ISSN 2077-7973
10.6977/IJoSI

International Journal of Systematic Innovation

VOL.02 NO.01
March, 2012

Published by the Society of Systematic Innovation

Opportunity Identification & Problem Solving

ISSN (Print): 2077-7973
ISSN (Online): 2077-8767
10.6977/IJoSI.201203_2(1)

The International Journal of Systematic Innovation

Publisher:
The Society of Systematic Innovation

Editorial Office:
The International Journal of Systematic Innovation
6 F, # 352, Sec. 2, Guanfu Rd,
Hsinchu, Taiwan, R.O.C.
e-mail:
editor@systematic-innovation.org
web site: http://www.IJoSI.org

IJoSI

INTERNATIONAL JOURNAL OF SYSTEMATIC INNOVATION

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Foreword

The International Journal of Systematic Innovation (IJoSI) provides a platform to publish all systematic innovation related tools, knowledge, theories, and practices including technical aspects, strategic-managerial aspects, and computer-aided innovation areas. This includes but not limited to TRIZ (Theory of Inventive Problem Solving) and its extensions, non-TRIZ human originated systematic innovation, and nature-inspired systematic innovations in order to identify opportunities and solve problems systematically and innovatively.

The IJoSI publishes high-quality papers with academic rigor in theoretical and practical studies in the areas of systematic innovation. This issue consists of four papers that were gone through careful peer-review processes under the Journal's regular publication guidelines. The first paper introduces a two-loop recursive trimming process is introduced to maximize the extent of trimming. The proposed method is tested on a semiconductor equipment problem with significant improvements which include component count reduction, rebuild cost reduction, and operational energy savings. In the second paper, environmental requirements are taken into account with the life cycle assessment (LCA) and some TRIZ tools such as ideal final result (IFR) and the laws of technical systems evolution (TSE) for proposing a new method for designing more sustainable products. Third paper develops an open architecture process failure mode and effects analysis (PFMEA) Web–based system with TRIZ for automotive manufacturing firm in Malaysia, which fills the current gap of deficiencies in traditional FMEA, such as tedious data maintenance and updating. The fourth paper proposes a systematic method of course development for cultivating the innovative capability of students at university based on a knowledge chain model. In general, these four papers contribute in both ways, theoretically and practically.

Finally, we appreciate all the authors of the above four papers for their submissions to the IJoSI and reviewers for their hard works. In order to serve even better functions of the IJoSI, you are cordially invited to submit your original papers to IJoSI electronically through the website at http://www.IJoSI.org. Any feedbacks or questions, please send email to editor@systematic-innovation.org.

Prof. D. Daniel Sheu, Editor-in-chief
Prof. Hsin Rau, Executive Editor

10.6977/IJoSI.201203_2(1).0001

TRIZ-based Systematic Device Trimming: Theory and Application

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(Received 14 March 2013; final version received 23 September 2013)

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.

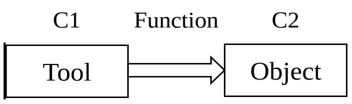

Fig. 1. Function-Component Diagram.

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 trim- med. 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.

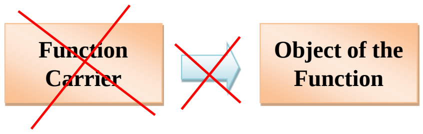

Fig. 3. Trimming Rule X.

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.

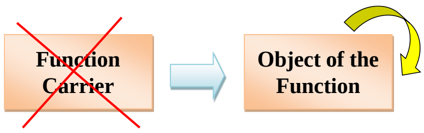

Fig. 4. Trimming Rule B.

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.

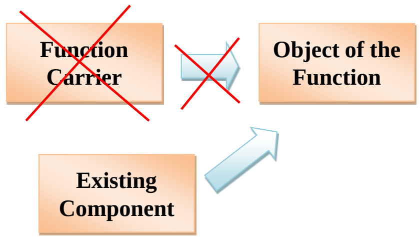

Fig. 5. Trimming Rule C.

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.

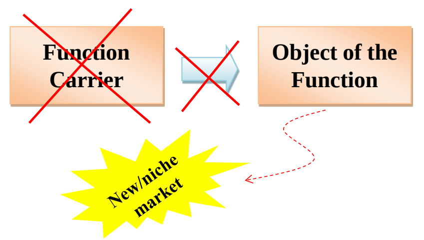

Fig. 6 Trimming Rule D

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.

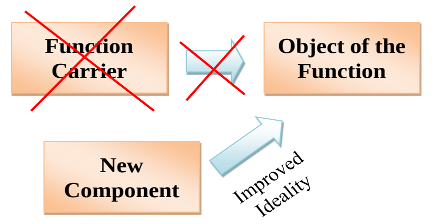

Fig. 7 Trimming Rule E

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.

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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").

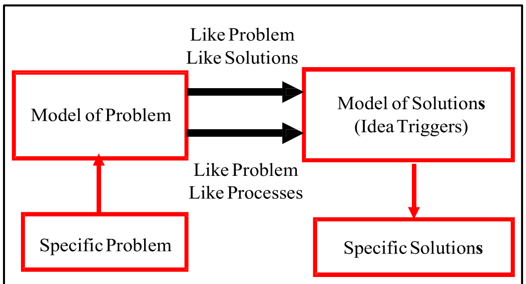

Fig. 8. TRIZ Model of Problem Solving.

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.

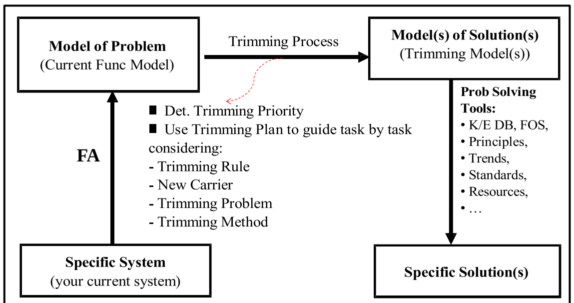

Fig. 9. Device Trimming Process.

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

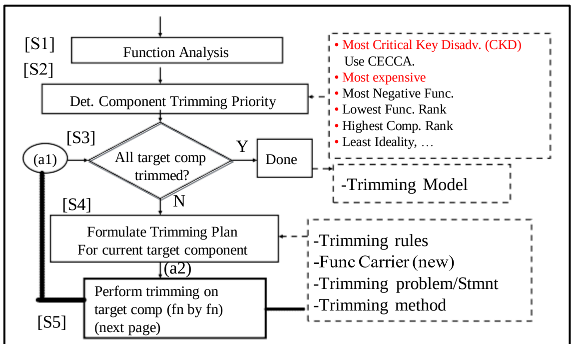

Fig. 10. Outer Loop of the Trimming Process.

- 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.

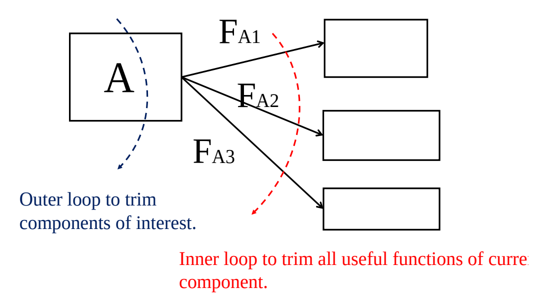

Fig. 11. Trimming of a component.

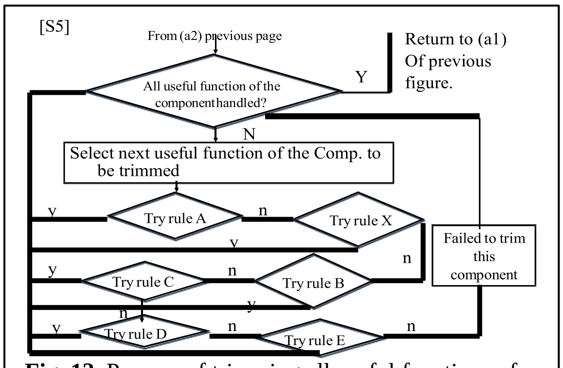

Fig. 12. Process of trimming all useful functions of a given component.

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

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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.

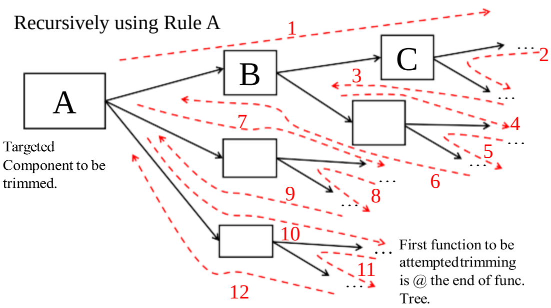


Fig. 13. Depth-first Recursive Trimming Sequence.

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.

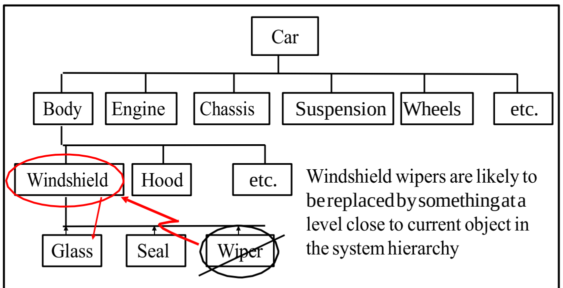


Fig. 14. System Component Hierarchy of a Car.

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.

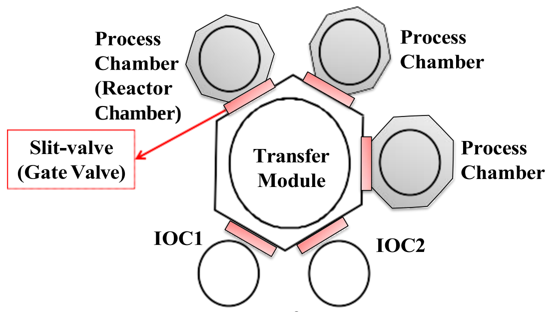


Fig. 15. Top View of the Equipment (Chemical Vapor Depositor, CVD).

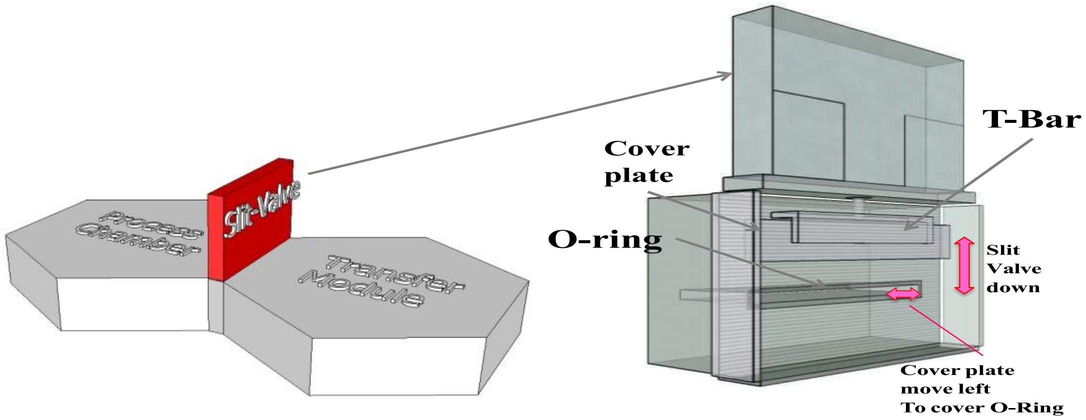
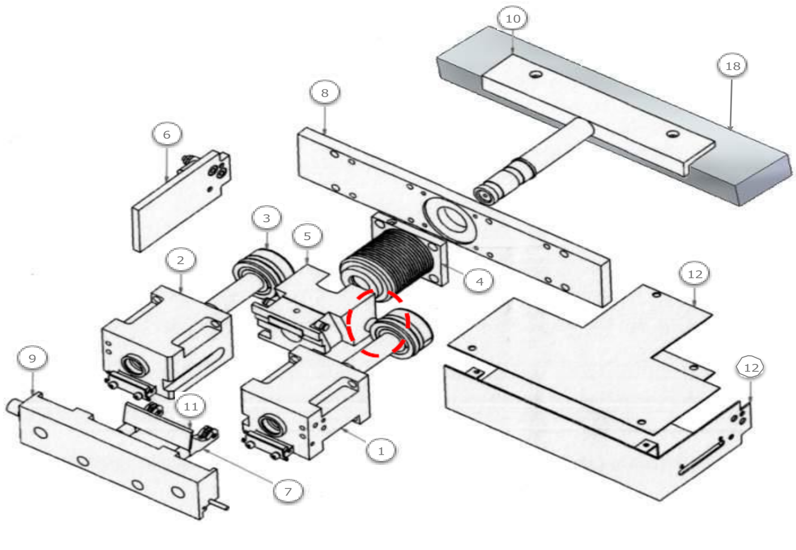


Fig. 16. Pictorial View of the Slit Valve and the Chamber.

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.

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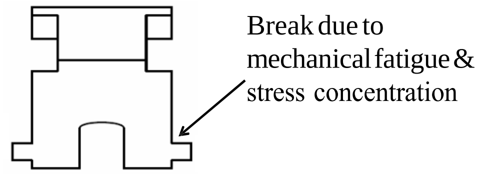

Fig. 18. Root sore point at the pin of the sliding guide assembly.

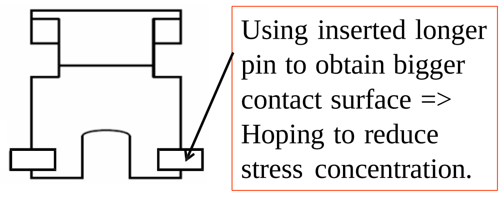

Fig. 19. Current solution by company engineers.

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.

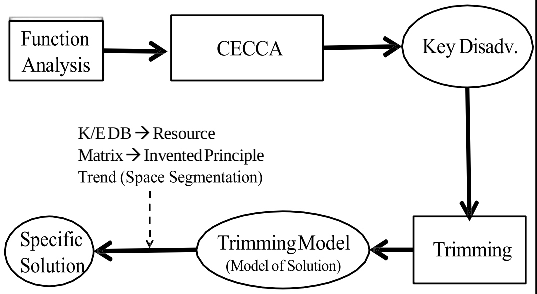

Fig. 20. The trimming process between FA and Specific Solutions of Fig. 9.

