem by replacing the problematic component. It is estimated that some 99% of people tend to use “Addition” or “Substitution” methods to solve problem. This paper established theoretical foundation and a systematic way of using “Subtraction” to solve problems consistent with TRIZ (Theory of Inventive Problem Solving) problem solving model. (Altshuller, 1998, 1999)

2. Theory of Trimming

2.1. Definition of System Levels

In the trimming process, it is convenient to differentiate super-system, system, and sub-system. Based on the free dictionary, a System is defined as a group of interacting, interrelated, or interdependent elements forming a complex whole. (Web dictionary, 2012) In the context of trimming, the system is the scope of current level of operations. A “sub-system” is any component of the system. A broad sense of “super-system” is a bigger system which contains the current system and its external elements which interact with the current system. Depending on the contexts, sometimes, the word super-system is interpreted in a narrow sense where it refers only to the external part of the super-system with the subject system excluded.

2.2. Definition of Trimming

The authors define that Trimming is a way of increasing system ideality by removing component(s) of the system. According to Genrich Altshuller (Mann, 2007), a system's Ideality is defined as Perceived Benefits/ (Cost+Harm). Ideality is a measure TRIZ used to define improvements. An improvement is recognized on a system when its ideality increases. A system is "better" than another system performing similar function when the ideality of the system is higher than that of the other system.

By all intents, trimming is to increase or maintain system ideality. Pure component trimming with decrease in ideality is not encouraged and not in our discussion scope. Note that in most cases, trimming can still maintain or enhance the system's original functionality. In minor cases, trimming allows for reduced functionality as long as the ideality is increased. This can be achieved by greatly reducing the cost or harm associated with the system fully offsetting the effect of functionality reduction.

2.3. Classification of Trimming

There are several ways of classifying types of trimming.

Based on the types of component to be trimmed, trimming can be classified as Device Trimming, Process Trimming, and Organizational Trimming. Device trimming refers to some components of physical product being trimmed to achieve increase of ideality. Process trimming refers to operations of certain process system being trimmed to increase system ideality. Organizational Trimming refers to some components (sub-organizations) of certain organization being trimming to achieve increase in organizational ideality. This papers concerns only about Device Trimming.

Based on the system level where trimming is to be initiated, we can classify trimming at the System level and at the super-system level. Trimming at the system level refers to trimming started from an investigation of the target system and the components of the system are being trimmed. Trimming at the super-system level refers to combining the components from the system and its super-system to form a "virtual system" and the trimming is to eliminate components from the combined virtual system to form a new system with less components and same or more functions than otherwise the sum of original individual systems. This paper deals only with trimming at the system's level. A way to do systematic trimming at the super system level will be presented in a future paper.

2.4. Usage of Trimming

Trimming provides an elegant way of achieving below business goals:

- To fix a problem or remove a harm by trimming either the problem causing component or the suffering component;
- To reduce product costs by trimming costly components;
- To reduce operational and/or maintenance costs by eliminating high energy consuming or maintenance intensive components;
- To reduce production or operational complexity by reducing part counts and removing complex parts;
- To reduce opportunities for errors/failures as more parts will have more opportunities for errors/failures;
- To circumvent a patent by trimming some components in the independent claims;
- To create a niche market or differentiate products by removing components relevant to unnecessary features for certain niche market; or simply,
- To improve product performance by removing negative impacting components.

The systematic method proposed by this paper can be used to achieve any of the above goals.

However, an example in problem solving and cost reduction through system re-design by trimming is presented.

2.1. Trimming Terminology

This section re-phrases some functional definitions from classical TRIZ and defines some new trimming terminology to facilitate the descriptions of trimming processes in the ensuing sections.

2.5.1 Tool, Function, and Object

Refer to Fig. 1. When a component C1 acts upon a component C2, if certain attributes (parameters) of component C2 is changed or maintained due to this action, then component C1 provides the function to the component C2. In this case, the action becomes a function. Component C1 is called a Function Carrier or Tool. Component C2 is called the Object of the Function, short as Object.

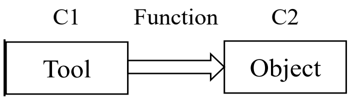


Fig. 1. Function-Component Diagram.

2.5.2 Trimming Task

The process of trimming components can be decomposed into multiple Trimming Tasks.

The Tool-Function-Object triplet described previously is the target of trimming operation in a trimming task. The goal of each trimming task is to trim the function of the triplet or making it un- necessary. Once all useful functions of a tool are trimmed, the tool is useless and can be trimmed. Only the useful functions are the target of trimming. The harmful functions are not concerned during the process of trimming as it will disappear once the component producing or suffering from the harmful function is trimmed.

2.5.3 Trimming Rules

Trimming rules are the modes of function trimming in the triplet (thus the function carrier). They serve as guiding principles for trimming. Six trimming rules are identified (Verduyn, 2006; Weaver, 2009; Ikovenko, 2009) and re-phrased as followed:

Trimming Rule A: The functions (thus its carrier) can be trimmed if the object of the function is trimmed. See Fig. 2. If executed successful, Rule A is very powerful as it trimmed two components in one shot.

Fig. 2. Trimming Rule A

Trimming Rule X: See Fig. 3. The function carrier can be trimmed if its useful function is trimmed or not needed. Rule X is also powerful as doing away with the current function often means using a completely different operational principle.

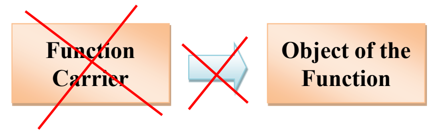


Fig. 3. Trimming Rule X.

Trimming Rule B: See Fig. 4. The function carrier can be trimmed if the object of the function can perform the useful function by itself. Rule B makes the object to serve itself thus no need to involve another component.

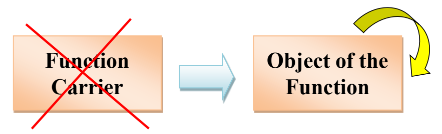


Fig. 4. Trimming Rule B.

Trimming Rule C: See Fig. 5. The function carrier can be trimmed if another existing component in the system or super system can perform the useful function by the current function carrier. Rule C needs to involve another existing component to perform the useful function regardless of the component being from the system or its environments.

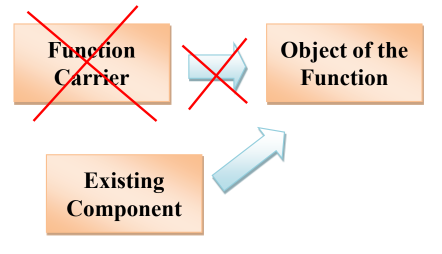


Fig. 5. Trimming Rule C.

Trimming Rule D: See Fig. 6. Function carrier can be trimmed if a new or niche market can be identified for the trimmed product. In this case, the function of the system may be degraded, but the ideality is still increased or maintained due to the reduction in costs/harm more than offsetting the reduction in the function/benefits.

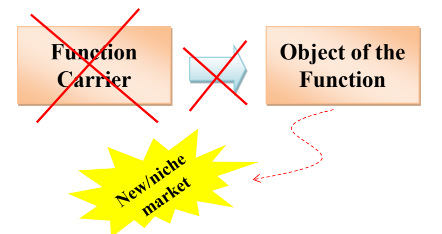


Fig. 6 Trimming Rule D

Trimming Rule E: See Fig. 7. Function carrier can be trimmed if the function can be performed better by a new/improved part providing enhanced performance or other benefits. The feature of this trimming mode is that 1) the replacement component does not already exist in the system or its environments. It is an additional part; 2) this component replacement improves system ideality by enhanced functional performance and/or reduction in costs/harm. Though strictly speaking, this rule does not trim but replace a component, it is part of options to improve the system during the trimming process. The authors consider it one of the valid trimming options.

