Utilization of TRIZ with DFMA to Maximize Value

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Abstract

An effective way to successfully apply Value Engineering (VE) principles in manufactured products and processes is to utilize TRIZ in combination with Design for Manufacturing and Assembly (DFMA). In order to obtain the optimum design for any given manufactured product or process it is best to utilize TRIZ and DFMA during the early concept stage of the project with a properly staffed cross-functional team and facilitated with a specialist whom understands function analysis. TRIZ by itself or DFMA by itself may not be sufficient to optimize the design efforts, but when both of these VE tools are utilized together with an understanding of function analysis, a very powerful solution may be obtained which can often bring innovation into reality for that new product or process and optimize value for the final customer. Manufacturing organizations today need to be able to apply new technology to their products and processes to be successful in the highly competitive global marketplace, and the usage of TRIZ in combination with DFMA can help them meet this objective. The success of this approach is due to the fact that product designer, material specialists, processing specialists, and manufacturing experts all have an opportunity to work together optimizing the design in conjunction with the capability of the manufacturing operations available to meet customer requirements which may be portrayed in terms of functions. This early involvement by all of the related specialists helps to highlight how customer functions may be matched with process and material functions to obtain an optimum design solution. This technical paper will explain these VE related tools and demonstrate how they can boost the innovation efforts for manufactured products and processes and bring maximum value for the ultimate customers involved.

Introduction

Many design and development approaches commonly utilized today for manufactured products and processes such as Quality Function Deployment (QFD) show *what* to solve but not always *how* to solve the technology roadblocks that are generated. The solution is often limited by the specific experience of the team at hand, thus potentially missing a solution that might be simpler and potentially less expensive. For example, if an application engineer who has experience with rubber damping techniques needs to dampen a vibration, he may limit his focus to only rubber based materials since that is his or her most familiar area. A more efficient solution might lie in using a magnetic field, but because his knowledge base was not familiar with that technology, this potential solution was never pursued. This example highlights why few new and truly creative ideas are generated, for if you use the same people with the same experiences, with the same approach, and the same tools, creativity is certainly limited.

For any given product or process design there are two sorts of problems: those where the solution is generally known and those where it is not. If the solution is generally known, it can be found in books, journals, or technical papers. Problems where the solution is not generally known are called inventive problems and often offer contradictory requirements. Most times in order to resolve contradictory requirements or conflict, many people will choose a compromised solution, where not all of the requirements are met and those that are met, are not optimized. The use of TRIZ will help to resolve conflict and generate new solutions from outside the experience generally available at any one person along or even any given cross-functional team.

Design for Manufacture and Assembly (DFMA) uses a question and answer approach to help determine the most cost effective and efficient assembly method, manufacturing process, and materials for a particular product or process. The goal of DFMA is to determine what a product should ***really*** cost to manufacture based upon the desired functions of the customer. The application of DFMA gives engineers the tools for deciding where cost is necessary in a design based upon customer functions, and where cost may be removed by either eliminating components, combining components, or integrating components together to accomplish the same required customer functions. This optimization in achieving the lowest cost for any given product or process may also be accomplished by changing materials or processes to more closely match customer functions. This is the basic definition of Value which is:

$$\textbf{VALUE} = \frac{\textbf{FUNCTION}}{\textbf{COST}}$$

where the highest value is obtained by providing the maximum function at the lowest possible cost. DFMA may be used to help the design team to simplify the product, improve quality, reduce assembly and manufacturing costs, as well as to quantify the improvements of the design. A second very important use of DFMA, is to study competitors products and processes from a design, quality, material selection, number of components, manufacturing method, etc. point of view, and then evaluate assembly and/or manufacturing difficulties in an effort to design a superior product based upon the results of this detailed analysis. This technique has been developed extensively in many of the Southeastern Asian countries over the last 40 years, with the result, that a variety of products manufactured in that region of the world today, are ‘best in class’ and is closely linked to the methodology of ‘target costing’ where cost tables are developed for a variety of products and processes based upon years of experience and the collection of data of such products and processes.