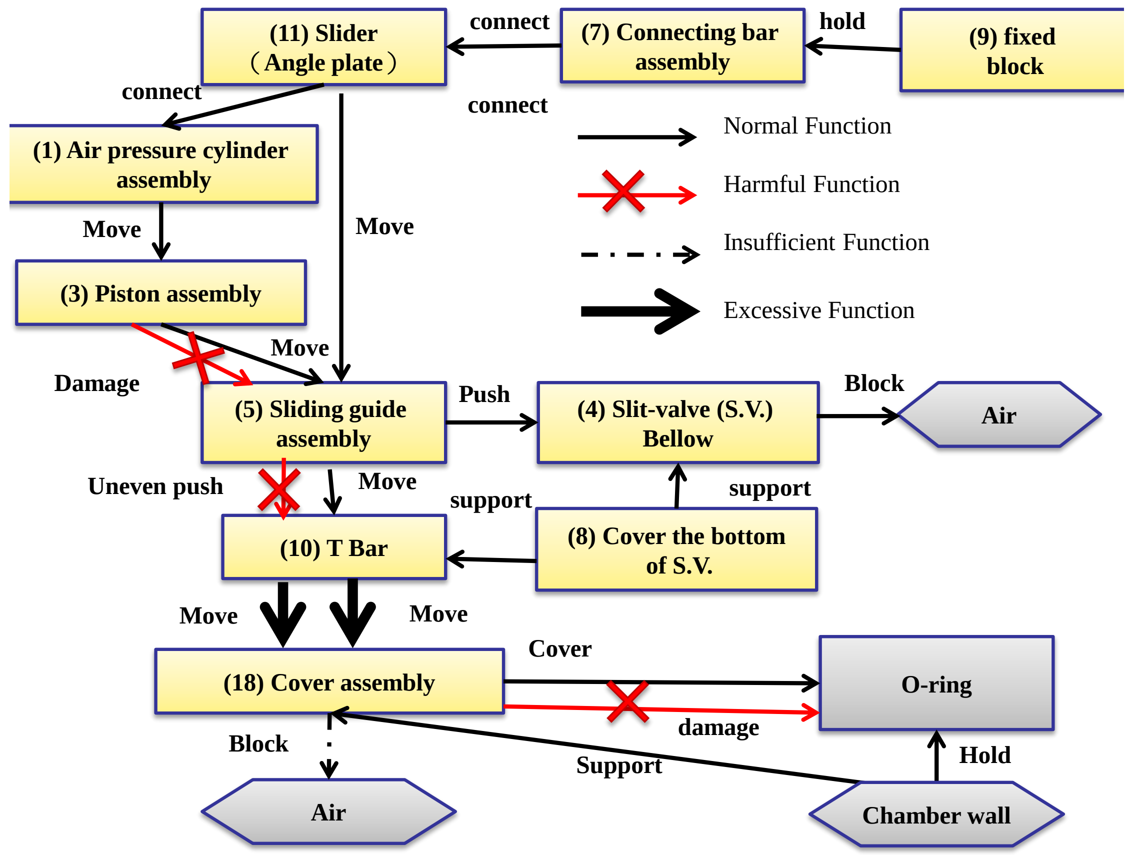

Fig. 21. Functional Model of the System under Failure Situation.

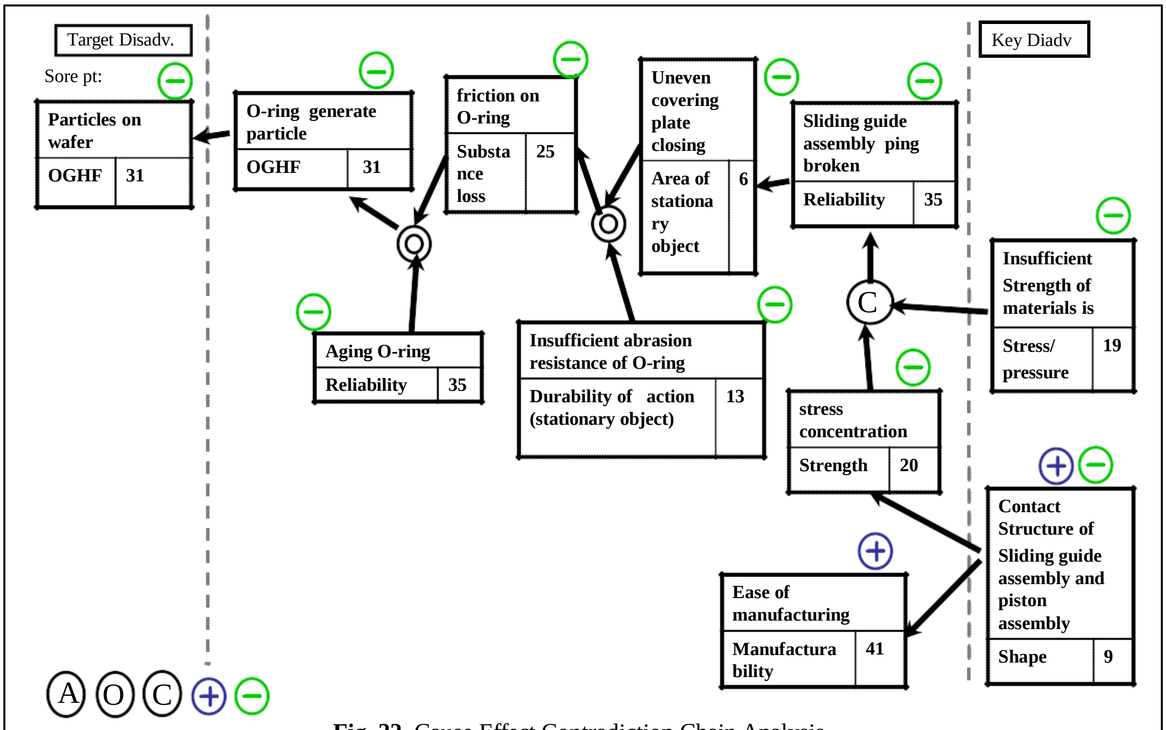

Fig. 22. Cause Effect Contradiction Chain Analysis.

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.

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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.

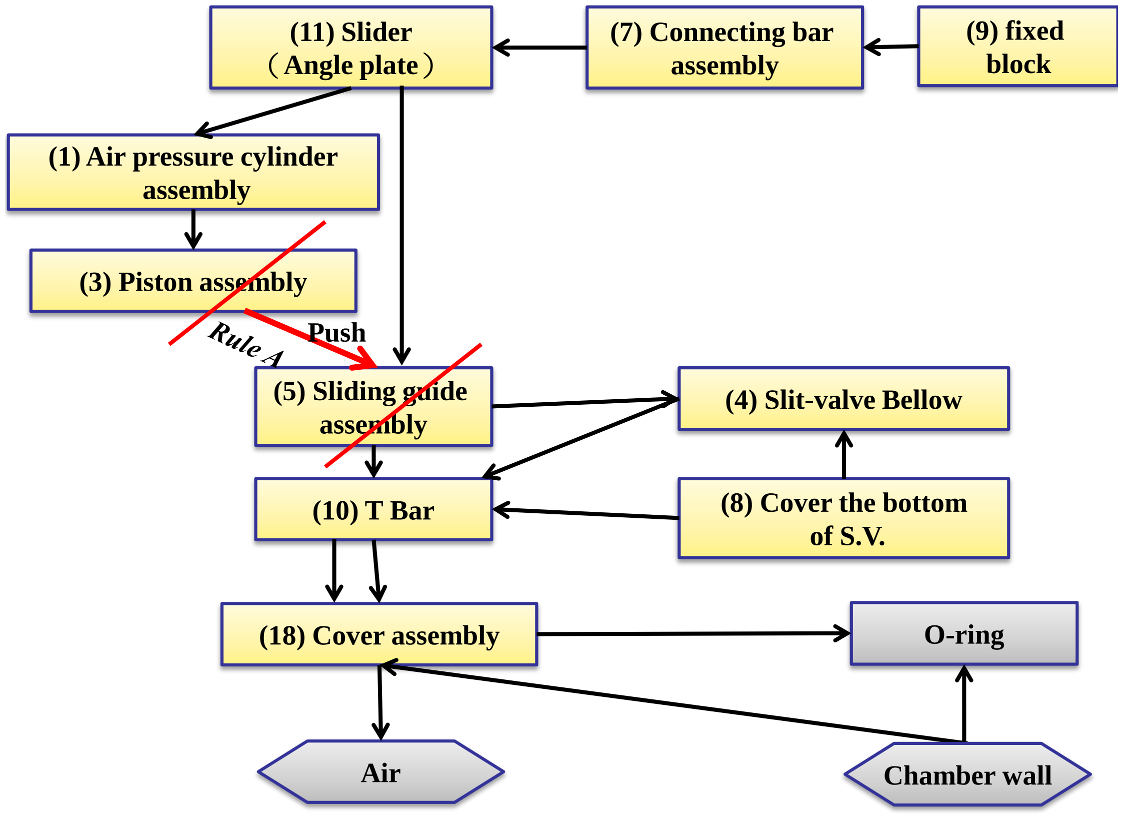

Fig. 23. Trimming Piston Assembly.

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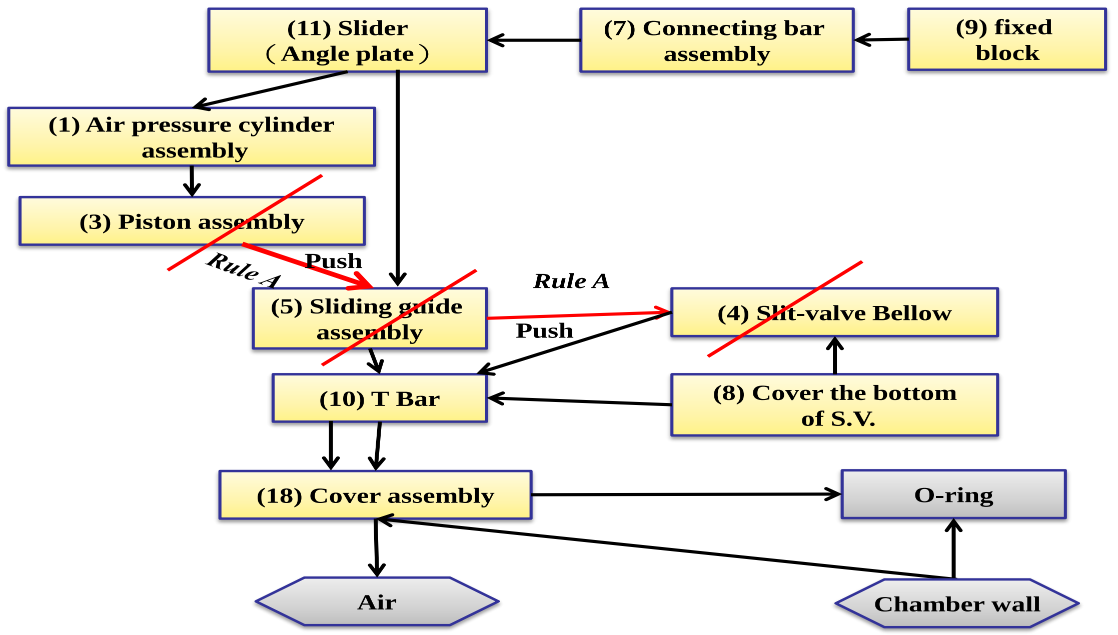

Fig. 24. Trimming Sliding Guide Assembly.

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)

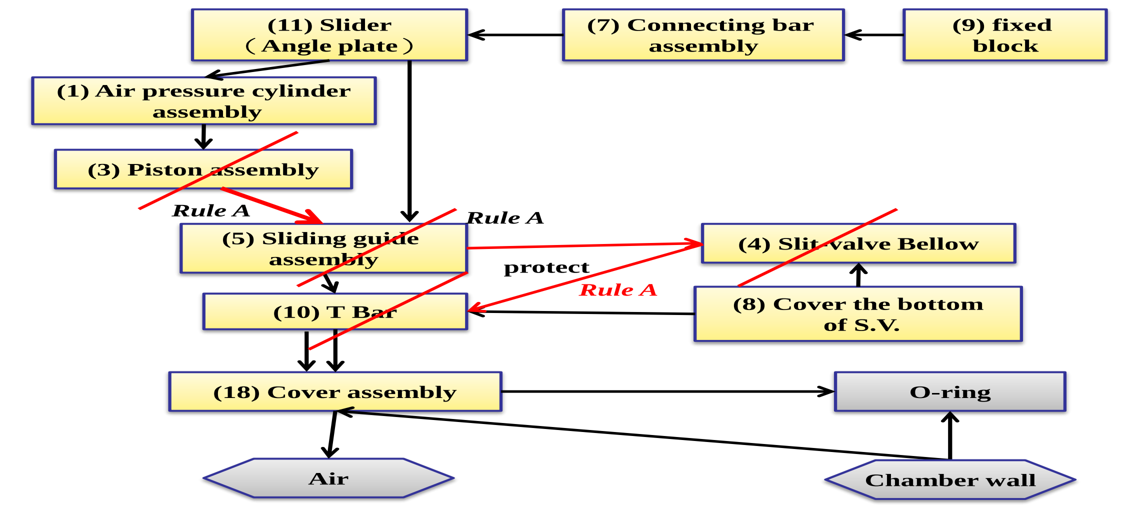

Fig. 25. Trimming Slit Valve Bellow.

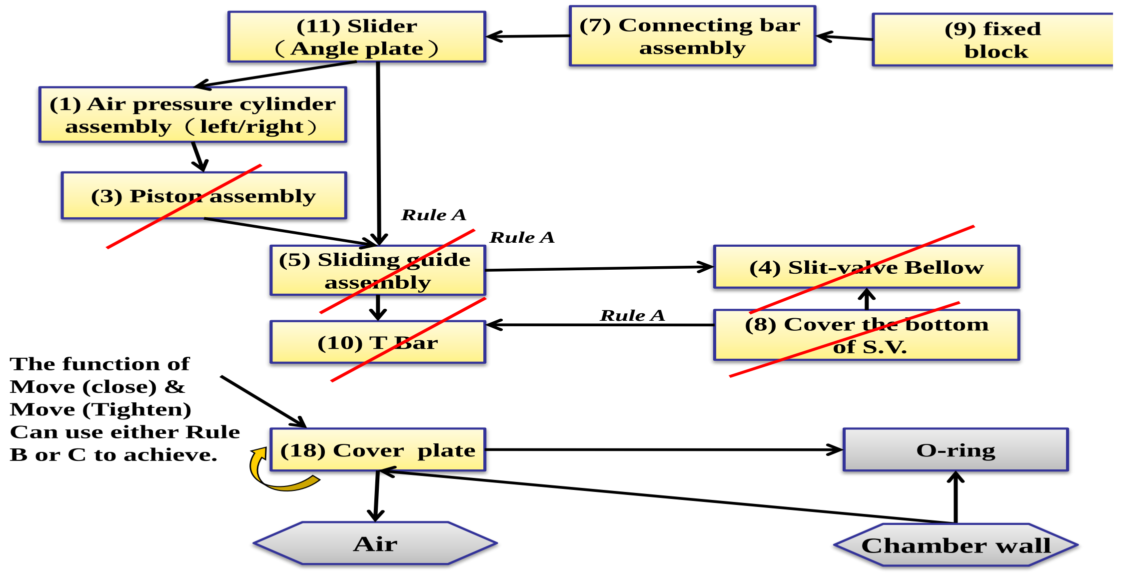

Fig. 26. Final Status of Trimming.

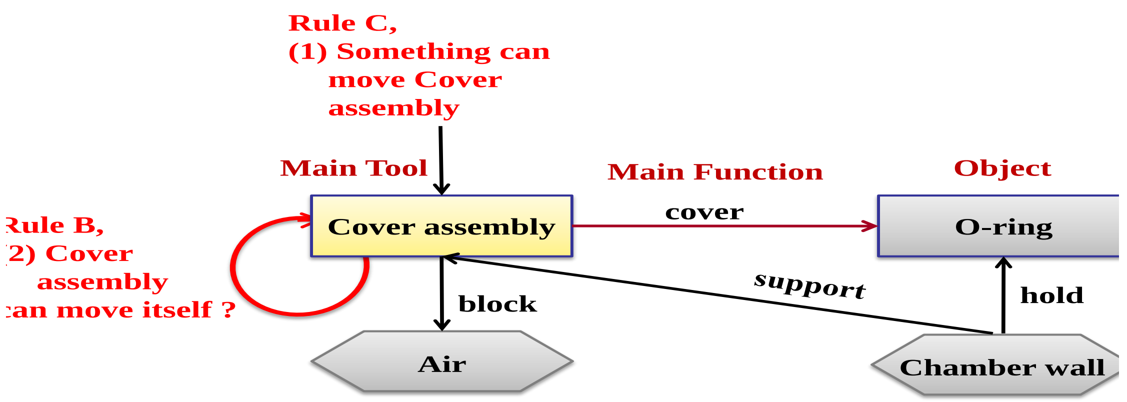

Fig. 27. Final Trimming Model.

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.