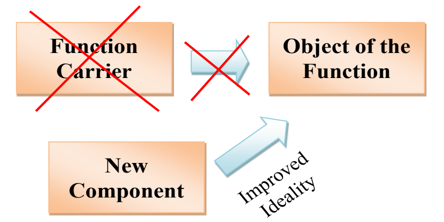


Fig. 7 Trimming Rule E

Priority of the trimming rules: In general, the recommended priority of the trimming rules is A, X, B, C, D, E in that order based on their effectiveness. However, there might be cases where Rule E is preferred over Rule D or Rule B maybe preferred over Rule X. Once a higher priority rule is successfully applied, the function is trimmed and the remaining rules can be neglected for this function. As long as any one rule is successfully applied, the trimming on this function is successful. Otherwise, the trimming of this particular function fails and the function carrier cannot be trimmed.

2.5.4 Trimming Plan

Refer to Table 1, the Trimming Plan is a form which is used to guide us through the proper sequence of the trimming tasks. Each task makes up a line on the trimming plan and attempts to trim a function at a time. On each task, the plan prompts the users to address the issues of this trimming task in proper order. These issues are shown as columns on the trimming plan and explained in Table 2. Additional explanations follow.

Table 1. Trimming Plan.

Function carrier to be trimmed: C1

Current carrier	Function	Object	Trimming Rule	New carrier	Trimming Problem	Trimming Method
C1	**F**	**C2**	**A**	**Null**	**How can I eliminate C2**	**Next task**
…						

Each line on the Trimming Plan is one task at a time attempting to trim a function using various trimming rules in the priority sequence.

Table 2. Trimming Terminology.

Terms	Contents	Roles
Current carrier ("Tool")	Current function carrier to be trimmed.	Target of trimming
Function	Current useful function to be trimmed.	Target of this trimming task.
Object	Object of the subject function	Recipient of the function.
New carrier	The new component that the subject function can be transferred to.	Enabling the removal of the current carrier.
Trimming task	The broken down work items of the trimming process. Each task refers to trimming of a function in the (Tool-Function-Object) triplet using certain mode of trimming.	Individual work item of the trimming process.
Trimming rule	The mode with which the trimming of the current task is to be performed.	Providing directional approach to trim the function.
Trimming plan	Providing a step-by-step form to guide the systematic thought sequence of the full trimming processes. Each row in the trimming plan contains key elements of a trimming task.	Orchestrator of the whole trimming process. Also laying out the thought process for documentation.
Trimming Problem (or. **Statement)**	A thought provoking challenging question pointing to the problem statement of the subject trimming task.	Focusing our thoughts to the key issue of this trimming task.
Trimming Method	The method which we use to resolve the current trimming task regardless if the task is successful or not.	Closing up the result of this trimming task.
Trimming model	The functional model of the trimmed system. It is a model of solution for the current trimming problem – a trigger solution.	Providing the abstract form of the solution upon which we deduce the specific solutions.
Specific Solution	The final substantiated specific conceptual solution to the trimming problem.	The resultant solutions that can be implemented.

Trimming Problem (Statement): It is a statement of challenging question to help us focus on the key issue that the subject trimming task is to resolve. The general format of the trimming statement looks like below:

- For Rule A: Ask: How can I trim C2? (Where C2 is the Object of this function.)
- For Rule X: Ask: How can I make the function F not necessary? (F is the subject function with respect to this Trimming Task.)
- For Rule B: Ask: How can I make the object, C2, to perform this function F by itself?
- For Rule C: Ask: Is there any existing component in or around the system which we can use to perform the subject function F?
- For Rule D: Ask: Is there a niche market which can use my resultant (degraded) system, if the component is removed?
- For Rule E: Ask: Is there an additional component that I can use to replace the function carrier while enhancing the performance and/ or reducing the costs/harm of the system?

Trimming Method: In this cell, the method to resolve the subject trimming task is indicated. If the task cannot be achieved, the step-back task is indicated and a conclusion is drawn for this task.

Table 2 summarizes all the trimming related to terminology.

2.5. The Proposed Model of Device Trimming Processes

A generic TRIZ problem solving process is shown in Fig. 8. A variant of the process can be found in (Sheu, 2007, 2011) the process starts with a specific problem to be resolved on the lower left corner of the Fig. TRIZ has many tools for problem analysis. After problem analysis the process converts the specific problem into an abstract level of "model of the problem". There are many ways of analyzing the specific problem thus producing multiple models of the problem. For each model of the problem, there are two categories of problem solving approaches: 1) Similar problems have similar attributes, therefore, the solutions will be similar (The path of "Like Problem Like Solutions"); 2) Similar problems can be solved by similar processes even though the "Like Solution" may not be available (The path of "Like Problem, Like Processes").

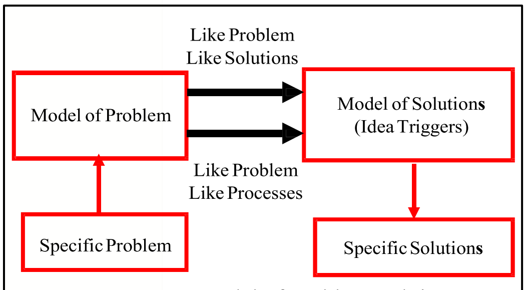


Fig. 8. TRIZ Model of Problem Solving.

The proposed Device Trimming Process is shown in Fig. 9. This matches the more generic TRIZ problem solving processes in the category of "Like problem, like processes". On the left side of Fig. 8, the current system is analyzed using TRIZ Functional Analysis (FA) to form the functional model of the system. The functional model of the current system is the "Model of the Problem". A trimming process, as detailed in the next section, will take the "model of problem" into "model(s) of solution(s)" which is the proposed functional model for the final trimmed system - the Trimming Model. It is quite possible that one "Model of Problem" can be converted into multiple "Models of Solutions" and one Model of Solutions" can be converted into multiple "Specific Solutions".
Theoretically, any TRIZ or other problem solving tool can convert each trimming model into some specific solution(s) of the problem. However, the indicated problem solving tools on the right side of Fig. 8 have higher likelihood to substantiate the trimming model into specific solution(s).

2.6. Details of The trimming process

2.7.1 Algorithm of the Trimming Process

Details of the trimming process on the upper line of Fig. 9 are explained in this section. The broken-down processes are shown in Fig. 9, 10, and 11. This loop trims target components one-by-one according to a specified priority.

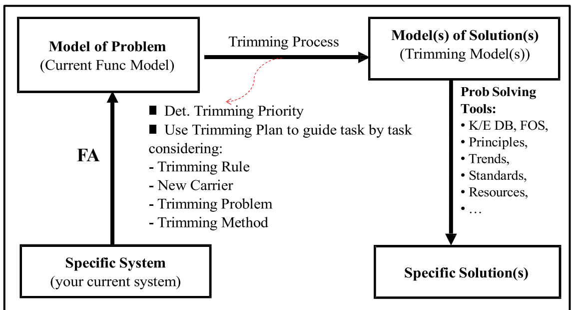


Fig. 9. Device Trimming Process.

Fig. 10 shows the outer loop of the pro- posed trimming process.

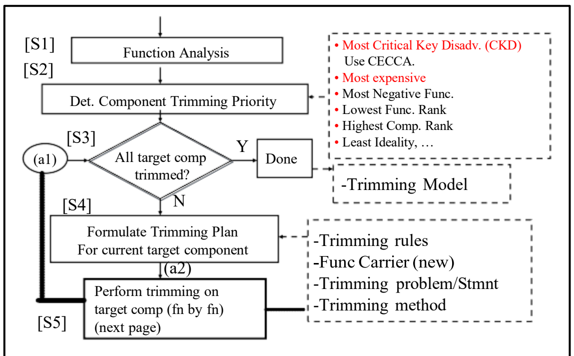


Fig. 10. Outer Loop of the Trimming Process.

- Step [S1]： Functional analysis (FA) of the current system is executed and the current FA model is the starting point for the trimming process.
- Step [S2]： This step determines the component(s) to be trimmed and their priority of trimming. Many ways have been proposed for determination of component trimming priority. The authors specifically

recommend either the “Most Critical Key Disadvantage” or the “Most expensive components” be used for determination of trimming priorities.