Finally, the third area where DFMA can be used effectively today is to hold suppliers accountable by using DFMA as a 'should cost' tool to provide cost predictions where supplier quotations may be analyzed in detail based upon industry standards for any given product or process. This in turn holds suppliers to a higher standard and will require them to justify their quotations if they don't closely match the results of the DFMA industry generated cost models. Once again, this technique has been developed and used effectively by various Southeastern Asian countries over many years to understand the cost of products at the early design phase of any given program. The DFMA methodology can be developed and used by various manufacturing organizations to help them generate their own internal 'cost models' which will be able to predict the cost of future products before they are tooled and fully developed.

The Need for Integrating DFMA with TRIZ for Manufactured Products

Most manufacturing organizations today, at least in North America, are not utilizing the optimum product development process for the introduction of new or future products. Unfortunately, many of these companies are still using the traditional 'design first and then throw it across the wall to manufacturing' approach as illustrated in the cartoon below. By the time the manufacturing plants

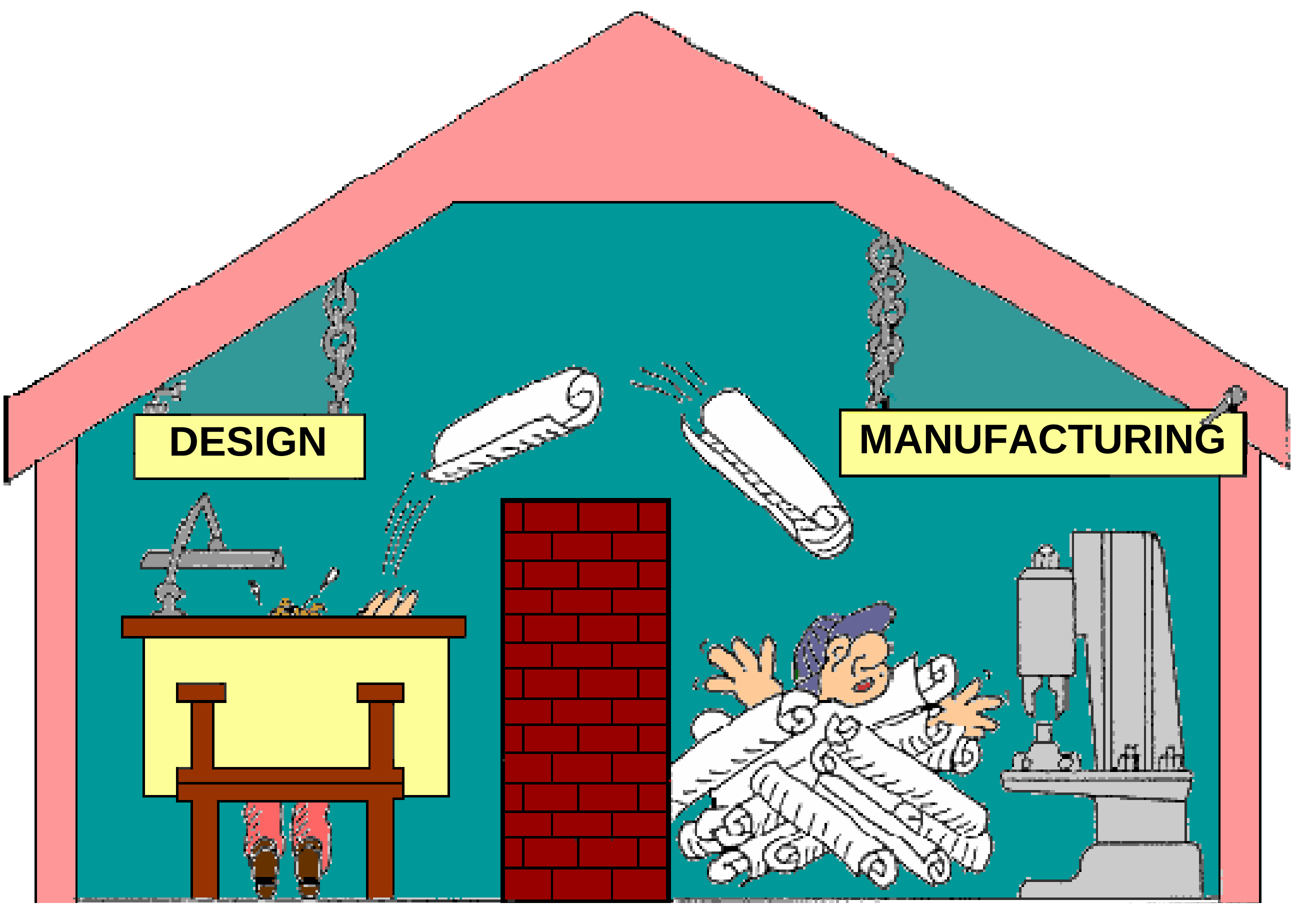


Figure 1

have a chance to react or give input to the design, it is too late to make any meaningful changes or suggestions for improvements since many times the designs have already gone through concept validation and prototype tools have already been ordered. Even though many of these manufacturing organizations have cross-functional teams to try and prevent this scenario, most of these teams are formed to late to have any real impact on the design and in almost all cases, the teams are formed after the customer has awarded the business which locks in the pricing, tooling, and delivery schedule. In these cases, there is little opportunity to greatly optimize the design or reduce cost significantly, as the team's main focus it to maintain the timing promised to the customer.

If a DFMA workshop or activity with a cross-functional team that understand function analysis was performed prior to the customer award of business, then there would be the opportunity to optimize the design and take into account the best material and processing techniques to meet the customer expectations. This in combination with the application of TRIZ principles, could really not only optimize the design concept, but could in fact lead to an innovative design solution which could be a real competitive advantage for that manufacturing organization willing to use this approach. A brief description of both the DFMA methodology and the TRIZ approach will be explained next to set the stage for how these two Value Management (VM) tools can maximize value with an optimized design solution.

Basic Principles of DFMA

DFMA consists of two distinct methodologies, Design for Assembly (DFA) and Design for Manufacture (DFM) which work together to develop a total product cost by optimizing the design using the best materials and processes in an effort to meet the customer functions at the lowest possible cost. Although these methodologies will initially be discussed separately, they will be merged at the end to arrive at the maximum value for the client or customer involved.