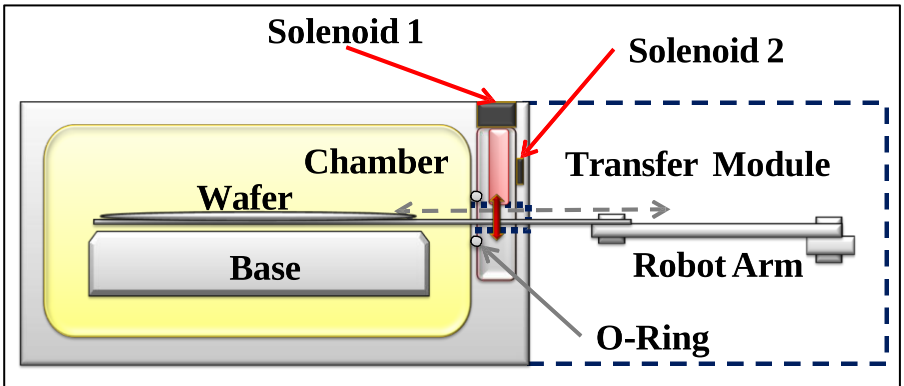

Fig. 28. Representative Solution of the Slit Valve.

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

The development of this theory is partially funded by National Science Council Project number: NSC 99-2221-E-007 -026 -MY3.

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10.6977/IJoSI.201203_2(1).0002
D. Russo, V. Birolini / Int. J. Systematic Innovation, 2(1), 22-32 (2012)

A TRIZ based method for making systematic innovation in Eco-design

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(Received 17 October 2012; final version received 5 September 2013)

Abstract

Today innovation has to meet the environmental aspects. The ever increasing scarcity of resources and the higher level of pollution are orienting consumers and therefore industries towards a cleaner production and green products. Within a time to market which is constantly reducing, companies need tools to quickly develop new products which provide customer and business value together with a lower environmental impacts.

In this paper, we propose a method to support innovation projects, taking into account also environmental requirements. The specific goal is to drive systematically the designer towards more sustainable products or processes, without interfering with its traditional design approach.

The method is based on an integration of Life Cycle Assessment (LCA) tools for collecting and processing information from all life cycle phases of the product, with a reworking of the TRIZ fundamentals (as the Ideal Final Results, Laws of Technical Systems Evolution and resources) for identifying where and how to intervene on it.

An application case is used to show the potentiality of the presented method.

Keyword: Eco-Design, Eco-guidelines, IFR, LCA,TRIZ.

1. Introduction

During last decades, functions, quality, and cost were the unique aspects considered in products/processes design. Now the sensibility of consumers toward green products and process, and the governor directives oblige companies to consider Eco-design. It is defined an approach to design of a product with special consideration for the environmental impacts of the product during its whole life cycle.

Different approaches have been performed in order to face the environmental problems. The first one is the so-called “Pipe and chimney solutions”, in which the dangerous emissions were moved away from inhabited zones. With the progress of the urbanization, and due to the impossibility to move the dangerous emission away, they were treated with filters and with the so called “End of Pipe Solutions.” The processes were less dangerous because the direct emissions to the environment are less, but they produced a great amount of waste. The following step was to implement cleaner and more efficient production processes in order to decrease the used resources and the discards. Actually, the tendency is to make innovation adopting “Product Oriented Solutions”, considering the whole life cycle of a product. Adverse impact on the environment can indeed occurs in any life cycle stage, as material extraction, manufacturing, use, distribution and end of life.

So, companies need to analyze and evaluate the impact of products during their entire life cycle (Tsai, Lee et al. 2011). Especially for small medium enterprises (SMEs) that is a time consuming and expensive activity, and it generally requires very specific competences, often extern to the company self.

Moreover, companies have to quickly improve or develop new products with less environmental load. Although at the state of the art many systems are present for supporting SMEs to make green products, they are still too abstract for a direct and easy application (Crals and Vereeck, 2005).

Additionally, we discovered that in Eco-design it’s a common practice to under-evaluate the role of resources; actually, most methods focus only on materials and energy and with quite a superficial attitude. For instance, the "companies' guidelines" for the choice of material are limited to a simple classification that goes from good materials to be used freely to awful materials not to be taken into account (Luttropp and Lagerstedt, 2006; Russo, Regazzoni et al., 2011).

By means of the combination of simplified evaluation environmental tools as abridged LCA with concepts from systematic problem solving practices, this paper provides a quickly and more effective method for designing more sustainable products. Particularly the integration of the IFR (Ideal Final Result) (Altshuller, 1984) concept into the LCA method, allows to identify the most effective energy/material key point on which is working.

The introduction of other TRIZ concepts as the Technical Laws of system Evolution (LTSE) and resources (Altshuller and Rodman, 1999) allow to transform the results of the previous LCA assessment into problems to be solved. A specific set of guidelines for supporting the ECO-improvement has been prepared and introduced into the methodology to find easier and faster new solutions. They have been constituted by combining the more widespread environmental suggestions with the TRIZ design philosophy and tools.

In the subsequent paragraphs, a literature review of methods and tools for eco-innovation introduces to the proposed method. A case study is then presented with qualitative and quantitative results, with the aim of defining limits and potentialities of that method.

2. State of the art of the Eco-Design tools for SMEs

In former times, engineers were only concerned about achieving design to cost and/or performance. The natural consequence was the manufacturing industry has been accused of operating a system that takes, makes and wastes, although it also has the potential to become a creator of products that generate ecological, social and economic value (Knight and Jenkins, 2009).

One possible way to improve on this viewpoint was for industry to embrace the "eco-efficiency" approaches providing a benefit to the customer/user at the lowest environmental/economic "cost" (Luttropp and Lagerstedt, 2006). In order to fulfill this goal, many methods and tools have been developed in the last decades, working on different levels of design (for product improvement, product redesign, new product concept, new production system definition) (Brezet, 1997).

Byggeth (Byggeth and Hochschorner, 2006) offered a classification of Eco-design tools in five classes according to their specific goal:

1. method and tools for the assessment of environmental impacts;
2. method and tools for the identification of environmental critical aspects;
3. method and tools for the comparison of environmental design strategies;
4. method and tools for the comparison of product solutions;
5. method and tools for the prescription of improvement strategies.

More generally the first four classes can be grouped in a wider category defined as analysis and assessment, while the last class is dedicated to the improvement (Le Pochat, Bertoluci et al., 2007).

2.1 Eco-Assessment tools

Eco assessment and benchmark environmental tools have been developed since the last three decades (Finnveden and Moberg, 2005; Ness, Urbel-Piirsalu et al., 2007), taking a huge magnitude of different approaches. One group includes those tools that focus their attention on material or energy flows, as MFA (Material Flow Accounting), TMR (Total Material Requirement), DMI (Direct Material Input), DMC (Direct Material Consumption), MIPS (Material Intensity Per Unit Service), SFA (Substance Flow Analysis) and EN (Energy Analysis). Furthermore, there are other approaches which take into account environmental impacts at a wider point of view: LCA (Life Cycle Assessment), SEA (Strategic Environmental Assessment), EMS (Environmental Management System) and EIA (Environmental Impact Assessment) belong to this group. Finally, there are those tools and methods that also include economic aspects, as CBA (Cost-Benefit Analysis), LCC (Life Cycle Costing), SEEA (System of Economic and Environmental Accounts) and IOA (Input-Output Analysis).

Amongst different environmental assessment tools and methods, LCA is the most established, well-developed and effective tool to evaluate the environmental impacts of a product throughout its life cycle (Le Pochat, Bertoluci et al., 2007). It is an approach which analyses real and potential impact that a product has on the environment during raw material acquisition, production process, use, and disposal of the product (Ness, Urbel-Piirsalu et al., 2007).

Although the interest in LCA grew rapidly during the 1990s, and a strong development and harmonization has occurred (Finnveden, Hauschild et al., 2009), many authors identified some weaknesses in the LCA approach, hoping for its further developments (Finnveden, 2000).

The main barriers to a wider LCA diffusion are (Consultants, 2000; Hur, Lee, et al. 2005):

- complexity of data collection;
- complexity of interpretation of results;
- expensive software and databases;
- high LCA required knowledge;
- no support provided to designers to improve situation AS-IS.

Therefore, there is a need for simplified methods that involve less cost, time and effort, but yet provide similar results (Hur, Lee et al., 2005).

So specific simplified (or abridged or streamlined) LCA methods have been developed (Hochschorner and Finnveden, 2003; Hur, Lee et al. 2005) and different depth levels of LCA analysis were defined (Wenzel, 1998).

In order to improve LCA approach, some specific projects have been supported by the European community such as the E-LCA and E-LCA2 projects (Buttol, Buonamici et al.). These projects‟ goals were to develop a simplified LCA tools and databases, called eVerdEE (Masoni, Sara et al., 2004) for simplifying the methodological aspects of ISO 14040, minimizing time and resource investments and not requiring people skilled in LCA. Good results have been obtained at level of environmental impacts assessment, thanks to a clear and ease interaction with a huge database of substances, but several efforts are still needed mainly to identify the environmental critical aspects, to compare different solutions and to prescribe improvement strategies.

This work tries to overcome these eVerdEE„s weaknesses in a more complete methodology dedicated to SMEs.

2.2 Eco-Improving tools

Tools dedicated to product/process eco-improvement can be grouped mainly in two categories: guidelines and checklists (Fitzgerald, Herrmann et al., 2007).

Checklist is a list of questions which enterprises can easily use checking the presence of features of a reference system (Le Pochat, Bertoluci et al., 2007).

Guidelines are indications which provide broad support, with little detail, but applicable either across the whole product development process and lifecycle, or covering a significant area (e.g. design for X) (Knight and Jenkins, 2009).

Although the use of checklists easily suggests environmental weakness of the analyzed system, they don’t suggest how to concretely reach the target of the feature out of value, but provide only abstract strategies of action without giving concrete innovation suggestions.

In addition, despite their apparent benefits it’s unclear if also guidelines are effectively used and if they have any real effects on product system innovation (Luttropp and Lagerstedt, 2006). Indeed some researches indicate that their application by SMEs is limited (Baumann, Boons et al., 2002). The main reason is the poor level of detail and the scarcity of indication for implementing the guidelines in a practical way (Crals and Vereeck, 2005).

3. Proposal

Based on this analysis, we define a methodological framework that introduces several novelties to the current state of art of ECO-design methods and tools. The main proposal is in the following:

- Information is collected adopting design techniques for process modeling, that works as interface of LCA tools used to assess automatically the environmental impacts. In this way also people not skilled in LCA can calculate the impacts just working through energy and material flows, already organized by life cycle phases.
- The identification of environmental critical aspects is not demanded to LCA tools, but it is conducted with a new design phase based on TRIZ IFR concept. We introduce the concept of “maximum potential reduction of impact” instead of “the maximum impact” caused by a flux. Furthermore, in order to near users to this approach the hot spots are graphically managed directly on the map of the process so avoiding any graphs or statistics.
- The improvement phase is dedicated to translate the hot spots in real problems to be solved. For the problem solving phase we have adopted the most structured problem solving methods, like TRIZ, rearranging them from a green perspective and making them usable by non-experts too. A wide set of Eco-guidelines, obtained combining

TRIZ based suggestions with best Eco-design practices, is provided.

These proposals are finally combined in a unique framework addressed to make Eco-design accessible to SMEs.

4. Framework overview

Due to the necessity to create an easy and effective method for guiding SMEs in the eco-innovation process, LCA software and eco-guidelines have been integrated in a wider system in order to jointly provide a quantitative assessment of products‟ or processes‟ ecological impact, and a relevant improvement strategy for designers.

The assessment of environmental impacts

The LCA assessment approach has been chosen as a foundation system in order to integrate inventing TRIZ capabilities to provide a more efficient approach.

The first novelty proposed in this work is that LCA assessment is not directly done on LCA software, but a more friendly process map, based on the IDEFØ (Integration Definition for Function Modeling), that is a method designed to model the decisions, actions, and activities of an organization or system by a graphic modeling language.

This allows an important simplification for users not skilled in the art.

The aim of this modeling phase (see Fig. 1) is to clearly visualize all the data and additional information of processes and products, in order to automate the eVerdEE SW compilation. The AS-IS situation map allows to show clearly all material and energy flows as well as their loops, with the values really used into *eVerdEE* SW during the quantitative analysis.

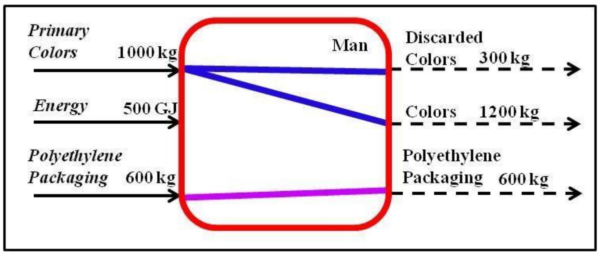

Fig. 1. IDEFØ modelling is used to collect gate to gate product and process information.

In order to visualize the environmental critical aspects, a similar map (see Fig.2) is proposed to visualize the quantitative impact of each flow on each considered environmental indicator. Every map shows the impact calculated with eVerdEE. Every flux is converted in its percentage impact rate: higher is the percentage rate, higher is the size of the arrow which refers to that flux. Fig. 2 shows the material and energy flows characterizing one of the painting activities in the manufacturing phase of a coloured tissue.

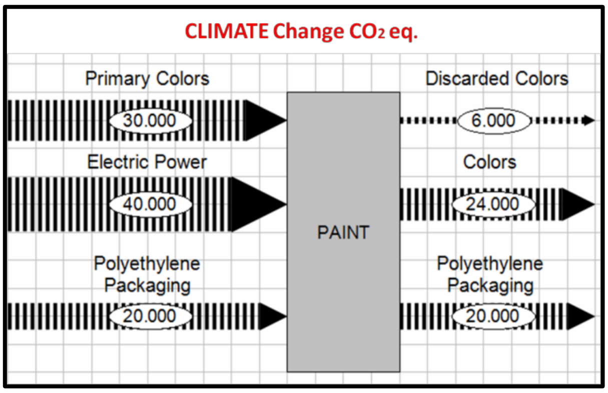

Figure 2 The map shows the impact on climate change (CO_2 eq.) of the main 3 flows characterizing one of the painting activities in the manufacturing phase of a coloured tissue.

The identification of environmental critical aspects by IFR

The aim of this phase is to identify the hotspot, that is the flux with the greater potential improvement. To reach this goal, IFR index is applied to every flux to weight how could be potentially reduced with a radical implementation.

By means of the definition of the Ideality and IFR concept, Genrich Altshuller was the first to realize that the direction of progress, or technical evolution, is defined by increasing the ideality level (Altshuller and Rodman, 1999).

For a technical system the ideality can be defined as:

$$\text{Ideality} = \frac{\sum \text{Useful functions}}{\sum \text{Harmful functions} + \sum \text{Cost}} \qquad (1)$$

All systems become more ideal during their evolution and different strategies to accomplish can be applied (Petrov and Seredinski, 2005).

Applying IFR means to rethink the redesign each part of our process according to the following definitions of ideal machine, methods, process, substance and technology (Savransky, 2000):

- the ideal machine which has no mass or volume but accomplishes the required work;

- the ideal method which expends no energy or time but obtains the necessary effect in a self-regulating manner;
- the ideal process which actually is only the process result without the process itself: momentary obtaining of a result;
- the ideal substance which is actually no substance (a vacuum), but whose function is performed;
- the ideal technique which occupies no space, has no weight, requires no labor or maintenance, and delivers benefit without harm, etc., and "does it itself," without any additional energy, mechanisms, cost, or raw materials.

Starting from these definitions, the IFR is the theoretical best solution of a problem for the given conditions.

Based on the IFR concept, an engineer can make "a step back from Ideality", that from an ECO-design point of view means no energy or material and consequently zero pollution. Stating the IFR and retreating from it as little as possible offers strong technical solutions, due to the possibility of designing the system that works almost without environmental impact. The application of IFR can result in an elimination of a flux, a strong reduction moving to best available technology or the introduction of a recycling loop.