- Most Critical Key Disadvantages: Disadvantages refer to the negative functions found in the FA model. They include harmful functions, excessive functions, and insufficient functions. Usually, the harmful functions are the priority target(s) of elimination. Cause Effect Chain Analysis (CECA) or Cause Effect Contradiction Chain Analysis (CECCA) can be used to identify Key disadvantages and the most critical key disadvantages (Sheu and Tsai, 2012; Sheu *et al*., 2012). CECA starts from a target disadvantage, where the sensed sort point is, step-by-step sorting out the causes of the underlying negative events that caused the surface sore point. The negative events at the very bottom of the cause hierarchy are the Key Disadvantages. The Critical Key Disadvantages are the minimum set of Key Disadvantages which if eliminated will eliminate all the target disadvantages of concern. The CECCA is an enhancement of CECA with the addition of the relevant parameters for the negative event and the positive event generated from the negative events enabling the identification of contradictions. An example of the CECCA is given in the example in section 3.2.
- Another recommended way to prioritize the components to be trimmed is based on the cost of each component. Naturally, the higher the component costs, the higher the priority to be trimmed.
- Other ways of determining trimming priorities on Fig. 9 are considered less significant and are omitted in this paper. (Mann, 2007).

- Step [S3] , [S4], and [S5]：These constitute the outer and inner loops of the trimming where each component to be trimmed are examined for trimming one by one.

Fig. 11 shows that in order to trim a component C1, all the useful functions the component C1 provides must be handled – either be trimmed or made unnecessary. Based on this concept, the inner loop of trimming all the useful functions of a given component is shown in Fig. 12. In short, the outer loop, [S3] through [S5], deals with the trimming of each component to be trimmed based on priority sequence. The inner loop, within [S5], deals with the trimming of all useful functions provided by the current component to be trimmed. The process of the inner loop trimming is further expanded in Fig. 11.

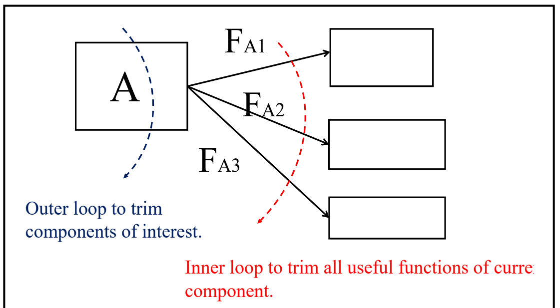


Fig. 11. Trimming of a component.

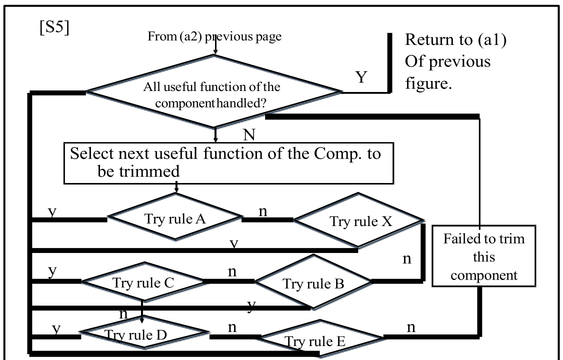


Fig. 12. Process of trimming all useful functions of a given component.

Trimming of each useful function constitutes a trimming task defined previously in the trimming plan of Table 1. Fig. 11 shows the application priority of the trimming rules A through E based on the recommended priority mentioned previously. If any earlier rule can be executed successfully, the later rules can be dropped and the trimming of the subject function succeeds. If none of the trimming rules can be successfully executed, the task of trimming this particular function fails. That means the component providing this function can not be trimmed. In this case, instead of jumping out of the inner loop directly and go on to challenge the trimming of the next component, the authors suggest to continue challenging the trimming of the next functions for the current component until all functions of the current component are handled to gain most trimming effects. This is indicated in Fig. 12.

Refer to Fig. 13. While applying Rule A to trim the object (B) of the current function, it is required to trim all useful functions of that object. Then, a new trimming task of trimming that object B as a function carrier emerges. The same rule set of A-E will then be used to challenge trimming of all the functions of that now function carrier B.

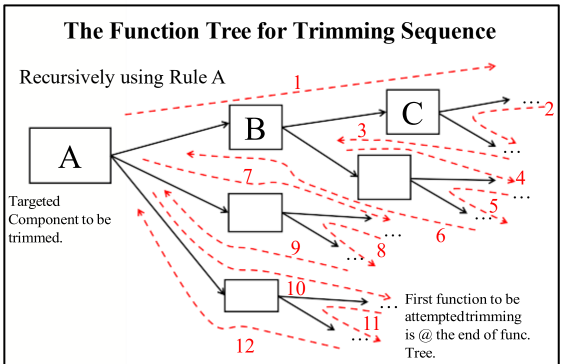


Fig. 13. Depth-first Recursive Trimming Sequence.

Fig. 13 shows this Depth-first Recursive Trimming Sequence with its component visiting sequence from the highest node to the deepest node using the set of trimming rules A-E on each node. The trimming task sequence of each function is indicated in Fig. 13. Regardless of the success or failure of each trimming task, the process will eventually visit all downstream components and functions in depth-first manner to achieve the most comprehensive trimming result. The functional model of the final system after trimming is the Trimming Model to be used as the goal for substantiation into specific solutions.

2.7.2 Usage of Trimming Plan to Orchestrate

Execution of Trimming Tasks

During the process of executing each trimming task as represented by the arrows in Fig. 12, the Trimming Plan similar to that in Table 1 is used to orchestrate the efforts in logical sequence. When a component C1 is identified as the function carrier to be trimmed, all the trimming tasks spanning from that component are listed one by one on the trimming plan. The sequence of trimming tasks thus spanned follows the Depth-first Trimming Sequence Map as shown in Fig. 12. The elements of each trimming task are entered onto the next row of trimming plan one task a line. The process of trimming each task on the plan is as follows: (Refer to Table 1.)

1. Fill in the function carrier to be trimmed.
2. Fill in the next useful function of the current function carrier to be trimmed.
3. Fill in the object of the function.
4. Fill the next trimming rule to be used. Refer to Fig. 11. For each function to be trimmed, we will challenge Rules A through E in recommended order. As long as an earlier rule is successfully challenged, the subject function is successfully trimmed and the remaining rules are dropped for this function. If all the trimming rules have been exhausted without any success to trim the function, we failed to trim the function and thus the corresponding function carrier. We are back to the first decision point of step [S5] on Fig. 11. In any case, continue trimming effort on the next function for this carrier until all functions of this carrier are handled.
5. Based on the trimming rule under consideration, determine the new function carrier to replace the current function carrier. In the case of using Rules A, X, B, E, there is no need for a new carrier. For the rules of C & D, a new carrier is needed. Guidelines to locate a new carrier are explained in the next section.
6. Form a Trimming Problem to focus our thoughts for the “execution” of this trimming task. Typical patterns of trimming problem have been described in Section 2.5.4.
7. Use the information from 1) to 6) to conceive a trimming method for this trimming task.
   - Case of using trimming rule A: the execution of this task is passed onto the execution of next task which is the trimming of the current object as the function carrier of the next task. Indicate next task as the trimming method. Proceed to the trimming of the next component and its functions, which generates another

inner loop of recursive trimming with the path similar to that shown in Fig. 13, before returning to conclude this task.

- Case of using rule X: The user needs to find some different working principles that the object will NOT need the current function. State that approach.
- Case of using rule B: Find a way to allow the object self-serve the function. Indicate that situation.
- Case of using rule C & D: Indicate how the new carrier maybe able to take on the function needed.
- Case of using rule E: Indicate what niche market situation the reduced system can be used so the carrier and the function can simply be dropped.

Once all the useful functions of a component are handled, the component is handled. When all components are handled, the Trimming Model is thus created as the abstract model of the trimmed solution. This is the model of the desired solution. Substantiation of this model into a specific solution concept is described in Section 2.7.4.

2.7.3 Guidelines to Identify a New Carrier

Two sets of guidelines were available to identify a new carrier; Table 3 shows the function relationship consideration for new carrier selection. When there is a need to select a Component as a substitute new function carrier, it is recommended that at least one of the four conditions should be satisfied: (Ikovenko, 2009).

Table 3. Function Relationship Consideration.