The Design for Assembly (DFA) methodology is utilized for evaluating the overall design of components and/or assemblies/processes and allows one to identify as well as quantify the unnecessary components for any given product or process by determining the optimum design solution based upon functional requirements. In reality, this methodology when used properly, will determine the absolute minimum number of 'theoretical' components that are required for any given product or process. This 'minimum part count' is the key to the development of the most cost effective product based upon the required functions that the product must meet. Although a manual method is available to achieve this target of arriving at the most competitive product, Boothroyd and Dewhurst Inc. (BDI) has developed software which makes the manual method much more user friendly and faster to accomplish this task.

By utilizing the BDI developed software, the product engineer can assess the cost contribution of each component and then simplify the product design through component reduction strategies. These strategies involve incorporating as many features or functions into one component as economically feasible by using some very strict guidelines when determining the necessity for any given component. Although the DFA software will not create a new design for the user, it will suggest items in the order of highest component cost, higher labor cost, etc. that need to be investigated for integration into other existing components. The outcome of a DFA-based design is a more efficient product which is easier as well as more cost effective to produce (generally with fewer components) but still meets the same desired functions. The extended benefits to using DFA are generally a lower bill of material cost, a lower overall product cost, an improvement in quality and higher reliability due a product with less components, and a faster overall product development time. The following illustration in Figure 2 shows the detailed analysis to determine the securing method and the minimum part count for a given part as well as the penalties that can be applied depending on part symmetry, handling difficulties, insertion difficulties and item fetching time. Each of these factors will determine the actual labor time to assemble a given part to the preceding component and then when combined with a labor rate, will result in the labor cost to assemble the product. In this example, a motor assembly is evaluated with 12 different types of components (motor base, bushing, motor, motor screw, stand-off, sensor, set screw, end plate, end plate screw, grommet, cover, and cover screws) in the product structure (upper left side of Figure 2) along with two different process operations of feed wire/cable and reorientation. The purpose of this product structure is to develop a complete assembly process (either in assembly order or disassembly order) including all of the components and all of the operations needed to assemble these components such that the complete costs for the components and the processes needed to assemble these components is captured. Up to three different product structures may be analyzed at one time, however, in Figure 2, only two product