For example, as shown in Fig. 3, taking into account the amount of energy used by a torch, the IFR application can be interpreted as an elimination of additional chemical sources by exploiting non pollutant resources as solar, or manual energy, or just as a strong reduction in the use of energy looking for low consumption technology as led.

Figure 3- An example of IFR Redesign on a battery torch. IFR thinking forces to conceive solutions not using any pollutant sources as the hand rechargeable or solar torches

At the same time, IFR forces to imagine a recycle loop in order to stop the material consumption or recover unemployed energy. For example, as shown in Fig. 4, taking into account the amount of paper used by a printer, the IFR application forces to imagine how to stop paper consumption, suggesting to move to recycled paper or towards new technologies for erasable and rewritable paper.

Figure 4- An example of IFR application on paper for printing. IFR means to 100% recycle paper without any pollutant material addition as in the case of erasable paper.

The application of IFR consists in redesign every flow of the map assigning the percentage rate of virtual reduction in the ideal situation (see Fig.5).

Adopting this index we are capable to associate each flow of energy or substance in input with the maximum potential reduction that can be theoretically achieved. Fig.5 shows the new ranking compared to that in Fig. 2: polyethylene packaging is now on top, because it can be totally eliminated, while primary colours are on the bottom. According to the new rank, it is suggested to work first on packaging and then reducing energy flow.

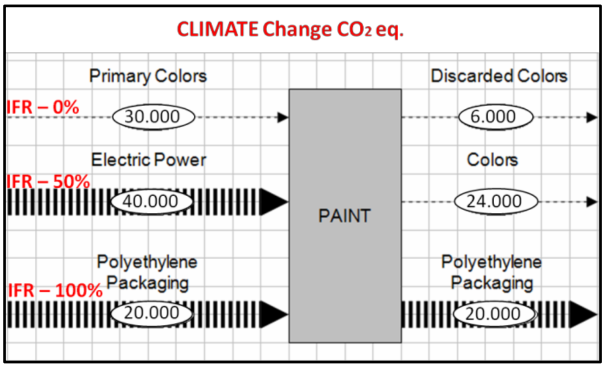

Figure 5- The map shows the new impact on climate change (CO2 eq.) of the material and energy flows calculated by introducing IFR index.

A sensitivity analysis on all flows based on realistic design criteria is so performed. Using this new index, the assessment is then made not only on actual criticality of existing flows but also on possible future theoretical improvement.

Applying the IFR index to each flux calculated by LCA SW, fluxes which initially have the greater impact, often are not the primary hot spots on which operate.

That means the application of the IFR index can overturn the initial ranking of the percentage impact rate of the considered fluxes.

The prescription of improvement strategies

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Genrich Altshuller has developed an analytical approach for technology forecasting and its theoretical foundation is a set of “Laws of Technical Systems Evolution”. These laws can be used for a judicious analysis and evaluation of the future designs of the systems of interest (Fey and Rivin, 1999); at the same time, they can be evaluated as a potential ally for existing eco-improvement methods (Jones and Harrison, 2000; Russo and Regazzoni, 2008).

Particularly, the tendency of some TRIZ fundamental such as ideality and laws of technical systems evolution (Altshuller, 1984) is to lead the existing technical systems toward ideality (Russo, Regazzoni et al., 2011). This process starts working from a resource using optimization (particularly material, energy and spatial resources) till they completely disappear. Our goal was to translate this process in the form of practical eco-guidelines (Russo, Regazzoni et al., 2011).

These guidelines have been extracted from the TRIZ laws of evolutions (Altshuller, 1984), and so their main theme is to reduce resource consumption (mainly material, energy and space) and to increase systems’ efficiency. This is possible by taking into account the best heuristics and theories of problem solving, and also taking into account new trends, technologies and best practices in green design.

According to the structure of LTSE, in the first versions only eight guidelines were developed. They were conceived with the aim of improving the initial system in the phase of use and they were directed mainly for TRIZ experts.

That work was then extended to all phases of the product life cycle, and new directions for action were added. At present, the guidelines constitute over 330 actions organized by pre-manufacturing, manufacturing, product use and end of life.

They are conceived to support the designer for improving a product, a process or a service according to their own “green requirements” until the end of the problem solving process. Eco-guidelines contain very detailed suggestions and strategies to solve problems, tricks and best practices in Eco-design, best available technologies and more other (see Fig. 6).

Each life cycle phase set of guidelines contains a list of objects to which the guidelines refer to. For every object there is a list of potential goals, opportunely translated in terms of resource abatement. For making a better product, user has to reach more goals as possible for increasing the energy efficiency, decreasing the material exploitation and the volume, both directly on the product and for all other auxiliary related products and processes (Russo, 2011). The existent architecture of that guidelines work firstly on system efficiency, on technologies substitution and secondly on flows substitution and optimization. Indeed, the first step of each goal offers a way to interpret and follow the IFR strategy.

If the solution is obtained by eliminating or reducing only existing flows (without introducing any new ones), automatically the reduction of environmental impact is given, while if the solution requires adding a new flow to the previous system, then it is necessary to realize a new LCA calculation taking into account the variants on the overall phases of the process. Only in this way, it is possible to verify the global effectiveness of the improvement action.

Among all the directions from “Guideline # act on packaging in use phase” one of them suggests reduce the packaging mass.

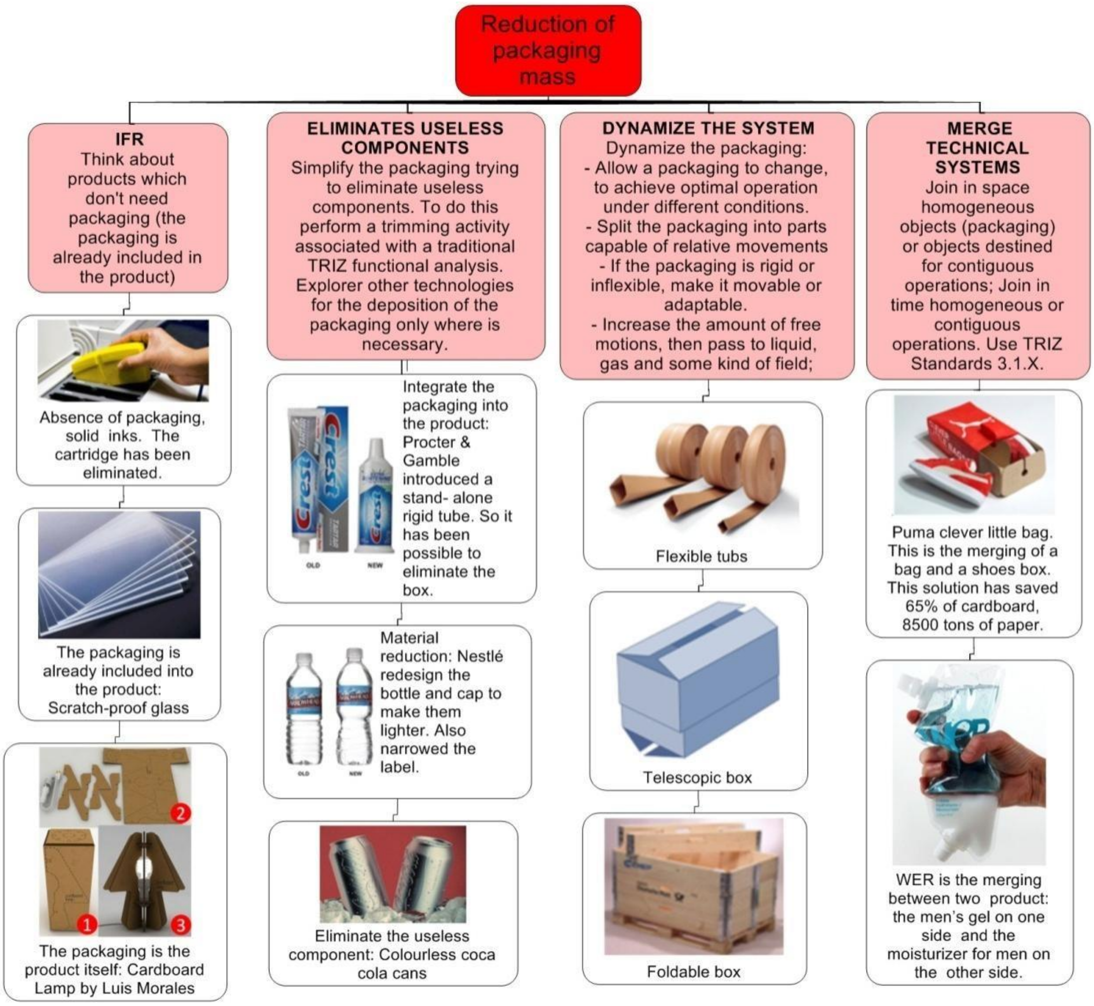

Figure 6. Example of a set of the 330 guidelines dealing with how to "reduce the packaging mass".

4. Case study

The case study concerns an industrial textile home-furnishings and bed linens painting company. The company itself produces the machines for painting and produces over 30 million m^2 of coloured fabric.

Actually, the process can be synthetically described by four different phases:

Pre-manufacturing: pigments and varnishes are prepared combining additives and other substances with water. Then auxiliary devices mix and transport the colours into the painting machines.

Manufacturing: four painting machines manage the colour delivery onto the fabric; another device recovers extra painting and cleans the dirty parts of the machines and auxiliaries. Another important phase of the manufacturing is post painting: here all processes dealing with drying are grouped: polymerization, vaporization, surface treatment, extra colour removal, and packaging.

Use: the phase of use of the fabric is not taken into account; all other related aspects were put into the manufacturing part.

End of use: this phase concerns all treatments of wastes, polluted water, solid/liquid chemical substances, exhausted colours, gas etc.

All the main functions of the painting process have been filled into the IDEF0 diagram decomposing in energy flows and substances.

Compatible with the availability of data (type of substances and energies) of our simplified LCA software database, the quantitative data associated with each flow has been broken down as much as possible, to ensure better accuracy of the analysis (for example, instead of entering an aggregate date relative to paint flow, it has been broken down in each chemical substance that composes the paint).

Assessment of environmental impacts

Once the diagram is complete, all collected information mapped as input in the diagram are processed by eVerdEE in order to calculate results of the impacts of every flow.

The authors decided to focus only on a set of potential indexes as criteria to determine the hot points:

- amount of material flow (kg)
- amount of energy flow (MJ)
- consumption of non-renewable energy (MJ)
- consumption of fresh water (m3)
- climate change (kg CO2 eq.)
- acidification (kg SO2 eq.)
- eutrophication (kg PO4 eq.)

Results for any environmental index are mapped in form of IDEF0 process map. According to LCA assessment, the map in Fig.7 suggests to intervene on white fabric (the biggest arrows among inputs).

The overall analysis allowed identification of the global environmental impact of the company. In particular, it emerged that every year the company produces 23,000 ton of CO2eq., where the fabric contributes 18,000t, energy (gas, electricity, gasoline) 1,600t, CO2 direct emissions a further 1,600t, nickel and steel 60t, chemicals for water treatment 60t, colours dyes 40t, etc.

In this analysis, flows with the highest environmental impact are fabric and methane.

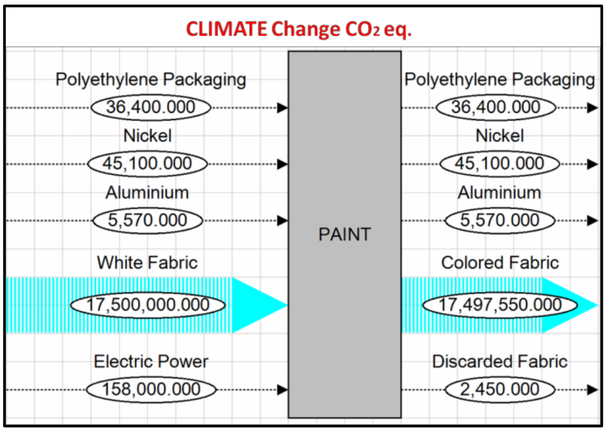

Fig. 7. IDEF0 model of a LCA results, before IFR index calculation

Here IFR index is introduced for any flow in order to evaluate where there could be the potential maximum reduction. Thus, a new ranking is provided, as shown in Fig.8. The element with the highest potential impact can be visualized by the width of its arrow. In this case, the new IFR assessment suggests to act for reducing nickel impact, fabric waste and electric power. Ranking of LCA is upset; white fabric is not considered a strategic target in order to reduce CO_2.

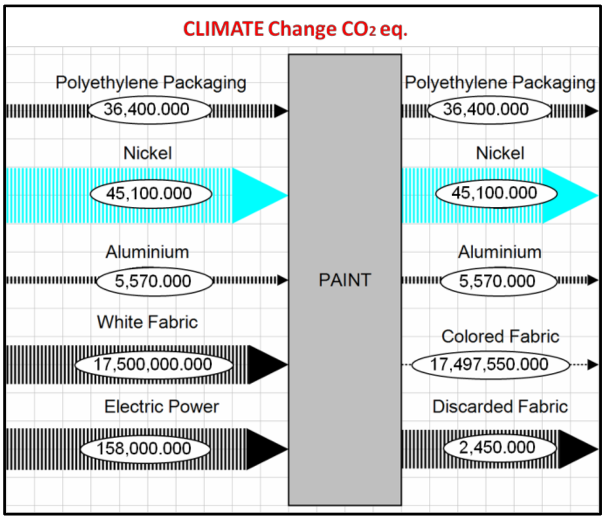

Fig. 6. IDEF0 model of a LCA results, after IFR index calculation

The prescription of improvement strategies

Next step consists in reducing elements in the top of IFR assessment as the Nickel.

Nickel is used in micro-perforated rolls employed in the painting phase. Every year over than 1,500 rolls of nickel are substituted and thrown away due to small deformations that appear on the external surface during the use and/or the removal phases.

Every roll is longer than 3 meters, it is constituted of a very thin sheet of nickel and it works in contact with the fabric that over time can make a dent that compromises the right functionality. Moreover, every roll is a very expensive component, it costs about a thousand euro.

This means if we introduce IFR index to eliminate nickel waste, it will be possible to reach both ecological and economic benefits.

Our new problem is to prevent the nickel tube is damaged or allowing its recovery.

This goal can be achieved by Eco-guidelines. There are several subsets of guidelines that can be checked to find a solution. For the sake of brevity, we take into account just the maintenance set:

1	re-design/use products with the highest

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	reliability and requiring the lowest maintenance;
2	remove causes of damage or think about a self-repairing/self-regenerating object.

This direction suggests preventing damage of the tube for example putting a metallic spiral inside the tube, as shown in fig. 10. This way can increase the robustness of the thin sheet metal of the tube, keeping it in traction and avoiding wrinkles on the external surface.

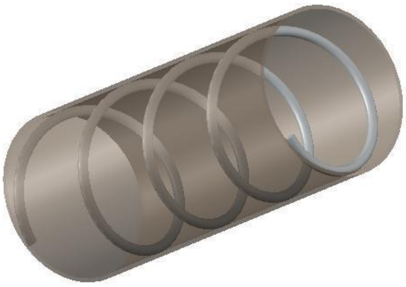


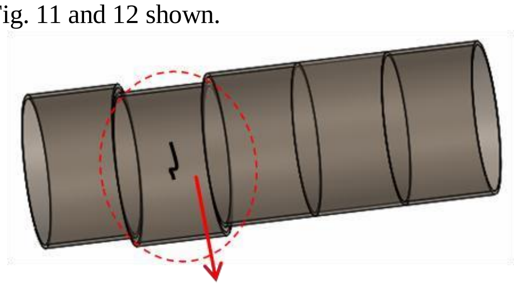
Fig. 7. Tube with an internal spiral which is maintained in traction with the tube.

In this way the increase in the useful life of the product has a positive impact on the reduction of the number of pieces used per year.

3	re-design/use easy reparable products; think about modular products, for example using the segmentation.