Priority	Same Function	Same object
1	Y	Y
2	Y	N
3	N	Y
4	N (w/ applicable resources)	N

1. The Component already performs an identical or similar function on the Object of Function.
2. The Component already performs an identical or similar function on another object.
3. The Component performs any function on the Object of Function or at a minimum simply interacts with the Object of Function.
4. The Component possesses the set of resources necessary to perform the required function.

Another consideration is the Closeness in a system component hierarchy. A new carrier is easier to obtain from the nearby components on the product component hierarchy when we decompose the component hierarchy in a tree structure for the system. An example taken from (Mann, 2007) is used to illustrate this point as shown in Fig. 14. When a windshield is broken, we can trim the windshield and delegate its function to its close neighbor on the component hierarchy – the window glass.

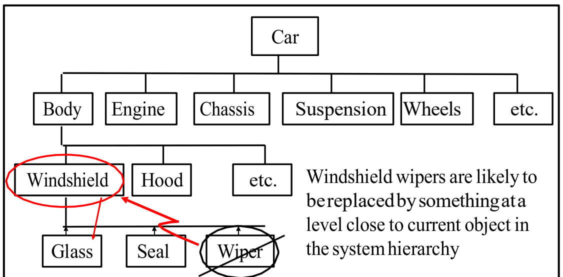


Fig. 14. System Component Hierarchy of a Car.

2.7.4 Converting from a Trimming Model to Its Specific Solution(s)

All the abovementioned process takes us to the stage of "Model of Solution" as shown in Fig. 8. The Trimming Model thus produced is the abstraction of our Specific Solution. The last step is to substantiate the trimming model into specific solution(s). Theoretically, any problem solving tools can be used to convert the trimming model to specific solutions. The below TRIZ tools have been found effective in substantiating the Model of Solution into Specific Solutions:

- Function Oriented Search (FOS): It is a process which converts our problem solving requirements into a set of Function(s) and related attributes needed to successfully achieve the planned trimming. Then the functions/attributes are used as key words to search world-wide data & knowledge base to find out any technology or fundamental scientific effects that can be used to achieve the desired functions/attributes.
- Knowledge-Effect Database (K/E DB): Based on previous millions of patents, many TRIZ researchers have compiled variants of Knowledge-Effect database that organize the knowledge by the physical/chemical effects which can achieve related functions. For example, if we look for something to "move liquid", the K/E DB will show more than 45 different ways to move liquid. A free simplified version is accessible on http://function.creax.com/. (CREAX Function Database, 2011) Though still useful, it is grossly incomplete. Another free version of K/E DB can be seen on http://www.oxfordcreativity.com. (Oxford- Creativity, 2012) Commercial TRIZ data- base systems such as Goldfire and Pro- Innovator contain more information and with more illustrations. They are expensive, too.
- Inventive Principles: The 40 inventive principles (Altshuller, 1998) can be used to provoke our thoughts and thus identifying specific solutions. If fundamental contradiction is already identified in the process of CECCA stated before, the contradiction matrix can be used to identify higher priority principles to solve the problem.
- Trends: TRIZ Trends of Engineering System Evolution can be used to identify solutions and provoke our thoughts toward specific solutions.
- Resources: TRIZ resource tool provides the user a systematic way of leveraging existing resources to achieve the same results. Either converting non-used/over-looked resources to be used or turning harmful "resources" into useful resources.

The example in the next section illustrates the usage of trimming process and TRIZ problem solving tools.

A Case Example

This section demonstrates the application of the proposed trimming process on semiconductor equipment with significant improvements. Other examples are available but omitted due to confidentiality concern and space limitation of the paper. (Sheu, 2011).

3.1 Case Background

Fig. 15 shows the top view of the CVD (Chemical Vapor Depositor) equipment used in one of major Taiwanese semiconductor manufacturers. The partial pictorial view of one of the chambers in connection with the transfer module and the slit valve, also known as gate valve, is shown in Fig. 16.

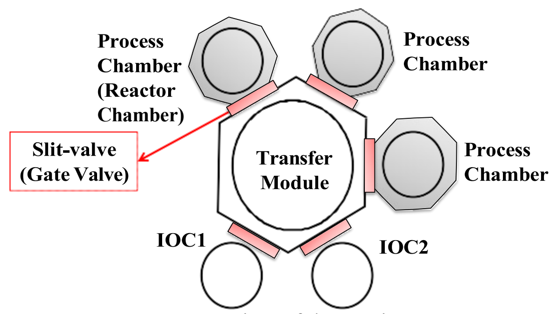


Fig. 15. Top View of the Equipment (Chemical Vapor Depositor, CVD).

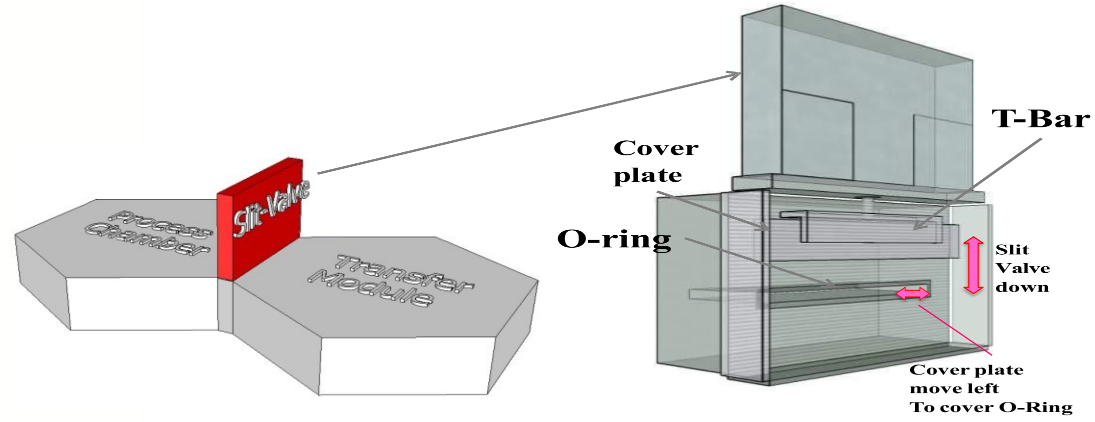
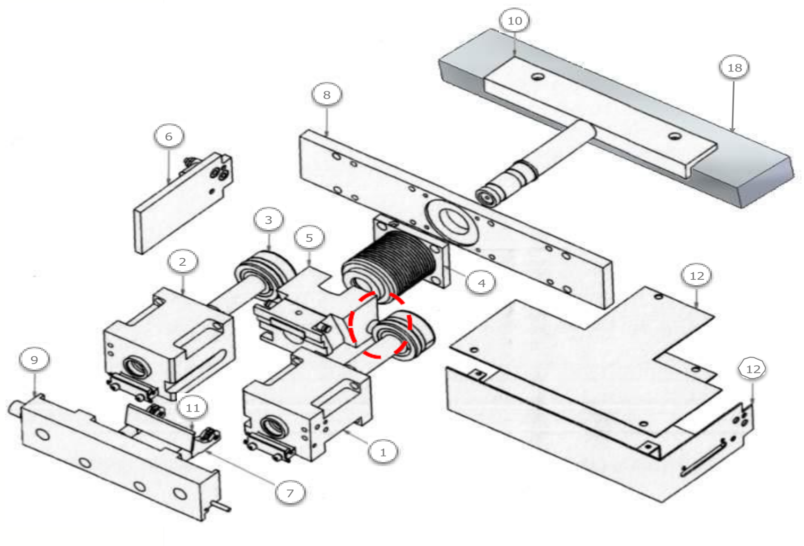


Fig. 16. Pictorial View of the Slit Valve and the Chamber.