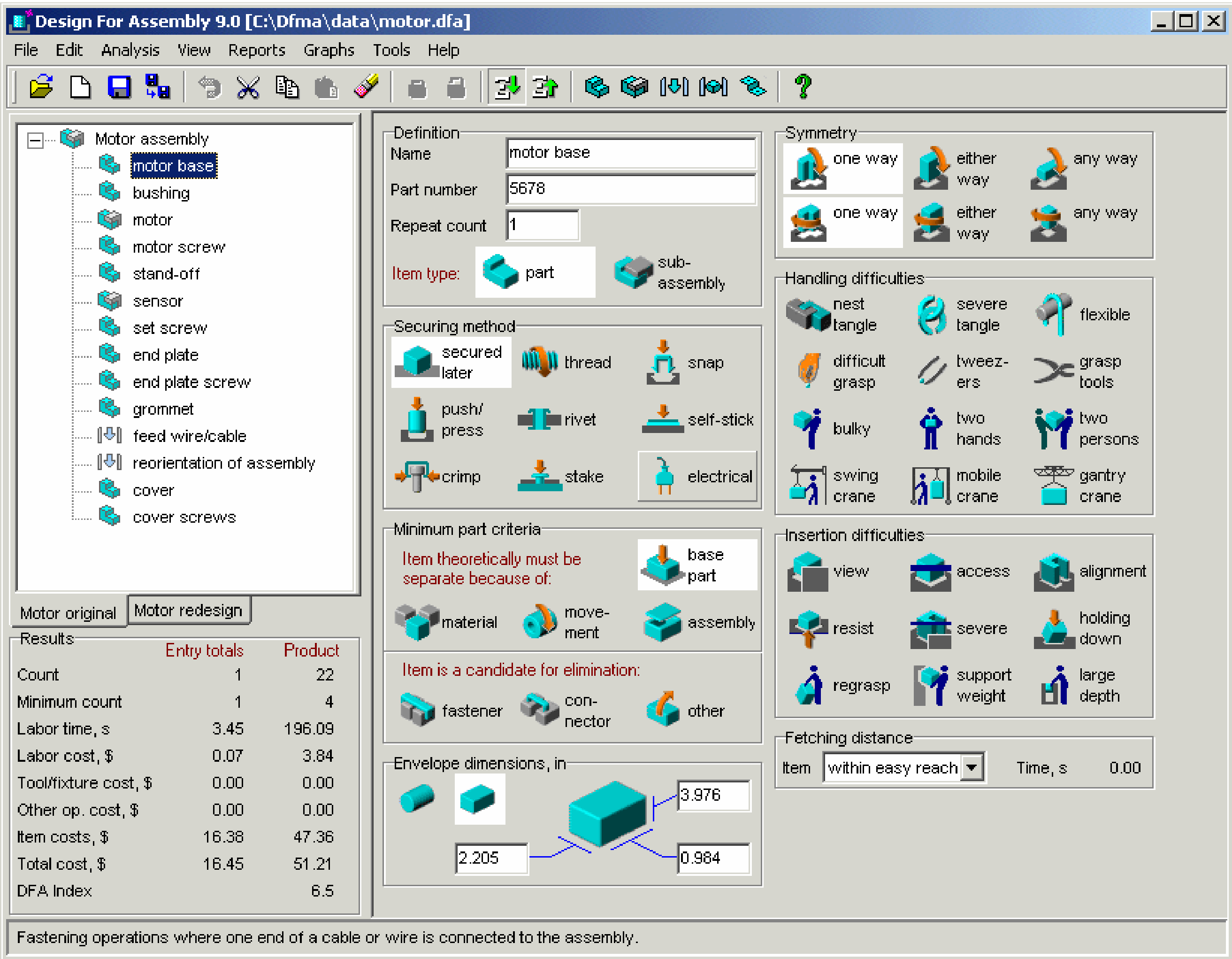


Figure 2

structures are shown (one of the original motor design and the other for the re-designed motor).