This direction can be achieved by avoiding employing a monolith tube and substituting it with a tube in more parts. So only damaged parts are removed and parts with the highest wear or with the highest probability of damage are made independent.

Segmentation can be achieved in different ways: a longitudinal segmentation and/or a transverse one, as the Fig. 11 and 12 shown.



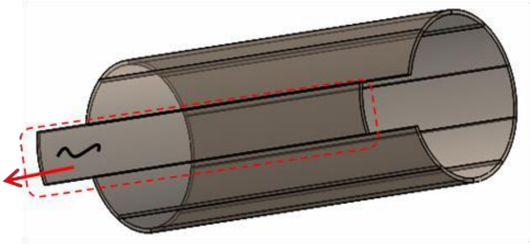


Fig. 8. Schematic representation of the application of transversal and longitudinal the segmentation.

4	re-design/use easy reparable products; think about modular products, for example using thermal deformation

Another option suggests thermal deformation. Localized heat treatment can be used for regeneration of the tube by making a deformation in opposition to those that arise during painting dyeing deposition.

All proposed solutions are currently under study and evaluation because all of that could potentially produce strong saving in costs and environmental impact. In fact, by avoiding wasting the nickel or recovering it at 100%, we can save 45 ton of CO_2eq., 8.9 ton of SO_2eq., 6.9*105 MJ of non-renewable energy and 856 m^3 of fresh water could be saved. For an economic evaluation, we need to take into account that a single nickel tube costs about a thousand euro and that each production batch uses at least 20 rolls at once, for a total yearly consumption of several hundred units (equivalent to 3000 Kg of Nickel).

Conclusions

In this paper, a new method has been presented for designing more sustainable products which meet the companies' needs to have a simple and quickly method for product improvement or redesigning.

Mainly addressed for SMEs, this method aims to simplify the general path of an Eco-design approach and to make the classical environmental tools more effective, by means of the integration with concepts of a problem solving theory as TRIZ.

Particularly the integration of the IFR concept into classical environmental assessment tools as LCA allows to move the attention from the key points to work on suggested by a classical LCA to those ones which permit a greatest potential impact reduction.

Doing that, the eco-design process can be more effective with a lower global environmental impact of the considered product/process.

Moreover, in order to help the designer to convert an abstract direction of intervention to a practical solution, the resource concept and the Laws of Technical Systems Evolution have been applied to create a new set of guidelines spitted up on the all life cycle phases.

The feasibility and the efficacy of the overall approach has been demonstrated by means of the application of the proposed method to an industrial case study concerning a textile home furnishing and bed linen painting dyeing company. The study was conducted downstream of a previous study aimed at obtaining environmental certification. A comparison between the new and the old production process reveals that the traditional critical points substantially overlap, whereas the introduction of additional assessment factors, such as the IFR factor, can generate new directions. IFR incites working on the flows with the largest potential reduction instead of the flows with the highest impact. Technical solutions are conceived by applying a list of pragmatic Eco-improvement guidelines. In particular, an example for eliminating waste of nickel during the painting phase is shown. Actually, one of these improvements is currently being tested and could potentially produce a saving of 45 ton of CO_2 and 8.9 ton of SO_2, contributing significantly both to reduction of eutrophication and global warming, and costs.

The methodology will be tested in future on new case studies in order to verify its limit. A further development regarding harmonization of the 300 guidelines is also on-going (Russo, 2011).

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AUTHOR BIOGRAPHIES

Davide Russo took his degree in Mechanical Engineering in 2003, and his PhD in Machine Design in 2007 at University of Florence. Now he is working as assistant professor at University of Bergamo, Italy. Since 2003, he has been working in the field of methods and techniques for innovation. He has experienced creative thinking tools and methods aimed at systematizing the process of understanding and structuring problems. The results of his research activity are reported in over than 50 paper publications and 7 patent applications. In particular, he is a TRIZ expert; the main subject of his PhD program has revealed how efficiently it can support a designer in his problem solving approach. At present, his main research is focused to create a new potential generation of CAI tools, both for problem solving, for knowledge management and sustainable design. He's also interested in testing new technologies for text-mining as a means for supporting new product development activities.

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10.6977/IJoSI.201203_2(1).0003

A Methodology for Integrating Web Based FMEA and TRIZ

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(Received 22 May 2012; final version received 18 October 2013)

Abstract

Failure Mode and Effects Analysis (FMEA) is a problem prevention technique predominantly used in industry. The applications of FMEA in Malaysia's automotive manufacturing firms are currently manually done on hard copies or into spreadsheets. However, these conventional approaches are not highly effective, since they are not living documents, and they involve tedious data maintenance and updating. Above that, the recommended actions are usually taken based on the accumulation of experience based on personal memory. This research aims to convert a traditional process Failure Mode and Effects Analysis (PFMEA) approach into an open architecture Process FMEA (PFMEA) web–based system, in conjunction with the automotive standard control plans, and to integrate invention problem solving methods (TRIZ) with this Web-based system. The Web-Based PFMEA model was validated using PFMEA data and failure reports provided by the Malaysian automotive manufacturing. This approach will help the process engineer to take action proactively when updating PFMEA and to improve or modify process control plans at a much lower cost. Integrated TRIZ with Web-based PFMEA can further assist in solving problems quickly and effectively. It also supports engineers to look for the most highly effective and creative solutions.

Keywords: FMEA, Internet Applications in Manufacturing, Web-Based Technology, TRIZ.

1. Introduction

FMEA is a methodology designed for identifying potential failure modes for a product or process, assessing the risk associated with those failure modes, ranking the issues in terms of importance, and identifying and carrying out corrective actions to address the most serious concerns.

Currently, FMEA has become a very important item among quality tools and has been increasingly adopted in manufacturing industries worldwide. In addition, FMEA has become standard practice in Japanese, American, and European manufacturing companies. For example, MIL-STD 1629A is the most widely used FMEA standard in the USA, similar to BS 5760 in the UK. (BS 5760, 1991).

In 1990, the International Organization for Standardization (ISO) recommended the use of FMEA for design review in the ISO 9000 series (Chen, 1996).

Basically, there are two main types of FMEA: design FMEA and process FMEA. Design FMEA is used in identifying design failures for products, machines, or tooling, while process FMEA is applied in the analysis of manufacturing processes prior to developing tooling or manufacturing equipment. In both cases, the effects of the failures are identified and the risks assessed accordingly (Stamatis, 2003).

Teamwork is critical to the success of the FMEA process. Therefore, the FMEA team from various departments must work in coordination and gather the required information to develop an effective FMEA report. The FMEA team must then analyze failure modes for each process involved in a product, and subsequently determine the potential causes and effects. Finally, the risk of each failure is prioritized based on the risk priority number (RPN).

RPN is a decision factor that provides a relative risk ranking. The higher the value of RPN, the higher is the potential risk. RPN is calculated for each failure mode and effect by multiplying the three rankings, that is, Multiply the The Severity of the effect, the frequency Occurrence of the cause of the failure, and the ability to detect (or prevent) the failure or effect. The ranking of the occurrence, the severity, and the detection method are based on a 1 to 10 scale.

Teoh (2005) stated that the traditional approach of conducting FMEA has several weaknesses. For example, the approach used for analyzing failure and problem solving is brainstorming, which can create many ideas, but most of which are not useful when solving problems. Also, the method used for recording the FMEA report is unsuitable for reuse as this method is recorded manually onto hard copies or into spreadsheets. With the development of the FMEA, it will thus become increasingly difficult to find specific information.

In the case of large and complex systems, the traditional approach offers restricted support for team members in carrying out an effective FMEA, and does not provide dynamic usage of information relations (Elmqvist, 2008).

However, it is increasingly difficult to use these techniques when the complexity of the system makes failure propagation hard to derive, often missing key failures. In addition, an FMEA developed late has no impact on key product and process decision-making. Moreover, in the traditional approach, the PFMEA is first utilized followed by the control plan process based on the risks identified, while a vital enhancement can be achieved through process control plans, and a dynamic PFMEA is used when updating the PFMEA or indicating internal /external failures and improving or modifying process control plan.

According to Daniele et al. (2011), it is becoming increasingly critical to manage risk in the product-development process, and traditional tools such as QFD and FMEA are not enhanced enough to address the risk. Therefore, there is a potential limitation if these tools are used separately. Thus, integrating the FMEA techniques with other methodologies used in product development, production, and maintenance will enhance FMEA capabilities. TRIZ inventive problem-solving approach can help in situations where unexpected problems have occurred and where the source or cause of the problem is unknown. TRIZ, the Theory of Inventive Problem Solving, a systematic approach that improves a team’s ability to solve problems, was founded by G.S. Altshuller, a Russian inventor, in 1946. Currently, it is becoming a powerful methodology in the developed countries of the world in research and application by producing systematic innovation and improving quality (Kim, 2009).

One way of dealing with the improvement of FMEA is to develop and apply a web-based system. There are high expectations that web-based manufacturing technology can and will provide satisfactory information to support integration and collaboration among the different partners of the product development team. Such a system can also improve product quality and reduce the cycle time and cost of product development, thus providing better global competitiveness of products in the marketplace.

The current research introduces a support tool for a web technology that will allow the involvement of FMEA process services on the internet to overcome the above limitations. In addition, by adopting the FMEA web-based system, an automotive manufacturing firm will be able to improve the efficiency and quality of product design production life-cycle integration, enterprise management, and customer service. Further, integrating the PFMEA web-based system with a control plan will activate the monitoring process and operation as a living document.

At the same time, the web-based PFMEA system is integrated with the TRIZ invention problem solving method. This facilitates a collaborative manufacturing environment for the team members, and makes up for the lack of design experience for new processes and products. This approach can also be used in the refining process phases, thereby making efficient improvements such as avoiding excessive brainstorming by shortening the time required. Recommendations arising from TRIZ contradiction matrix help engineers search for feasible solutions. As a result, better communication will be achieved, enabling team members from different departments to carry out product development activities as well as improve their abilities to solve problems.

2. Theory of Inventive Problem Solving (TRIZ)

TRIZ, "Teoriya Resheniya Izobreatatelskikh Zadatch" is the Russian acronym for Theory of Inventive Problem Solving, originated in the late of 1940’s, in the former Soviet Union as an attempt to develop a method, which would support a process of generating new ideas and finding solutions in a systematic way (Souchkov, 2007).

According to Savransky (2000) TRIZ is a human-oriented knowledge-based systematic methodology of inventive problem solving.

The originator of TRIZ, Genrikh Altshuller and his colleagues started development of this methodology. It is a problem solving methodology based on a systematic logic approach that was developed from reviewing thousands of patents and analysis of technology evolution. TRIZ can be used as a powerful tool for igniting the creative imagination to solve simple and difficult technical and technological problems more quickly and with better results (Kim *et al*., 2009).

The basic strategy of TRIZ is that " In most cases, the problem we're facing now, has already been faced by many other people at different times, at different places and in different situations, and most likely been solved in different ways". The TRIZ approach as shown in Fig. 1 is to "find the solution from those solutions" and allows connecting the problem to a standard problem and suggesting a standard solution, which provides the direction to follow to determine the best solution for the problem overcoming contradictions (John T. *et al.*, 2000).

There are various methods and tools in TRIZ innovation technology, which over the years have proven to be successful, including Problem Formulation, Contradiction Matrix, 40 Inventive Principles, Functional Analysis, Separation Principles, Substance-Field, Ideal Final Result, Effects, and ARIZ, etc. Users can select appropriate tools to solve their problem depending on the types of problems (Tien and Shao, 2011).

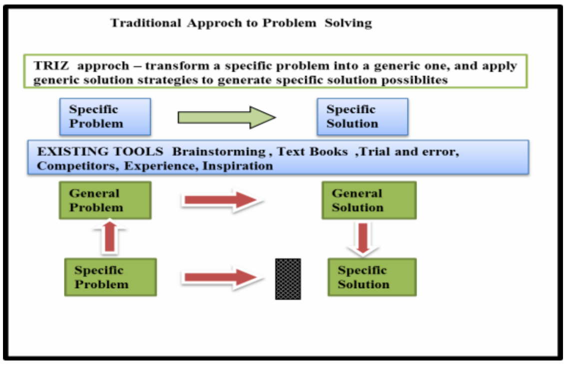

Fig. 1. Comparison between traditional and TRIZ

3. Related Works

It is recognized that the tedious of traditional FMEA approach make it not effectively used by industries. Hence, researchers have been interested in automating FMEA to improve its usability and several approaches have been highlighted in various studies to address the problems related to FMEA using different techniques and a number of collaborative product development systems or platforms have been developed. As a result, many commercial software packages have been developed (Huang and Mak, 2000).

Besides, the productivity increases and data management benefits such commercial programs, several issues limit their use at an industry-wide level, such as implementation costs, stand-alone, compatibility issues and they offer limited support for participation of team member over distance.

Neagoe (2010) stated that although, many automotive companies adopted FMEA since 1980, there are no real benefits that have been gained from the use of this technique in these companies, due to several important issues such as, the long time needed for the application of the analysis process, the ambiguity of certain technical aspects and the tedious project management lead to a difficult acceptance of the method to achieve the real improvements.

Kaufman and Sato (2004), pointed out that most automotive suppliers carry out FMEAs to placate their automotive manufacturers, or only because it is required by standards and regulations or specifically requested in their customer demands, and thus fail to consider and obtain the highest level of benefits.

D. Le Saux (2006) stated that the use of process control plans coupled with a dynamic failure mode effects analysis can spot potential high-risk process failures before they occur allowing the process engineers to take action proactively at a much lower cost.

A prototype software was created by Teoh (2005) and was evaluated using case studies from design and manufacture. However, there are some weaknesses from the prototype that needs further improvement, before it can be used in actual working environment. These limitations are its inability to represent different instances of the same model, to model logical processes, and to represent a dynamic behavior.

Huang (1999) argued that stand-alone FMEA software packages are unsuitable for team members in the FMEA process. They developed a prototype web-based FMEA platform that can be accessed by members at disparate locations via the Internet.

Huang and Mak (2000) developed a Web-based FMEA system for diagnosis and quality control. This system is composed of a Web server, a database server, and clients which provide better support for teamwork, remote and simultaneous access. A full evaluation of the system has not been conducted due to bugs in the implementation codes.

Neagoe (2011) pointed out that the geographic distribution of automotive production sites, and the development of the IT and communication infrastructure offer the possibility of using computer-aided management systems for the FMEA, with a web-based infrastructure that facilitates long distance collaboration, an essential requirement in multinational companies.

Johnson and Khan (2003) had conducted a study on the use of PFMEA in the automotive industries in the UK. He had established method on determining the effectiveness of FMEA. The study concluded that the PFMEA technique has limitations caused by issues such as the understanding of cause and effect and the practical aspects of managing the data and keeping it up to date. It was indicated that the suppliers found it difficult to quantify the true benefits of the PFMEA technique, in terms of costs, reliability improvements, and problem prevention.

Chung and Teng (2010) reported that the integrated Quality Functions Depeloement (QFD)/ AHP (Analytic Hierarchy Process) and TRIZ/FMEA for constructing the pattern of product design. This method can be practically used for a design strategic process executed in an enterprise. Such integration provides engineers an approach to convert customer's requirements to engineering parameters, avoid narrow thinking for products, and create new ideas.

Neagoe (2010) reported that using an FMEA web-based application allowed the participation of team members over distance, well suited for automotive international companies, with an efficient da- ta-management system and capability to reuse valuable FMEA information. Other advantages of using a computer-aided FMEA management system could be the integration with other reliability tools, various results reporting capabilities and the possibility to develop more complex risk-assessment models (integrating new factors such as costs) and automation capabilities. Mann (2000) pointed out that TRIZ is being integrated with other systematic innovation methodologies such as Six Sigma, FMEA, QFD, DFMA and Lean Manufacturing. The combined methods are beginning to be applied successfully across a number of widely disparate problem types.