On the Fig., the slit-valve closing operation consists of two steps: 1) Slit-valve pushes down T-Bar; 2) Cover plate move left pressing on the O-ring on the chamber wall. The opening of the slit valve follows the exact opposite order of the closing operation. The full mechanism of the slit valve is shown in Fig. 17 where 18 components, some parts and some assemblies, are indicated. The problem came when consistent defect patterns were found on the processed wafers. Engineers traced back to locate the causes and determined that the unexpected breakage on one of the two protruding pins, red circled in Fig. 16, of the Sliding Guide Assembly (part #5) caused the cover plate to close the door unevenly. The uneven movements of the cover release particles. The particles were the tucked in by the vacuum operation in the process chamber and deposited on the wafer at the area close to the gate opening. Fig. 18 shows the sliding guide assembly with protruding pins indicating where the mechanical fatigue and stress concentration occurred. The engineers in the factory solved the problem by replacing the pin on the sliding guide assembly as shown in Fig. 19 hoping that with bigger contact area the stress concentration can be eased. Even though the replaced pin of the sliding guide assembly was able to restore equipment back to work, the fundamental failure mode remains. The same problem can happen after a prolonged usage of the slit valve. Engineers tend to solve problem on where the problem is without a broader viewpoint. In the next section, the authors will demonstrate how trimming can solve a problem in another location that can produce a more powerful and yet elegant solution.



item	Parts Name
1	Air pressure cylinder assembly（left）
2	Air pressure cylinder assembly（right）
3	Piston assembly
4	Slit-valve（S.V.）Bellow/ G.V. Bellow
5	Sliding guide assembly
6	Cover assembly
7	Connecting bar assembly
8	Cover the bottom of S.V,
9	Piston fixed block
10	T Bar
11	Slider（Angle plate）
12	Upper and lower cover assembly
13~17	Hexagon screws
18	Cover

Fig. 17. Construction of the Slit Valve Mechanism.

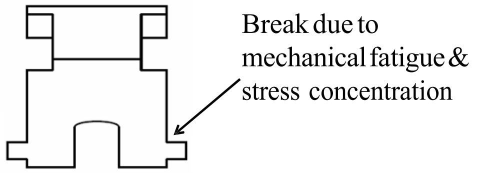


Fig. 18. Root sore point at the pin of the sliding guide assembly.

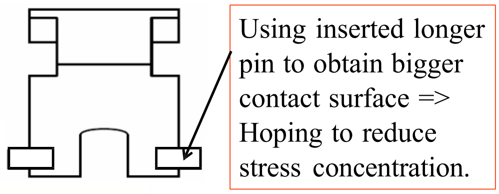


Fig. 19. Current solution by company engineers.

3.2 Overview of Our Problem Solving Approach

The authors applied the "Problem Solving by Trimming" approach using the method described in Section 2 and exemplified here. The overall steps to solve this problem are shown in Fig. 20. It follows the same process as described in Fig. 8. the functional model of the system is given in Figure
21. CECCA of the problem is given in Fig. 22.

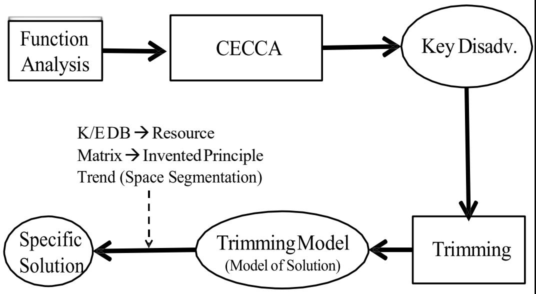


Fig. 20. The trimming process between FA and Specific Solutions of Fig. 9.

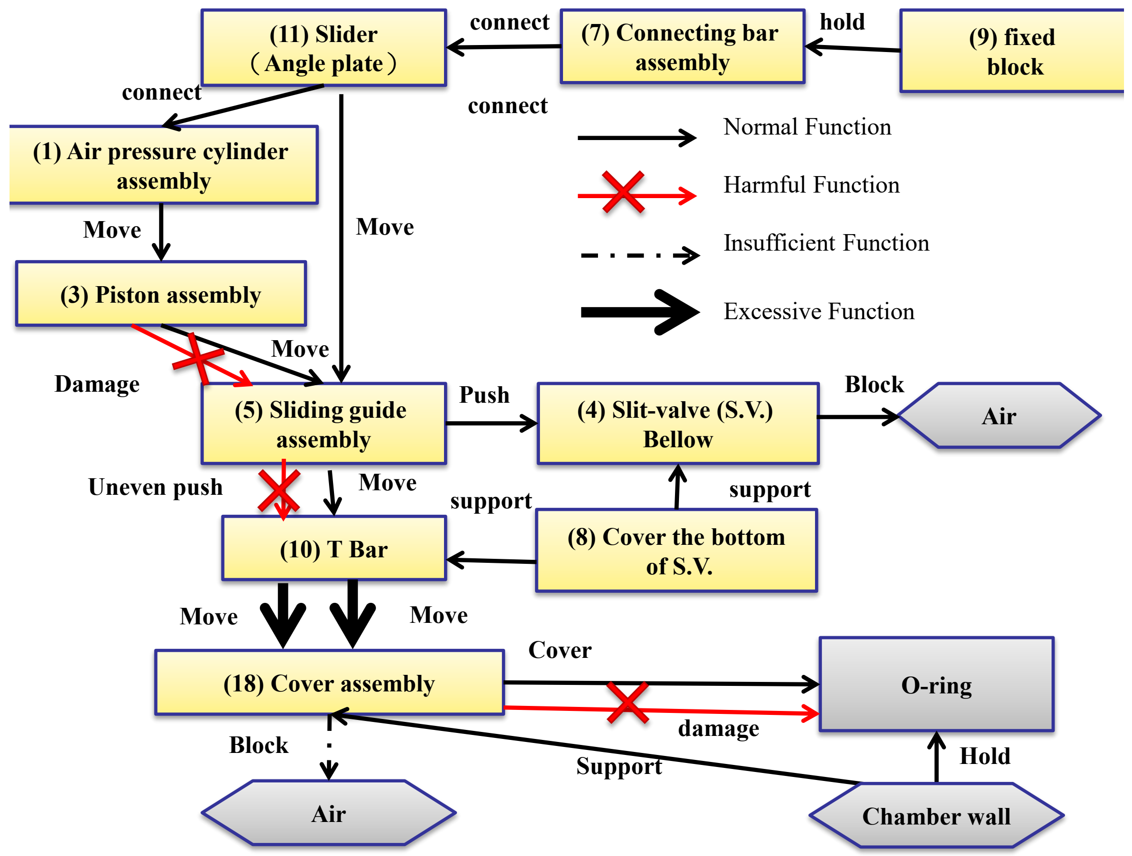


Fig. 21. Functional Model of the System under Failure Situation.

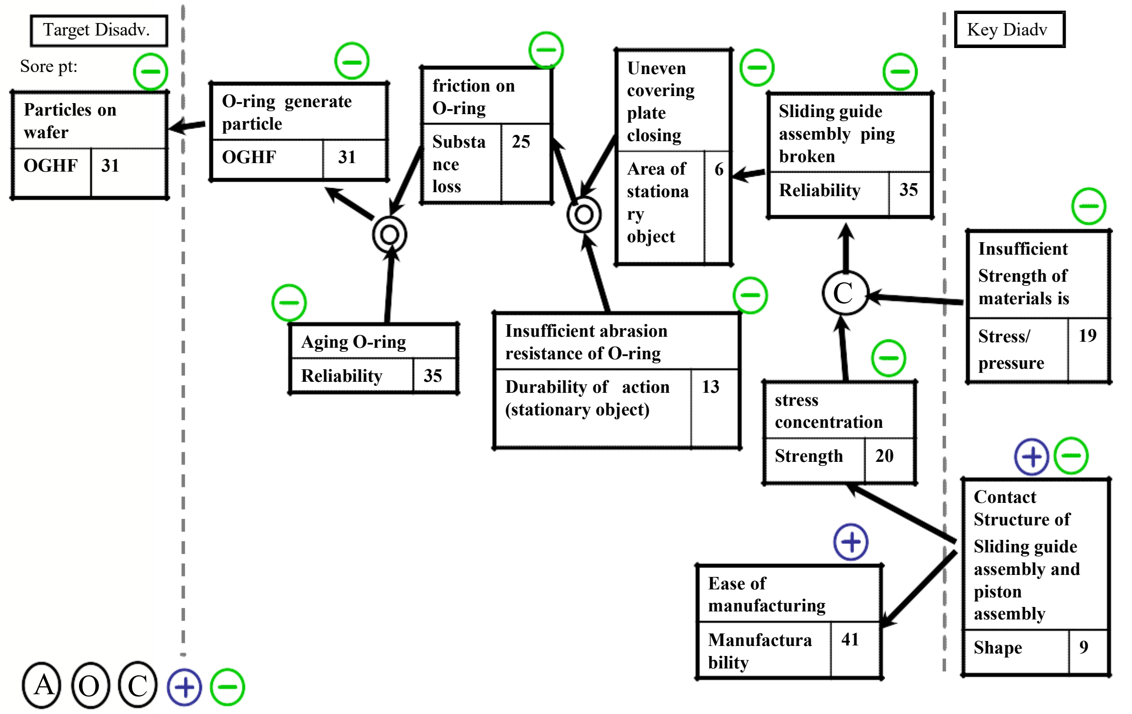


Fig. 22. Cause Effect Contradiction Chain Analysis.