The Design for Manufacturing (DFM) portion of the BDI software, contains process and material information with industry generated cost models for quickly estimating the cost of manufacturing and finishing a component. It is designed to isolate the principal cost components, to allow one to investigate design changes to reduce total product cost, and to compare alternative processes and materials for any given component. As with DFA, DFM uses a structured approach which helps with consistency and improves the ability of being able to repeat the analysis at a later point in time or with a slightly different group of people. The BDI DFM software offers a wide range of materials and properties that the average engineer may not be familiar with due to his specific background. Figure 3 below shows the various processes that may be selected and then determines which materials are most

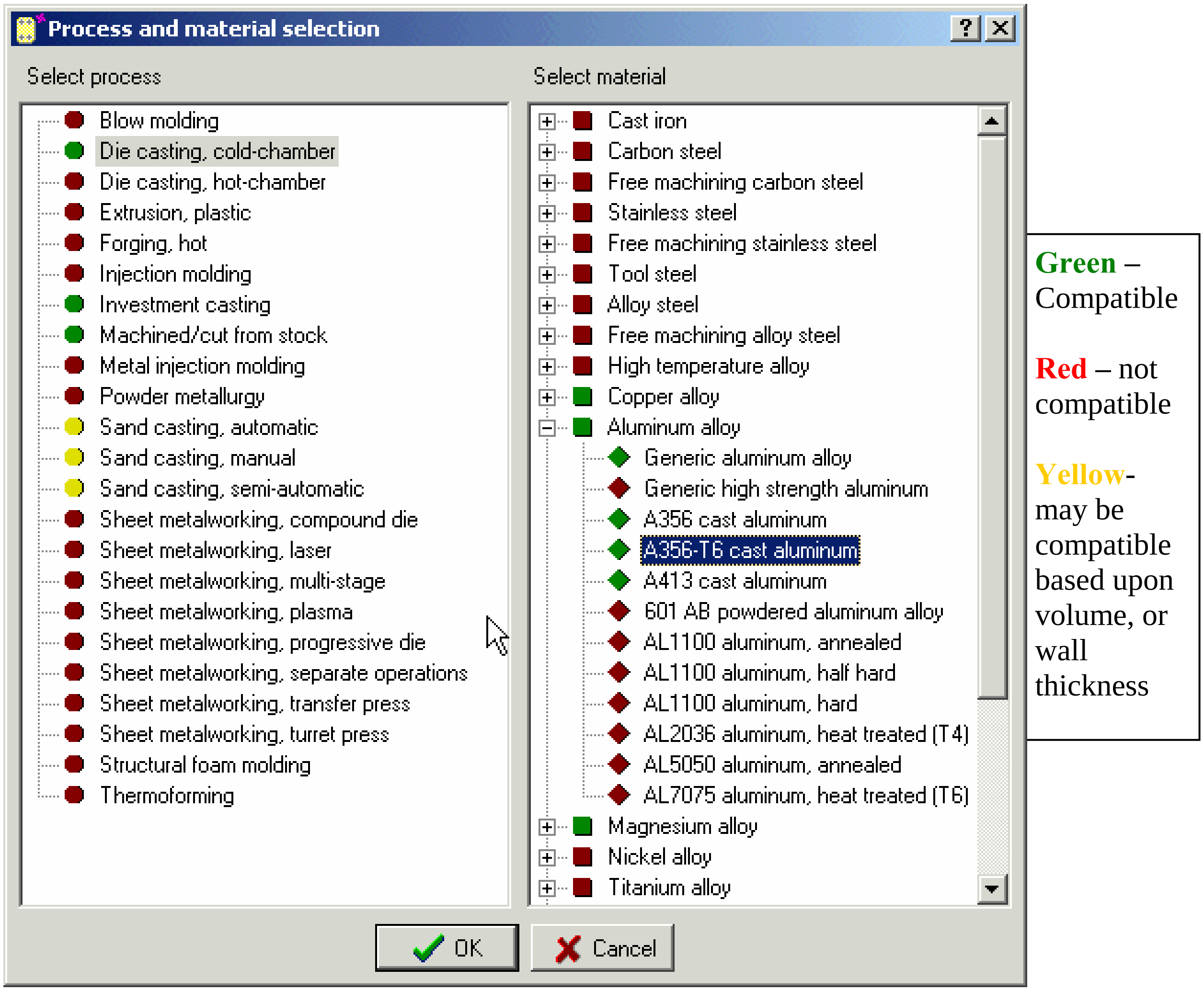


Figure 3

compatible with the selected process. The DFM software allows much quicker financial feedback on various design alternatives due to the fact that detailed drawings don't have to be generated and purchasing doesn't have to locate a supplier to manufacture the new 'widget'. The DFM analysis when completed properly will provide part, process, and tooling costs for any given component. Like DFA, it has the ability to use CAD data or use the geometry calculator to estimate the size and shape of the component to be estimated. This software tool will highlight cost drivers with respect to material, complexity of design, tooling, and secondary operations. DFM has the ability to quickly generate 'what if' scenarios using different materials and processes by comparing them side by side at different volume projections to optimize the least costly design given the customer factors or functions required. In addition, the DFM software helps to understand component and tooling supplier quotations and gives a good baseline for comparison to a 'should be' cost based on the industry standards loaded into the database.

Upon completion of the DFA analysis, those components which have been estimated utilizing the DFM portion of the software may now be imported into final DFA bill of material to complete a total product cost of the final product being studied. Although multiple design alternatives may be developed fairly quickly once the base product structure is developed, all of the alternatives may still not result in a total product cost which meets the 'target cost' established for the new product. This is where an inventive idea or solution may be necessary to arrive at that 'target cost' and this is where TRIZ may be utilized to help develop that 'creative' solution.