Yen (2005) proposed a tool instead of traditional FMEA that emphasized environmental, safety and healthy operations during the product's life cycle to evaluate the priority to remove the failures or reduce their risks, by integrating the TRIZ invention problem solving method.

4. Proposed method

4.1 Web–Based FMEA architecture

Internet–based technology has become widespread in recent years because it allows global and easy access to data and information from anywhere. One of the greatest advantages of web-based technology is that the system does not need complicated functions. Furthermore, the low cost of application has further popularized its use (Jui and Chong, 2008).

A proposed prototype for web- based PFMEA system runs on PFMEA web server and interacts with PFMEA clients through dynamic Web page internet information Server (IIS), a powerful web server released by Microsoft, which provides a highly reliable, manageable, and scalable Web application. It communicates with the FMEA database server, and all of these components are, linked through the internet. Fig. 2 gives an overview of setting up the components.

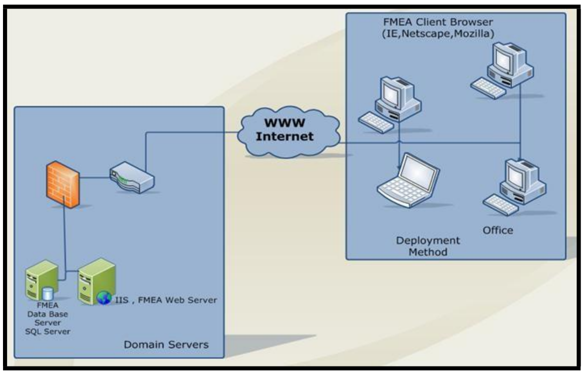

Fig.2. Web - Based FMEA Deployment

The Architecture consists of four main components, namely, Presentation Layer, Business Object layer, Data Access Layer and Resource Layer. Fig.3 shows Web–Based FMEA Framework Architecture.

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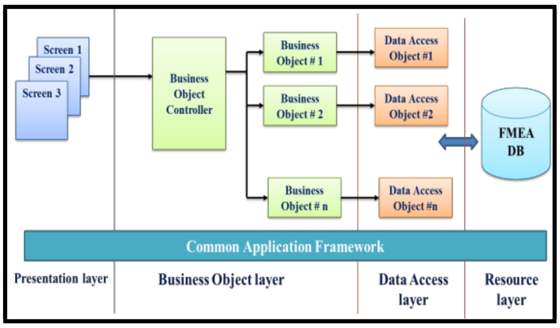

Fig. 3. Web–Based FMEA Framework Architecture

Presentation layer

A standard Internet Browser such as Internet Explorer is the primary client for the PFMEA application. HTML pages are delivered to the client browser by the FMEA application upon user request. In the presentation layer, the code-behind mechanism for ASP.NET pages and controls like text box, labels, command buttons, user controls, etc., are the prominent example of a layered design. The markup file defines the look and layout of the web form and the code behind file contains the presentation logic. It's a clean separation because both the markup and the code-behind layers house specific sets of functionality that benefit from being apart. It is also easy to maintain the design file and logic file separately.

Business Object Layer

The Business layer will implement the business rules for the application. It will host the business service components as well as business object (BO). These Business Services include Business Objects Controller including the .NET classes that will provide service API's to the business rules and operations required by the application. The business components are software units, and process business logic.

The business components will implement the following:

- Business rules, such as calculations and validations.
- Interfaces between the user Interface and the resource layer.

The business logic layer will run under the "Application Server" environment. Application Servers provide support for transaction control, thread management and other run-time services that make application development much simpler and reliable. Business components are generally computation-intensive. They will use Data Access Objects (DAO) to communicate with the database. The Business layer consists of:

- .NET classes: used to manage the data flow between the layers. Net classes on the other hand are simple .NET objects that provide utilities to the application. They may also contain business logic and provide other supporting services.

Data Access Layer

Data Access Objects using SQL DB connectivity will manage the interface to the database. Persistence can be complex in large applications using protocols like http. Neither the client nor the business component needs to be aware of this complexity. Moreover, there are many forms of storage ranging from databases to flat files. Decoupling the persistence logic from the business components and client allows for a flexible, easy to maintain application. The Data Access Object patter allows for the abstraction of the persistence from the business component. The Data Access Object manages the connection to the data source to obtain and store data. It encapsulates all access to the data store.

Resource Layer

The resource layer includes the underlying resources that the application uses to deliver its functionality. This includes using a database and file system information.

4.2 Web–Based PFMEA System development

The FMEA Web based system was carried out through different platforms on the Internet using web technology. The study has gone through four phases, including: (1) Developing FMEA into a web–based system. (2) Combining the FMEA web system with control plan and checklist. (3) Using TRIZ theory to determine the solution for potential Failure Modes, which worsens the product. (4)Returning to PFMAE to examine this solution, and whether it causes other devastating modes, in order to offer a user the perfect suggestion or solution. The interpretations of these steps are as follows:

Phase 1: FMEA

There are four main stages for its operation:

Stage 1:

FMEA Application hosted in a Web Server is accessible to a user via Internet Explorer. Security measures are taken into consideration, which enable only authorized users to login. Once the user is logged in, based on his access rights, he will be directed to his module whereby he can use the application accordingly. The system has included registration and functionality management.

Stage 2:

Client Internet Explorer will invoke/request the Web Server to provide FMEA System access. The Web Server will then communicate with the Database Server for DB Transactions using ODBC Connectivity. Communication between Web server and Database Server depend on user functionality.

Stage 3:

Product oriented functions, which define the operation for each process.

Administrator Process:

Here all the registration process takes place where immediately he/she can see all the registered users. Modification for such users is also introduced and groups will be created where the administrator can assign one of many users to each group. All the users who belong to a particular group will possess the same functionalities. System parameters will be able to configure this process for parameters including Severity, Detection, and Occurrence.

User Process:

1. Here the user fills in the required parameters accordingly to the existing failure modes whereby a user can choose any option to Add, Update or Delete such mode.
2. Once the parameters are satisfied, it will proceed to calculate the RPN.
3. Cause, Effects, Detention methods are recorded for failure cause.

Stage 4:

1. It includes the reporting service process. Users can view the report in chart view or text view for the failure's modes in terms of Severity, Occurrence, Detection and RPN.
2. Provision is provided to users to preview the report and to save to his system, as well as to print.

Phase 2: Control plan

The purpose of control plan methodology is to aid in the manufacture of quality products according to customer requirements. The control plan is an integral part of an overall quality process and is to be utilized as a living document. Therefore, Control Plan is used as the basis to perform the Failure Modes Analysis. The characteristics that are part of Failure Modes Analysis are transferred to the Control Plan. To achieve this, a Control Plan form is created and integrated with FMEA. To address which control plan needs to be linked is assigned in FMEA Tab once the FMEA is assigned in the control plan, Inspection Characteristics can be copied or transferred from FMEA into the control plan.

Consistency check of the Control plan is performed to ensure the consistency of assigned FMEA characteristics into all relevant task lists or inspection plans, followed by subsequent release of a control plan for Analysis of FMEA Characteristics. The FMEA Web-based system facilitates integration between FMEA and Control Plan.

The Procedure:

Creation of the control plan involves the following steps.

1. The user can create or Edit the Control plan by downloading the CP worksheet from the FMEA web server to the client machine during the access by clicking on the create Control Plan form.
2. The user can assign or copy FMEA to the Control plan by clicking the FMEA Tab.
3. Choose the FMEA column and assign the relevant FMEA in the Control Plan.
4. Save the transferred characteristics and close.

5. Click back icon to return to the Control Plan.
6. Click on the print preview of the Control Plan to view the CP structure with the Master data selection.

Phase 3; 4 Integrating PFMEA Web-Based System by TRIZ

In a traditional FMEA activity, engineers will usually define, identify, and eliminate known or potential failures, problems, and errors from the system, design, process or service before they reach customers. The RPN risk priority number of traditional FMEA consists of severity, occurrence, and detection. Severity is the seriousness of the failure, occurrence is the frequency of the failure, and detection is the ability to detect the failure before it reaches the customer.

The RPN can guide the engineers to find the more serious burdens and evaluate the priority to remove the failures or reduce their risks. Then, different kinds of recommendations are systematically uncovered, and any decisions taken depend on the accumulation of experience, but in some cases, team members do not have sufficient abilities to solve complex problems.

TRIZ techniques include Contradiction Matrix analysis, 40 principles of innovation, 39 parameters, Substance Field Analysis Model, and Seventy-six Standard Solutions Algorithm for Inventive-Problem Solving. Users can select appropriate tools depending on the type of problem and Fig. 4 shows the Integrated FMEA Web- based System with TRIZ.
The contradiction Matrix is the most popular tool. In this study contradiction matrix and 40 principles are used to solve the technical tradeoff problems during the process. Engineers can address unknown problems as well as explore different kinds of ideas and recommendations systematically. Moreover, it can compensate for the lack of practical design experience for new processes and products. Fig. 4 shows the Integrated PFMEA Web-based System by TRIZ.

The procedure

1. Identify and evaluate failures. Refer to failure checklist to gather the failure mode, effect and cause from PFMEA web-based system.
2. Prioritize the identified failure modes according to the RPN to sort the priorities for improvement.
3. Find out the TRIZ engineering parameters. Apply the TRIZ contradiction matrix table, compare and contrast these parameters with TRIZ inventive principles, 40 innovative principles, and 39 engineering parameters to search for the appropriate parameters, and then locate 1-4 suitable principles for resolving the particular problem. The engineers can obtain more feasible solutions and inspiration through the proposed approach.

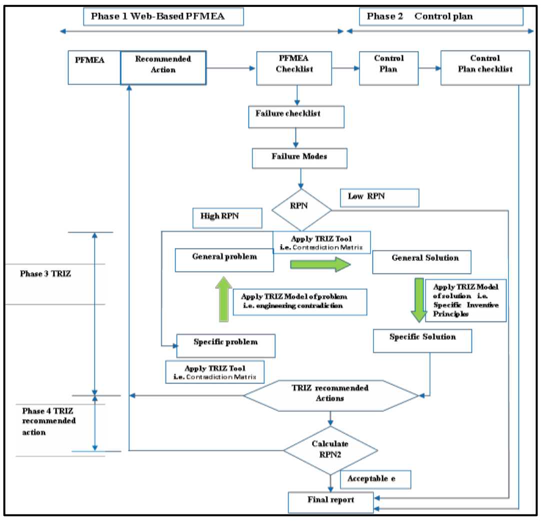

Fig. 4. Integrating PFMEA Web- based System by TRIZ

4. Take the suggested TRIZ action and return to PFMEA to examine whether this solution influences other effective modes in order to recommend a perfect solution to the user.

5. System Functionalities

5.1 PFMEA Form

This functional module consists of the following functions:

- Create New Form
- Approve Form
- Create New Checklist
- View Form

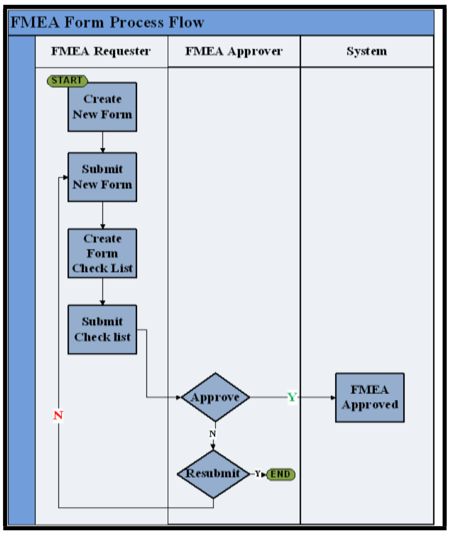

Fig. 5. Create FMEA Form Process Flow

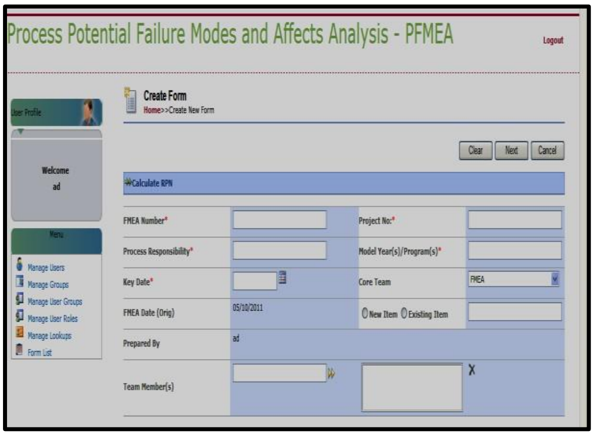

Fig.6. Create PFMEA new form screen design

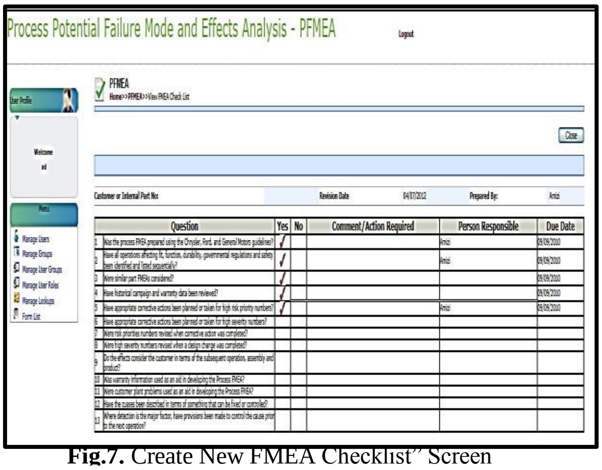

Fig.7. Create New FMEA Checklist" Screen

5.2 Control plan functional module

This functional module consists of the following functions:

- Create Control Plan
- Create Control Plan Checklist
- Approve Control Plan

Control Plan Process Flow

1. The FMEA Requester receives the FMEA Form from the FMEA Approver and creates a Control Plan.
2. The CP Approver will either approve/reject the Control Plan, if the services are no longer required.
3. If the Control Plan is approved, the FMEA status is changed. If the Control Plan is rejected, the Control Plan is returned to the FMEA Requester for amendment and resubmission. The FMEA status is then changed.

5.2.1 Create Control Plan

"Create Control Plan" allows the FMEA Requester to create a Control Plan for the PFMEA. However, once a Control Plan has been created and is in "Draft" version. They may edit the Control Plan that is in "Draft" version.

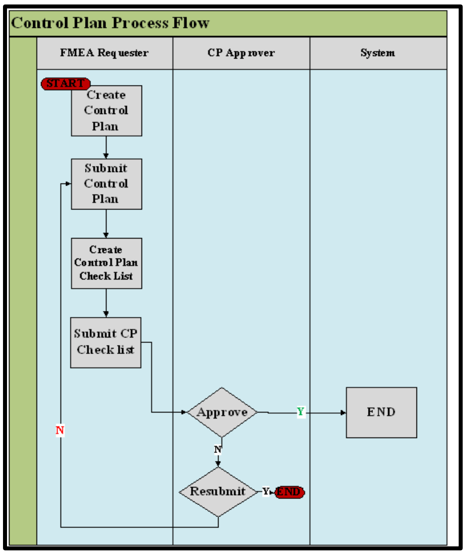

Fig. 8 Create control plan from process flow

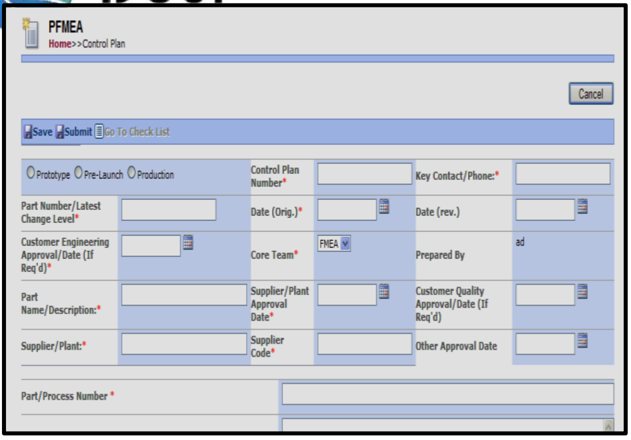

Fig.9. Create Control Plan Screen Design

5.2.2 Create CP Check List

This function allows the FMEA Requester to create a CP Check List for submission to the Control Plan Approver. The CP Approver is then able to approve/reject the CP Check List along with Control Plan. This is a mandatory task and cannot be bypassed.