The CECA starts from the surface sore point of the system as the target disadvantage(s) to be fixed. It then reasons for the causes of the target disadvantage in hierarchy till the lowest level key disadvantages on the far right in the Fig. 22. The fundamental causes at the lowest layer are the Key Disadvantages. The goals of CECCA are:

- Providing a hierarchical relationship of the problem cause structure so that one can attack the problem from the lowest fundamental level on the far right of Fig. 22. If we are not able to solve the problem at the most fundamental level, we can step back one level at a time to solve the problem at the less fundamental level. While starting from the key disadvantages backward, as long as we can solve the problem causes at any level the original target disadvantage will be resolved. CECCA provide us a full spectrum of problems to attack in order to solve the target disadvantage. Therefore, multiple solutions are quite possible due to the exposure of problem spectrum by CECCA.
- Allowing us to identify the contradictions underneath the surface disadvantage(s). By assigning the corresponding parameters associated with the subject cause items, the authors are able to identify the underlying contradictions of the surface disadvantage thus enabling us to use Contradiction Matrix and Inventive Principles to solve the problem.

After constructing the CECA, all the causes posted on the diagram are the disadvantages or some sort of failure. Therefore, they are all marked as (-) in a circle. We then examine for each disadvantage item, if there is anything good that this “bad” thing can produce? If there is, we have contradiction(s). The subject disadvantage not only contributed to the disadvantages above its cause-effect hierarchy (to the left on Fig. 22), it also contributed to the identified good thing. Therefore, the parameter associated with this subject disadvantage is under “physical contradiction” where contradictory requests are being asked on the parameter of the same system. The spot of physical contradiction is indicated by a (+) and a (-) circles side-by- side. Then, the “good” thing, marked as (+) circle, and the downstream bad things caused by the subject disadvantage may form “Engineering Contradictions” where contradictory requests are asked of two parameters.

Based on the CECCA, the insufficient strength of materials, the fatigue, and the contact structure of **sliding guide assembly** and **Piston assembly** are the key disadvantages. Addressing the material strength problem may be costly. The authors decided to address the problem from the contact structure of the sliding guide assembly and piston assembly. This determines the priority point to address. It is the contact between the piston assembly and the sliding guide assembly where the pin of the sliding guide assembly is broken.

The mind set of using Trimming to solve a problem is to ask:

1) What is the critical key disadvantage of the problem from CECCA? Answer: The piston assembly broke the pin of the sliding guide assembly.
2) Which component is the problem maker? Can we trim it?
3) Which component is victim of the problem? Can we trim it?

We then apply the trimming process as described in Section 2 Fig. 9-11 starting from the problem maker, the piston assembly.

3.3 The Trimming Process

Continuing on the reasoning from the previous section, the trimming process on the functional model is described below:

1) Trim Piston Assembly: The trimming task on top of Fig.2 shows that to trim the piston assembly using Rule A, we will trim sliding guide assembly. See Fig. 23.
2) Trim Sliding Guide Assembly: By the same token, to trim sliding guide assembly using Rule A, we need to trim slit valve bellow as shown in Fig. 24.

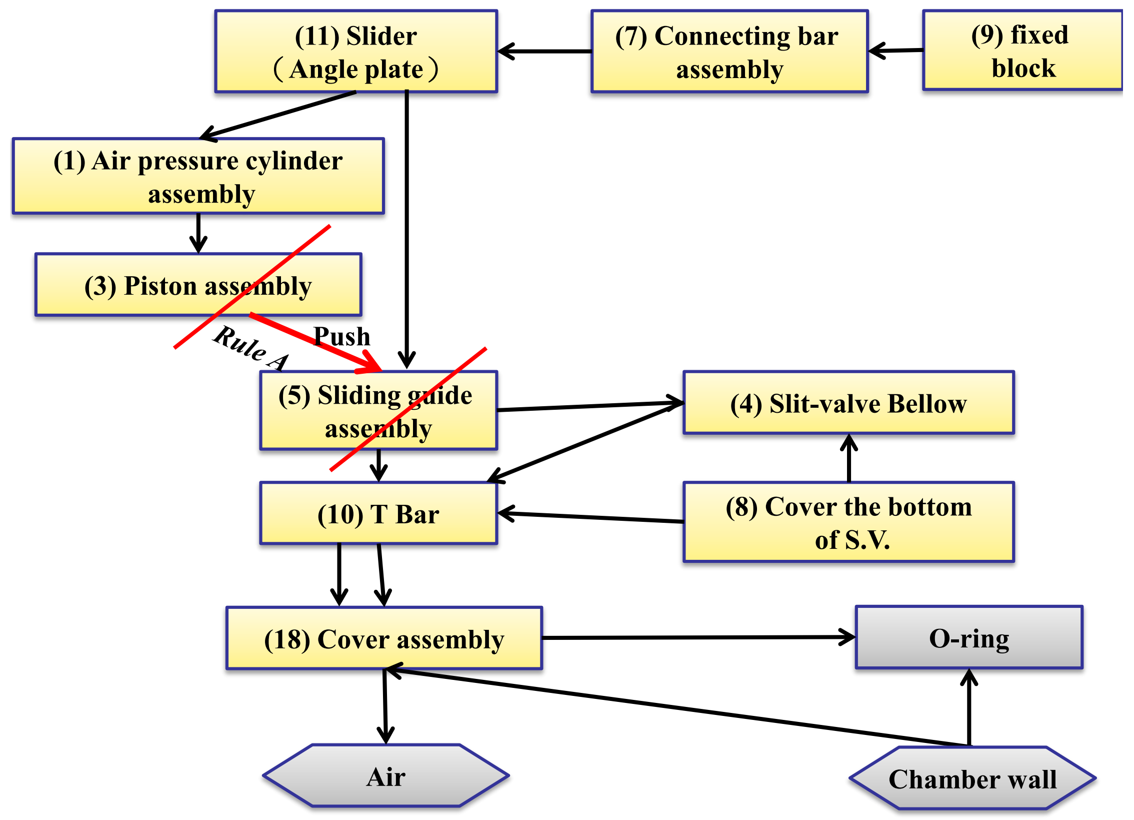


Fig. 23. Trimming Piston Assembly.

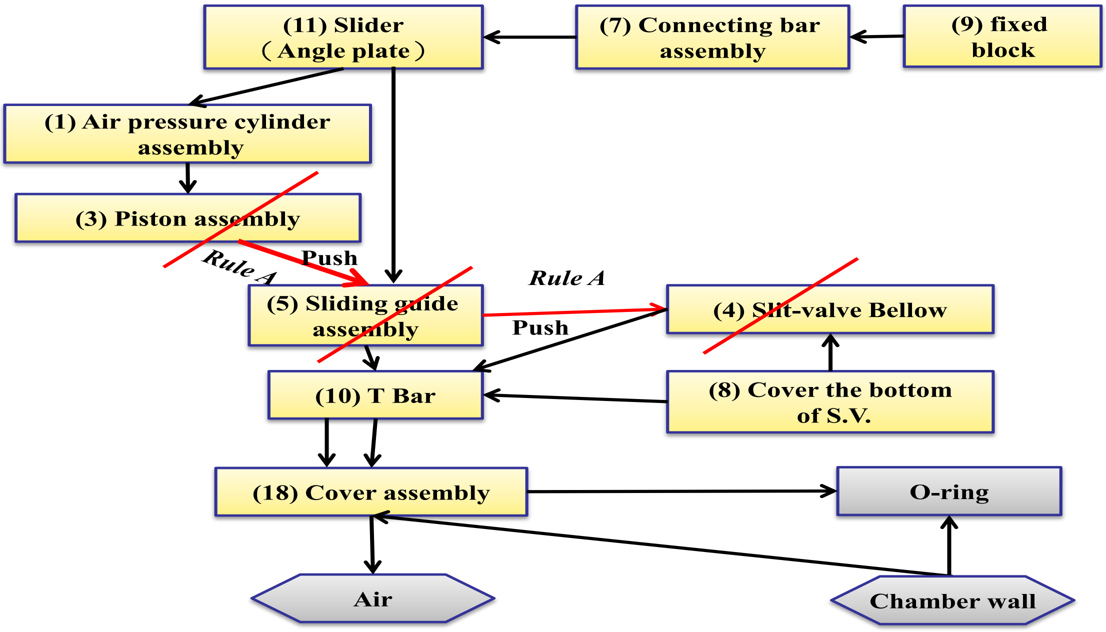


Fig. 24. Trimming Sliding Guide Assembly.

3) Trim Slit Valve Bellow: Using Rule A to trim slit valve bellow, we will trim the T-Bar. Refer to Fig. 25.
4) Trimming T-Bar: Table 4 shows the task sequence to trim T-Bar. Trimming rules A, X, B, C were tried. Since Cover Plate is the main tool of the system. We decided not to trim the cover plate. Therefore, Rules A and X failed. Fig. 26 depicts the final trimming status. At the end, since T-bar is trimmed, all supporting components of the T-Bar can be trimmed. The final trimming model is given in Fig. 27.

Table 4. Tasks for Trimming T-Bar.

Current carrier	Function	Object	Trimming rule	New carrier	Trimming problem	Trimming method
T-Bar	Move (close)	Cover Plate	Rule A	Null	How can I trim Cover plate?	Cover plate is main tool, Can't trim it. Rule A failed. Try Rule X.
T-Bar	Move (close)	Cover Plate	Rule X	Null	How can I NOT to move Cover plate?	Need to close cover plate, Rule X failed. Try Rule B.
T-Bar	Move (close)	Cover Plate	Rule B	Cover Plate	How can I make cover plate move itself?	This may be possible. I may use gravity or pressure diff.
T-Bar	Move (close)	Cover Plate	Rule C	??	How can I use ? To move (close) cover plate.	Possible as goal to substantiate later. (Eventually Used gravity)
T-Bar	Move (Tighten)	Cover Plate	Rule A	Null	How can I remove Cover plate?	Cover plate is main tool, Can't trim it. Rule A failed. Try Rule X.
T-Bar	Move (Tighten)	Cover Plate	Rule X	Null	How can I NOT to move Cover plate?	Need to close cover plate, Rule X failed. Try Rule B.
T-Bar	Move (Tighten)	Cover Plate	Rule B	Cover Plate	How can I make cover plate to move itself?	This may be possible. Or use Rule C next task.
T-Bar	Move (Tighten)	Cover Plate	Rule C	??	How can I use? To move (tighten) cover plate.	Possible as goal to substantiate later. (Eventually used pressure differential)

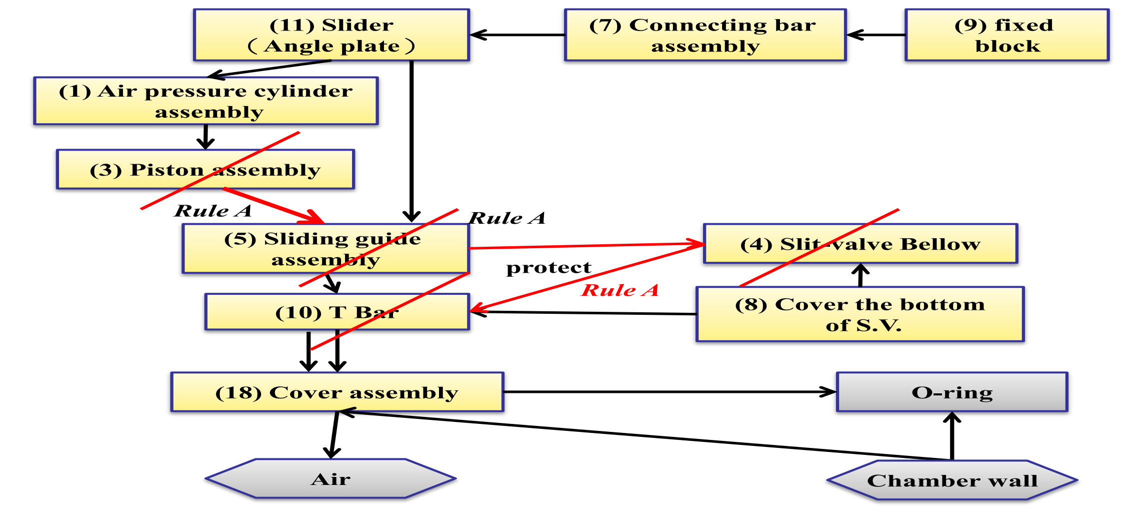


Fig. 25. Trimming Slit Valve Bellow.

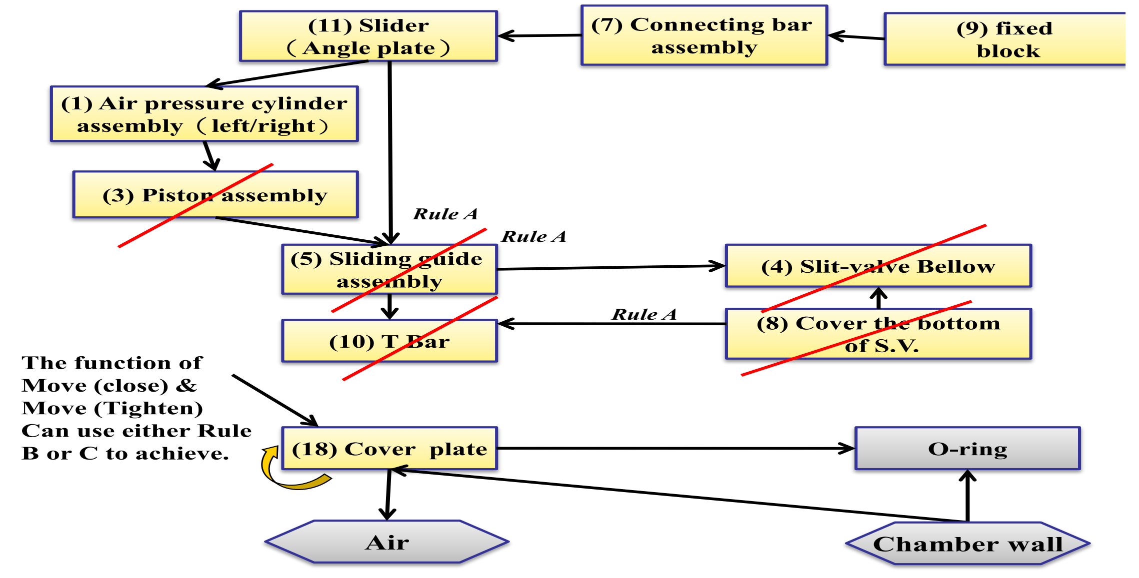


Fig. 26. Final Status of Trimming.