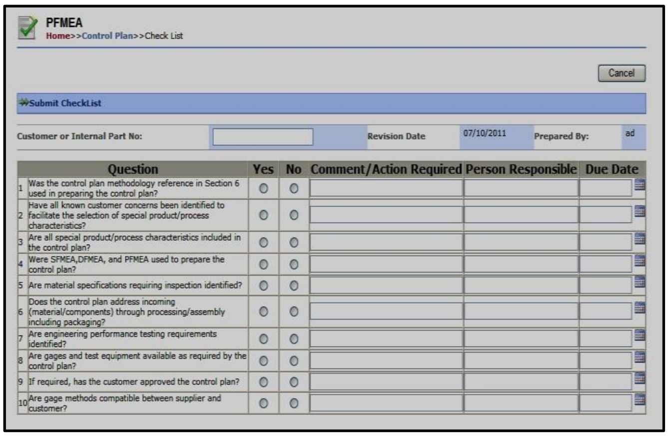

Fig. 10. Create CP Check List" Screen Design

6. Case Study

The case study was chosen from an automotive manufacturing factory in Malaysia. And the conducted data was part of the welding process, which includes a spot welding process. This case study demonstrated the capability of a web-based PFMEA system. It also provides a guide to utilize TRIZ theory to provide different kinds of recommendations. This will assist the engineers to find out the perfect suggestion of solution systematically. The data entry into the PFMEA web-based system in this case study was obtained based on the previous FMEA report as denoted in the table 1. The case study consists of four major steps which are illustrated in detail in the next section.

Table 1. PFMEA failure report

Requirements	Potential Failure Model	Potential Effects of Failure	Sev	Potential Cause(s) Mechanism(s) of Failure	Occ	Current Process Controls: Prevention	Current Process Controls: Detection	Det	RPN	Recommended Action(s)	Responsibility &Target Completion Date	Actions Results: Actions Taken	Actions Results: Sev	Actions Results: Occ	Actions Results: Det	Actions Results: RPN
Welding process																
	Spot crack	Strength Durability	8	Wrong parameter setting	6	- Do test piece every morning - 1pe/2hrs visual check by QC Inspector - S.O.P. & training provided for this process	- 100% check & marking by operator - In-process inspection 1pe/2hrs by QS	6	288							

Step 1: Create the PFMEA worksheet to identify potential failure and to prioritize the identified failure modes according to the RPN to sort the priorities for improvement.

The PFMEA users can access to the system to create a new form. The PFMEA users simply obtain a subscription to a private and secure account.

Step 2: The Risk Priority Numbers (RPNs) are then calculated automatically by the software based on the selections from the fully configurable rating scales for severity, occurrence, and detection. Then, the color-coded zones indicate the highest risk items.

For example, if the user specified that all records associated with an RPN ≥200 are considered to be in high priority, then those records will be highlighted with a color that represents high-priority issues.

In this case study, the results demonstrated that the RPN is higher than the level range, then **Step 3** The user begins to enhance the PFMEA capabilities through its integration with the TRIZ. In this web page, user can click on the TRIZ tab where the web page with the TRIZ map diagram is displayed as a static page. The TRIZ here is not part of the dynamic web-based PFMEA system, but it is used in conjunction with PFMEA based on the RPN results, as shown in the Fig.11.

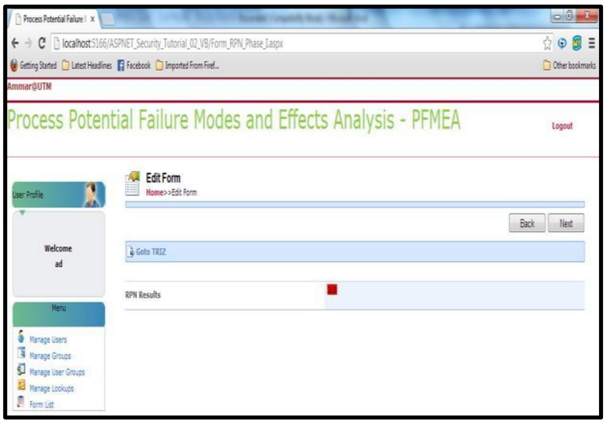

Fig 11. RPN Results with risk factor

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Such RPN rate needs to be refined by taking action and updating the severity, occurrence and detection. In almost all existing resources of failure mode and effect analysis (FMEA), recommended actions are being determined based on the engineer's experiences. In this case study, the application of the new PFMEA-TRIZ procedure is described to provide an example of a real application. Since failures with high RPN it was (288) as has been shown in Fig. 11 have been identified, the failure mode was a spot crack for the spot welding process the effects of this failure are weak strength durability. Thus, welding requires a parameter setting. The technical problem goes through the TRIZ's 39 engineering parameters and becomes a TRIZ problem. The input heat improvement and control are important engineering parameters in welding and can be regarded as the "#15 Durability of moving object" in the TRIZ engineering feature. In the meantime, the TRIZ worsening parameter as "#14-Strength." when the user maps these into the terms of the 39 parameters of the contradiction matrix to get pairs of improving-worsening features, the corresponding inventive principles are dentified according to the pair as shown in Table 2.

There are three potential inventive principles for this situation:

Principle # 27. Cheap short-living objects

- Replace an inexpensive object with a multiple of inexpensive objects, comprising certain qualities (such as service life, for instance).

Principle # 3. Local quality

- Change an object's structure from uniform to non-uniform, change an external environment (or external influence) from uniform tonon-uniform. Make each part of an object function in conditions most suitable for its operation.
- Make each part of an object fulfill a different and useful function.

Principle # 10. Preliminary action

- Perform, before it is needed, the required change of an object (either fully or partially).
- Pre-arrange objects such that they can come into action from the most convenient place and without losing time for their delivery.

The cracks defects, are considered to be the worst in spot welding which is widely used in the joining of sheet metal for autobodies, since even a small crack can grow and affect weld quality then lead to failure. Spot welds can fail in the circumferential failure mode where the failure occurs along the nugget circumference when the weld has a weaker strength than the base metal, and /or the weld nugget size is too small compared to the thickness, the welded sheets can separate along the interface in the interfacial failure.

Therefore, principle #3 Local quality" has high feasibility in this problem is a suitable choice.

The above inventive principles bring innovative solutions to the PFMEA that enables one to track the completion of recommended actions, which may eliminate or reduce the chance of potential failure of product or process and its effects. Fig. 12 indicates the recommended TRIZ action based on the inventive principles solutions.

Table 2 TRIZ solutions of feature #15 relative to feature #14

Improving features	Worsening features
# 14: Strength	15: Durability of moving obj. without damaging
	27, 3, 10

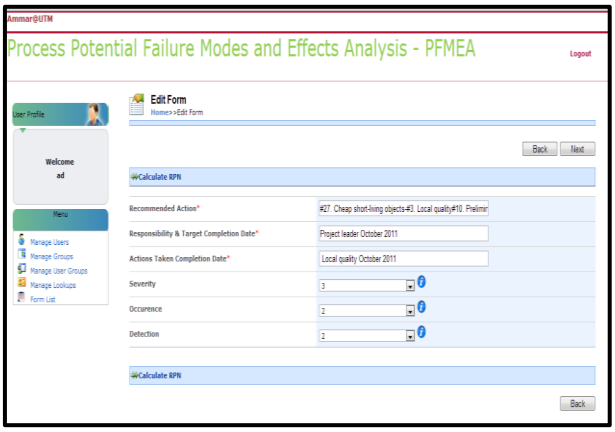

Fig. 12. TRIZ recommended actions

Then the PFMEA data can be presented via reports, and integrate the PFMEA with related analyses, such as the process control plans. From this stage, it is also possible to move to the other forms such as the PFMEA checklist, which is used to evaluate the PFMEA's.

Step 4: Create the process control plan form, allows the PFMEA requester to create a control plan for the PFMEA. However, once a control plan has been created and is in a “Draft” version, they may edit the control plan that is in the “Draft” version. The PFMEA system is used in combination with the control plan which allows users to automatically generate a control plan form based on relevant data from an existing PFMEA. The data field carried out for the case study is displayed in the process control plan form as shown in Fig. 8. Once the control plan is completed, the user can create the control plan checklist to assist in its evaluation. Fig. 9 illustrates the process control plan checklist.

7. Discussion

Basically, there are three types of software tools needed in creating data driven applications, a modeling tool, a programming tool, and a database. In this research, Microsoft Net Technologies was selected for programming reasons, such as ease of usage and availability. This is to ensure that the development cycle time is minimized, and the research objective can be met. Microsoft Net Technologies has matured into a robust and versatile development environment for both windows-based and web-based application development. With its emphasis on XML technology and Web Services, .NET allows businesses of all sized to take advantage of the Internet for distributed computational power. Nevertheless, preliminary tests have been conducted within a limited scope. In terms of the usability, the prototype system has been tested within an industrial environment. Small sample size is one of the limitations in this approach. This research was conducted within a single company in the automotive industry. Secondly, due to the time constraints of this research, only three in-depth case studies were conducted for theory building, and testing the prototype. The comprehensiveness and robustness might be improved if more test cases were applied. However, the results and analysis are based on the information available. In terms of performance, the prototype system is considered acceptable within the test environment in terms of the time required for creating the PFMEA worksheets, creating PFMEA checklist form, creating process control plan form, creating a control plan checklist form, and integrating the system with TRIZ, connecting to the remote database, and working with the system after it is downloaded at the client page. However, it is unclear if a similar acceptable performance can be achieved when the PFMEA web server, PFMEA database server, and the clients are distributed far away. Problems have been encountered when accessing the remote PFMEA database.

Future research could focus on enhancing this software to be much user- friendly, improve the security level of the web browser, and use the system in early design stages.

8. Conclusions

FMEA is a methodology designed for identifying potential failure modes for a product or process, assessing the risk associated with those failure modes, ranking the issues in terms of importance, and identifying and carrying out corrective actions to address the most serious concerns. In traditional FMEA, users face many difficulties due to the weaknesses of the current approach. An effective way to improve the effectiveness of the FMEA is to propose a support tool for a web technology that will allow the involvement of FMEA process services on the Internet to overcome the convention FMEA limitations.

This paper makes a significant attempt to employ Internet technology to provide a PFMEA system for the automotive manufacturing firm in Malaysia, which fills the current gap of deficiencies in traditional FMEA. This approach will help the process engineer to take action proactively when updating FMEA and to improve or modify process control plans at a much lower cost. Integrated TRIZ with Web based FMEA can further assist in solving problems quickly and effectively. It also supports engineers look for the most highly effective and creative solutions.

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10.6977/IJoSI.201203_2(1).0004

J. P. Tsai, Y. G. Chen / Int. J. Systematic Innovation, 2(1), 46-54

Approach of course development for cultivation of innovative capability of students at university

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(Received 27 November 2013; final version received 29 November 2013)

Abstract

Course design and development need to be considered in many aspects such as goals, features, resources, and constraints of each institution. Furthermore, it should conform to society's needs and should be improved according to the advances of knowledge. In order to cultivate students' capabilities corresponding to the needs of industries so that they can better cope with the severe competition in today's knowledge economy era, schools should have responsibility and endeavors to instruct students how to acquire innovative knowledge rapidly. In this paper, a systematic method of course development for cultivating the innovative capability of students at university was proposed based on knowledge chain model. An example implemented at Far East University in Taiwan was used to illustrate the feasibility of the proposed method. The concept and method proposed in this paper might be used as a reference and guidelines to promote the education of patent related courses at university.

Keywords: Course Design and Development, Patent Application and Protection, IDEF0 System Analysis, Knowledge Chain Model, Engineering Innovation Education.

1. Introduction

The cultivation of student's innovative capability has become more important for promoting his competitiveness in this knowledge economy era. However, due to the diversity of student's backgrounds and interests, how to effectively elicit the interest and reach the potentials of students is an indispensible prerequisite to approach the above-mentioned goal and this is also a problem worth studying. Though there are many courses which provide various tools and methods to cultivate the creative or innovative capability for the students, it is still insufficient to ensure whether the teaching objective of the course and the learning performance of student have been achieved, especially for the advanced creative courses or project-oriented courses. Therefore, in order to elicit the student's innovative capability, it is necessary to systematically analyze, plan and design a framework or method to reinforce engineering innovative education from a context-oriented perspective considering prior professional knowledge, basic creative knowledge, advanced creative knowledge, individual interests, etc.

Recently, TRIZ has attracted huge attention of industries and proved its effectiveness on innovative product development. Many innovative approaches have been proposed to increase the development efficiency of the product and process so as to help enterprise to enhance the competitiveness within it. Samsung Advanced Institute for Technology (SAIT) proposed a novel approach to predict prioritized directions of innovation as well as to create the most promising design of practical concept design so as to align the feasible direction of innovation based on the general evolutionary patterns of technical systems (Song et al., 2012). Yang and Chen (2012) integrated TRIZ evolution patterns with CBR and simple LCA methods to forecast the design of eco-products and used an example of a cell phone to demonstrate the effectiveness of the proposed model. Yeh et al. (2012) integrated QFD and TRIZ in the research and development process of a notebook. They identified major QFD contradictions, TRIZ inventive principles, and eco-efficiency elements to achieve green-design solutions. Sheu et al. (2012) developed a suitable contradiction matrix and invention principles for Chemical Mechanical Processing (CMP) equipment and processes in the semiconductor industry. Li (2010) integrated TRIZ and AHP to develop innovative design for automated assembly systems. He used TRIZ to propose the automated design alternatives under the innovative design consideration and to use an AHP to evaluate and select the best feasible alternative under multiple criteria.

TRIZ contains a variety of useful tools such as 40 inventive principles and the matrix of contradictions, laws of technical system evolution, substance-field analysis, and ARIZ (algorithm of inventive problems solving). However, as some of the courseware and content in TRIZ is complicated for students, it is worth developing a systematic course design for diverse students with different backgrounds. Mann (2004) has provided a systematic innovation method including four stages- problem definition, tool selection, solution finding, and solution evaluation. Sheu and Lee (2011) proposed a new systematic innovative process to facilitate and pace the systematic innovation and a platform to integrate heterogeneous resources and tools, such as TRIZ and non-TRIZ tools. Ogot and Okudan (2006) introduced TRIZ in a first-year engineering design course and the research results indicated that TRIZ makes it easier for students to generate feasible concepts to design problems. Turner (2009) proposed the "Advanced Systematic Inventive Thinking" (ASIT) method as a problem solving strategy for education. Sokol et al. (2008) implemented an empirical study on the efficacy of the Thinking Approach (TA) to language teaching and learning for foreign language education. In order to guide a user with no TRIZ education to the analysis of inventive problems, Becattini et al. (2012) developed a model and algorithm for computer-aided inventive problem analysis based on an original model and a dialogue-based software application integrating the logic of ARIZ (Algorithm for the Inventive Problem Solving) with some OTSM-TRIZ (General Theory of Powerful Thinking) models.

The innovative education has become more imperative in this knowledge era. However, there are few papers to explore how to plan and design the course and arrange the sequence of the correlated courses with systematic method. Therefore, in this paper, we focused on engineering innovative education and proposed systematic approach to design and develop the course for cultivation of innovative capability of students at university. Based on the above-mentioned argument, it reveals that the plan, design and implementation for a feasible advanced innovative course need to face many problems such as prerequisite courses, prior background and knowledge of students, cultivation of teachers' expertise, adaptive selection of the teaching materials, availability and affordance of teaching equipment, application of e-learning platform, design of teaching tools and method. Therefore, an adequate and systematic approach to provide the regulations and criteria for the plan, implementation, control and evaluation of an innovative course is essential.