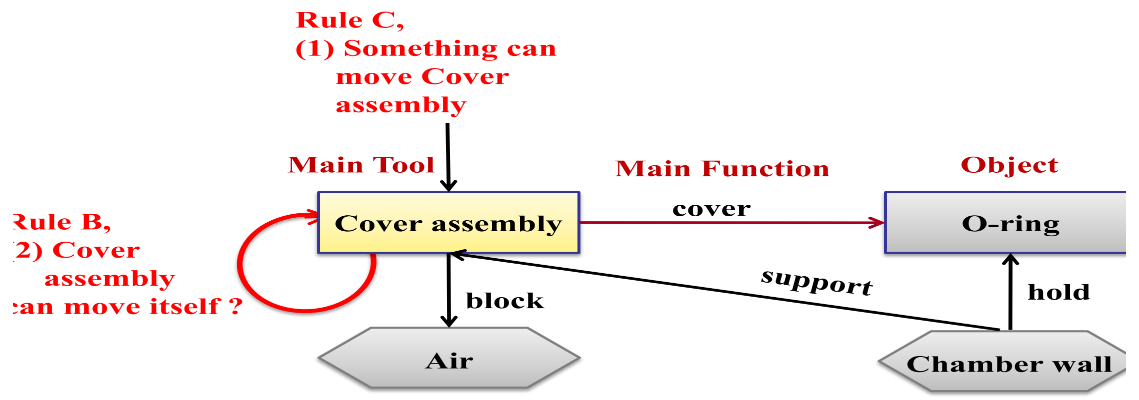


Fig. 27. Final Trimming Model.

3.4 Substantiation of the Trimming Model

Based on the final trimming model indicated in Fig. 27, we need to have the cover plate moved by itself or have something to move it so that it can cover the O-Ring and seal the gate properly. These functions converted to their fundamental level are "move solids". TRIZ Function Database is available for us to examine all principles that have been used in past patents on how to move solids. At least 36 ways of move solid can be found from CREAX Function Database [CREAX]. Further examining resources around the system, the authors determined that the three principles, Ferro-magnetism, Gravity, and Pressure Differential be used to substantiate the trimming model. Among them, gravity and pressure differential are free existing resources in the environments.

Furthermore, using the identified possible contradictions from the CECCA previously, the authors used Darrell Mann's Matrix+ software to locate the probably principles that can provide solution ideas. The identified possible parameter to improve are (19) Stress, (20) Strength, (25) Loss of substance, (35) Reliability; The identified stopping factors are (45) System Complexity and (41) Manufacturability. A number of principles were suggested by the Matrix+. The ones which we were able to draw specific solutions are (17) Another Dimension, (3) Local Quality, (28) Mechanics Substitution, and (13) The Other Way around. The one used in this solution for trimming is the principle 13, "The Other Way Around", generated the idea of embedding the cover plate inside the chamber wall instead of the traditional mechanism attaching onto the chamber wall. Side view of a representative solution is given in Fig. 28.

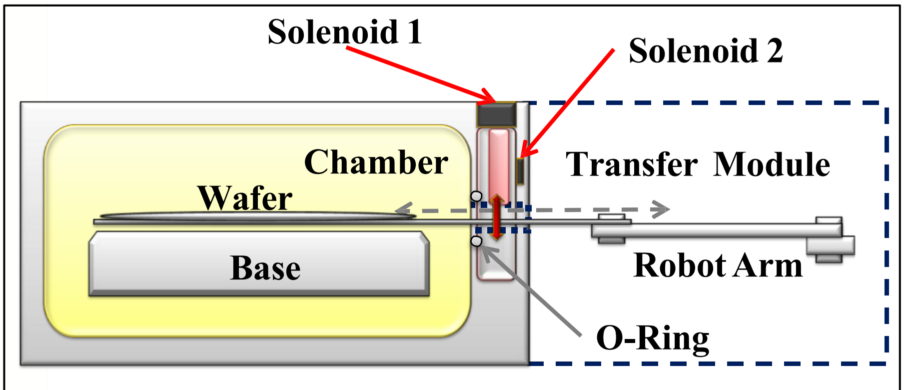


Fig. 28. Representative Solution of the Slit Valve.

The key points of the solution are:

- Instead of original huge external mechanical structure of 18 components/assemblies, the trimmed solution uses only 3 components: one cover plate inside the chamber and two solenoid valves on the side and on the top of the cover plate. The cover plate consists of magnetically attractable materials so that the solenoid valves can move the cover plate.
- During the closing operation, the gravity force moves down the cover plate without using any energy costs. The tightening of the valve can be achieved automatically by the pressure differential between the chamber and the transfer module. The chamber vacuum is needed by the process chamber before the wafer manufacturing processes. No additional operational energy is needed during the closing and the state of slit valve being closed. This constitutes 90% of the time for the equipment operations. To loosen the cover plate and open the slit valve, the side solenoid valve applies a pulse of energy to pull the cover plate away from the O-Ring and the top solenoid applies a pulse of energy to suck the plate up and open the gate. Unlike in the original mechanical operations, energy is needed all the time to move the approximately 6 kg cover mechanism and to maintain it, the proposed trimmed solution, needs only 10% of time to apply energy on solenoid valves and taking the load of approximately 0.6 kg cover plate. With 10%

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of time needing energy to operate and approximately 10% of original loading when needing the energy, the trimmed solution takes approximately 1% of original energy to operate.

- In addition, using TRIZ Trend of Space Segmentation, we can make the cover plate hollow or multiple hollow to further reducing its weight.

Compared to the original solution by the original equipment builder or the company's engineers, the benefits of the trimming solution are summarized in Table 5. The advantages of this trimming solution include:

- Eliminating the original equipment failure mode of pin breakage permanently by system re-design. The new system uses well-known reliable components with much fewer number of components and is less prone to failure.
- Significantly reducing the part count from 18 to 3 – a reduction of more than 80 % part count and 95+% of component costs.
- Taking advantage of existing resources, gravity and pressure differential, to close and tighten the valve for 90% of the time. Together with the reduction of 90% weight loading, the savings in operational energy is theoretically 99%.
- Embedding the slit-valve in the Chamber wall greatly reducing the overall space and materials usage.
- Allowing voids inside the cover plate to further reducing the weight thus energy and materials usage.

Table 5. Comparing the Original and the Trimmed Solutions.

	Item	Before	After	Improvement (%)
Original Solution	Component Counts	18	20	(18-20)/18=-11.1%
	System cost	NTD 229,000	NTD 80,000	NA
	Energy savings	None	None	Need energy to maintain 6 kg*20 (min)
Trimmed Solution	Component Counts	18	3	(18-3)/18=83.3%
	System cost	NTD 229,000	< NTD 10,000	(229000-10000)/ 229000 =95.6%
	Energy savings	120	1.2	From 6 (kg)* 20 (min) Full Cycle to 0.6 (kg)* 2 (min) Only in "open" state.

1. The repair cost of the original solution is 80K on overhaul, and price for a new system is 229K. (All costs are in New Taiwan Dollars.)
2. In an operating cycle of 20 minutes, the valve is in "closed" state for 18 minutes and only 2 minutes in the "open" state (10% time).
3. The new design uses electrical pulse only during the "open" state which is 1/10 of the time. With 0.6 kg cover plate, 1/10 of the original weight, the new design needs only 1/10 of the original energy level during open state, that is 1% of original energy level needed for operation.

The results of this work have been compiled into a patent application to USA and R.O.C. Patent offices. (Sheu and Hou, 2011a; Sheu and Hou, 2011b).

4. Conclusions and Contributions

This research established a theoretical framework and a systematic way of trimming products with physical components. It is termed as "Device Trimming" as contrasted to "Process

Trimming" and "Organizational Trimming". The model of device trimming process is formulated in a way consistent with TRIZ problem solving model. Trimming Plan was introduced to orchestrate all the Trimming Tasks which in turn apply Trimming Rules, Trimming Statements, to "virtually" trim the system into a Trimming Model. The Trimming Model is used to direct our thoughts of physical trimming into Specific Solution(s). A two-loop recursive trimming process was introduced to maximize the extent of trimming. The proposed method was tested on a semiconductor equipment problem with significant improvements which include more than 80% component count reduction, 95% of re- build cost reduction, and approximately 99% of operational energy savings.

Contributions of the paper includes: 1) Establishing the process and theory of trimming connecting it with TRIZ problem solving process; 2) Creating a Trimming plan to systematically organize the trimming steps in the trimming process; 3) Creating a 2-loop Recursive Trimming algorithm to maximize the trimming power; 4) Demonstrating a way to utilize Resources for trimming; 5) Applying the method to solve a semiconductor process-equipment problem with significant improvements.

Acknowledgment

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