The objective of this paper is to propose a systematic approach of course design and development for cultivation of innovative capability of students at university based on IDEF0 model and knowledge chain model for engineering education. The rest of the paper is laid out as follows. Section 2 describes the research method including the analysis for prerequisite courses of engineering innovative education, the plan of innovation-eliciting course, and the generation of a systematic framework and method for cultivation of innovative capability of students. Section 3 illustrates the application of the proposed method with a case study. Final section is the discussion and conclusion to illustrate the limitations, contribution and future steps of this paper.

2. Research Method

The approach of the course development includes three steps: first, analyze the prerequisite courses of engineering innovative education. Second, plan an innovation-eliciting course based on knowledge chain model. Third, generate a systematic potential eliciting and inspiring method. The detailed process was illustrated as follows.

2.1 Analysis of prerequisite courses

The analysis of the prerequisite courses of engineering innovative education was presented in this section. The IDEF0 is a structural analysis and modeling technique specially designed for the modeling of decisions, actions, and activities of organizations or for the complex and interrelated systems (Tsai et al., 2006). The results of an IDEF0 functional modeling is a hierarchical, functional decomposition of process functions, each of which consists of five basic elements: functional block, input, output, control, and mechanism. Fig. 1 shows the system analysis diagram for the prerequisite courses of engineering innovative education with the IDEF0 structural analysis model. The purpose of the process analysis is to fully understand the context of course development processes, including the activities and tasks involved, their constraints, and supporting resources, as well as the information flow in the process.

The activities in the Fig. 1 include (1) domain knowledge courses such as the professional course, (2) basic creative knowledge courses such as creative thinking and introduction to intellectual property rights, (3) advanced creative knowledge courses such as TRIZ and patent practices, and (4) integrated knowledge courses such as project-oriented or topic research courses. All of the activities, as shown in Fig. 1, involve many constraints such as course objective, prior knowledge of students, expertise and practice of teachers, affordance of equipment, and diversity of students. Furthermore, each activity involves plenty of iterative modification or refinement for course development. However, there are also various resources available such as teaching assistant, encouraging regulations, e-learning platform, Internet resources, and funds of project from government. By way of the IDEF0 analysis for prerequisite courses, it provides the visibility and direction of the innovative course development for eliciting student's interests and realize students' expertise.

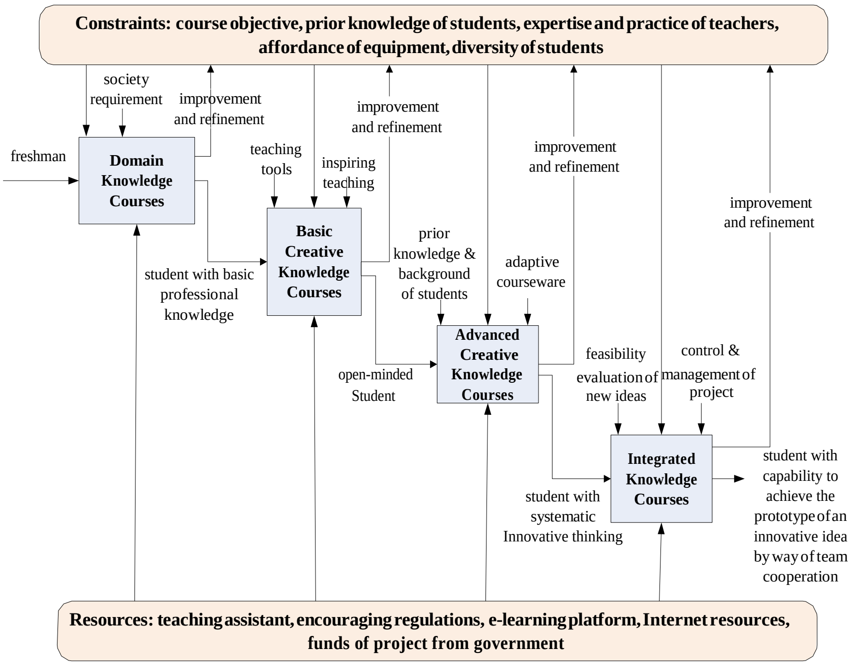

Fig. 1 System analysis of the prerequisite courses for engineering innovative education with IDEF0 diagram

2.2 Innovative Course Development based on Knowledge Chain

The concept of knowledge chain model proposed by Holsapple and Jones (2004) includes two groups of activities. One is the primary activities containing knowledge acquisition, knowledge selection, knowledge generation, knowledge assimilation, and knowledge emission. The second activities comprise leadership, coordination, control, and measurement. This framework could provide guidelines to approach the problem solving of course development from a systematic and context-based perspective.

As the knowledge chain model can provide guidelines and it gives a context-based perspective to manage, control and implement the knowledge management activities, this paper adopted it as a basis to propose a framework of course development for eliciting innovative potential as shown in Fig. 2. The primary activities of the knowledge chain framework are acquisition, selection, generation, assimilation, and emission. They focus on a sequential process and include acquiring knowledge from related courses, selecting needed knowledge to adapt student with different backgrounds, inspiring student to produce various new ideas by way of suitable course design, and encouraging students to write document such as a patent specification or achieve a prototype based a feasible idea, and supporting students to participate competition, to apply patents, to write a paper, etc.

The secondary activities are leadership, coordination, control, and measurement. They focus on planning the foresight strategies for teacher cultivation, curriculum plan, encouraging method; resolving disputes and reasonably allocating resources such as course arrangement, equipment, and funds; ensuring teaching quality and learning performance; and constructing objective evaluation criteria and mechanism. In order to effectively proceed the activities in the framework, it is necessary to consider the influence of resources and environment which are similar to the resources and constraints in the IDEF0 model. The final goal of overall activities is to enhance the competitiveness of students, schools, and even society.

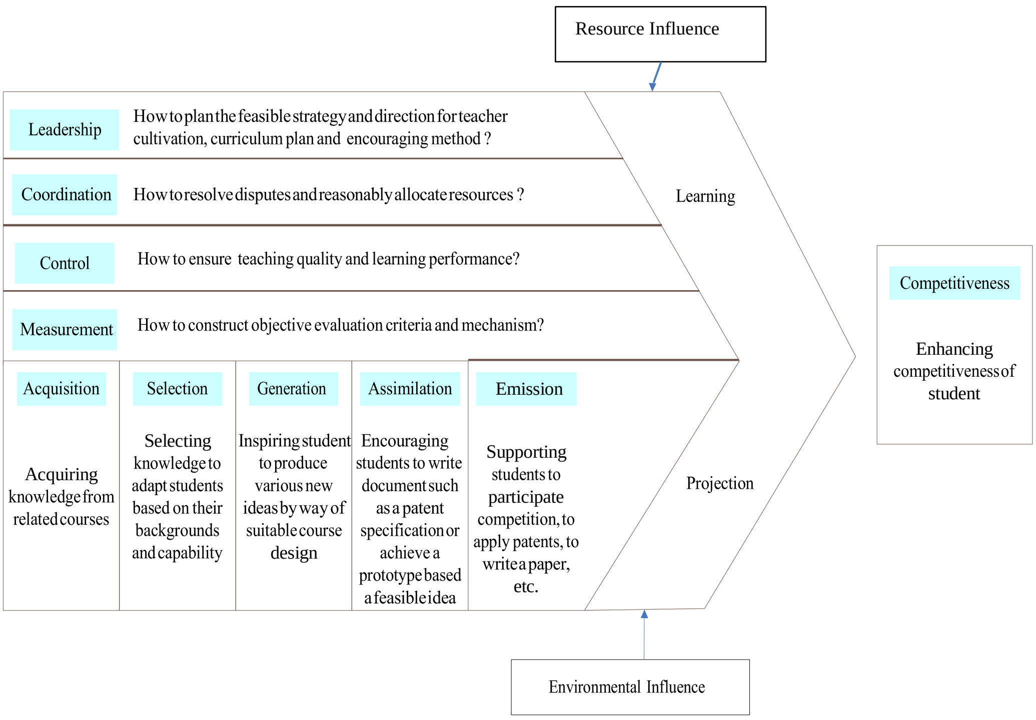

Fig. 2 Course design and development for cultivating innovative capability based on knowledge chain model.

3. Case Study

In this paper, we adopted a project implemented by the Department of Computer Science and Information Engineering at Far East University in Taiwan as an example to illustrate the proposed method. The name of the course is “High Technology Patent Application and Protection” and it is sponsored by Ministry of Education of Taiwan government. Prior to the course, Ministry of Education of Taiwan demand that every university participating this project needs to select at least one teacher as seeding teachers. All the seeding teachers need to join a 3-day training course in National Taiwan University. In the training course, the lecturer teaches patent knowledge and practices. As the electronic and information industries are very important for Taiwan, the contents of the training course were focused on case studies of patent application and protection. The expectation of Ministry of Education in this project is to educate the university students of electronic and information departments to have the patent knowledge to face the future challenge in their consequent career.

Fig. 3 shows the course development flowchart including course plan, course design, course implementation and evaluation along with the related resources and constraints. The aforementioned training course for seeding teachers could be considered as the problem-solving of the constraints in Fig. 3. By way of the resources of the sponsoring project, this course has double teachers. One is the seeding teacher and another is an industry expert with abundant practices experience of patent application and protection. In addition, Far East University also provides many incentive regulations for students to apply patents or join global competitions. The industry expert and incentive regulations could be considered as resources in Fig. 3.

Fig. 4 shows a snapshot of collaborative evaluation of students' reports with industrial expert. In Fig.3, the course plan module includes some activities such as to cultivate teachers, to analyze resources and constraints, to coordinate related members and to write projects to apply budgets. The course design module includes some activities such as to design teaching activities, to teach with industrial experts, to teach with the assistance of e-learning platform and to design homework and reports. The course implementation and evaluation module include some activities such as to teach patent knowledge, to analyze student’s background, to demand mid-term proposal submission and presentation, to demand final-term report submission and presentation, and to collaboratively evaluate students’ reports with industrial experts.

Besides the three main modules, there are also two modules, resources and constraints, needed to consider during the course development. The resources module includes elements such as industrial experts, teaching assistants, courseware provided by ministry of education, e-learning courseware, e-learning platform, and encouraging methods and mechanisms provided by schools. The constraints consists background and knowledge of teacher, background and capability of student, selection of feasible courseware, control of teaching activities, and quality control of final report.

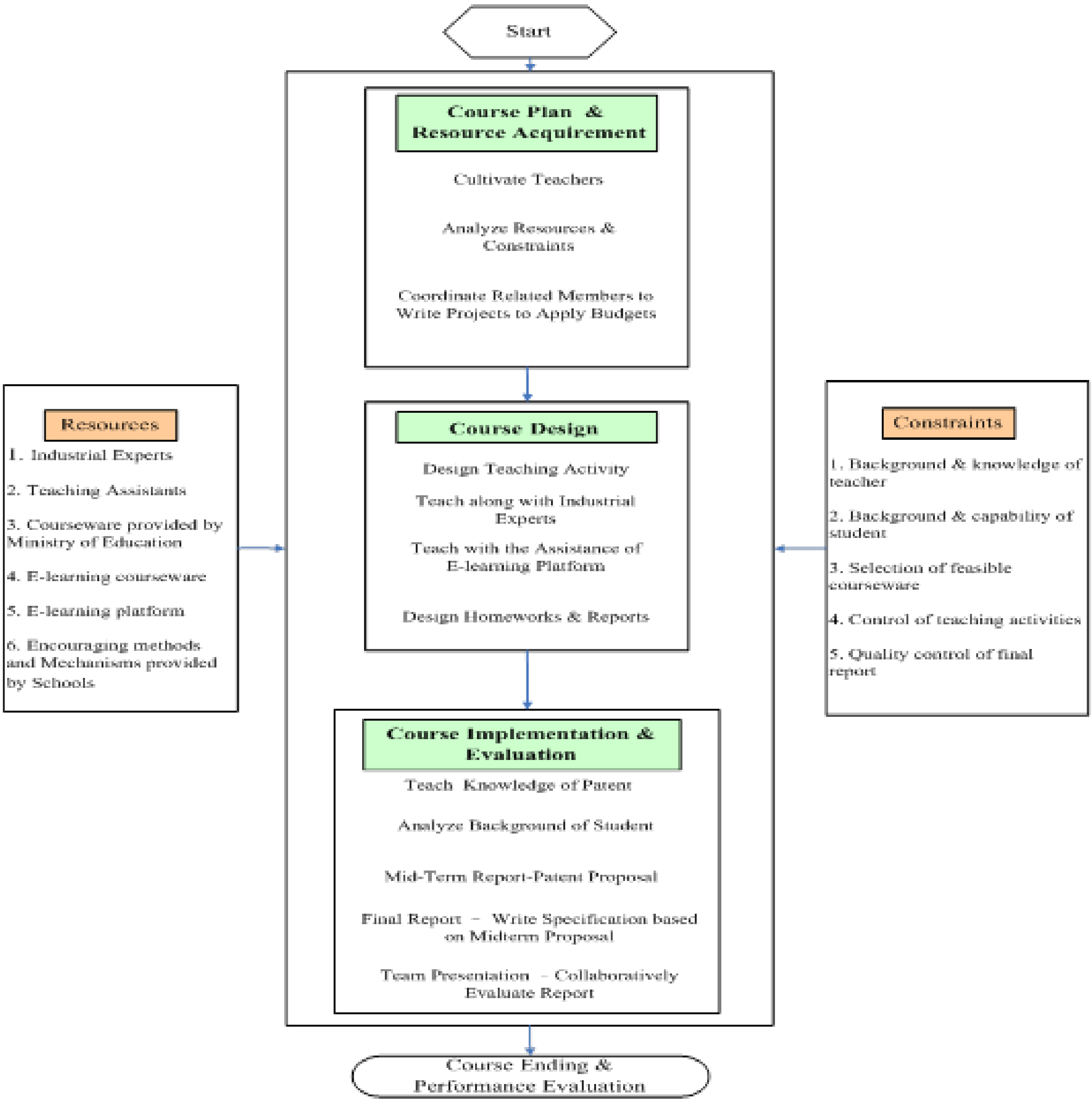

Fig. 3 The flowchart of plan, design, implementation and evaluation of course development

Fig. 4 A snapshot of collaborative evaluation of students' reports with industrial expert.

4. Conclusions

In this paper, we have analyzed the inputs, outputs, resources and constraints of a course development with IDEF0 system analysis. Subsequently, a framework of course development was proposed based on knowledge chain model. Furthermore, a case study was used to illustrate the implementing method and process based on proposed framework. The authors expect this research could provide guidelines or reference for enhancing engineering innovation education and the method proposed in this paper is general in form to be applied for the other disciplines.

Acknowledgments

The authors would like to thank for the financial supports from Ministry of Education (Educational Project - High-tech Patent Application, Offense and Defense, 2008), Taiwan, R.O.C.

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10.6977/IJoSI.201203_2(1).0004

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   SWIFT Code: ICBCTWTP203
   Bank code： 017-2037
   Bank Address: 69, Tung Chien Street Hsinchu City, Taiwan (R.O.C.)

VISA / Master/ JCB/ AMERICAN Cardholder Authorization for Journal Order

Card Holder Information

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<tr><td>Card Holder Name</td><td colspan="4">(as it appears on card)</td></tr>
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<tr><td>Card Number</td><td colspan="2">□□□□-□□□□-□□□□-□□□□</td><td>Security Code</td><td>□□□ </td></tr>
<tr><td>Amount Authorized</td><td></td><td>Special Messages</td><td colspan="2"></td></tr>
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The Society of Systematic Innovation
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