Basic Principles of TRIZ

TRIZ is a Russian acronym for, 'Theory of Inventive Problem Solving' and was originally created to guide problem solvers towards strong solutions to inventive problems. Today, TRIZ has evolved into a system that can be the cornerstone of a company's innovation practice. It was founded by Genrich Altshuller who was born in the former Soviet Union in 1926 and then later served in the Soviet Navy as a patent expert in the 1940's where his job was to help inventors apply for patents. He defined an inventive problem as one:

1. where there is no known means for solution
2. which contains high psychological barriers
3. where there is a lack of knowledge about available resources
4. which contains one or more contradictions

Altshuller also determined that few problems where truly inventive problems and in fact only roughly 0.30% of all problems are truly inventive problems as defined above. He classified problems into five levels per Figure 4 below with level 4 and 5 being inventive problems:

Solution Level	Type of Problem	Level of Innovation Required	Examples
Level 1	Inspection	No innovation required	Find the roots of a quadratic equation
Level 2	Engineering	Minimal innovation required	Design a system to pump 100 gpm of water to the top of a building
Level 3	Improvement	Innovation inside the paradigm	Development of touchtone dialing instead of rotary dialing
Level 4	Invention	Innovation outside the paradigm	Development of GSM mobile phone systems instead of land lines
Level 5	Discovery	Creation of new knowledge	Alexander Flemming discovers antibiotics in 1928. Penicillin commercialized in 1942.

Figure 4

One of the first steps in utilizing TRIZ is to define or refine the problem to be analyzed and determine what would be the ideal solution assuming there were 'no strings' attached. In other words, in an ideal world, "what might the solution look like?" By understanding the ideal solution, a clearer picture of the evolutionary goal of ideality becomes more evident. This concept of ideality is the first fundamental principle of TRIZ and it may be defined as the sum of useful functions divided by the sum of harmful functions or as a formula:

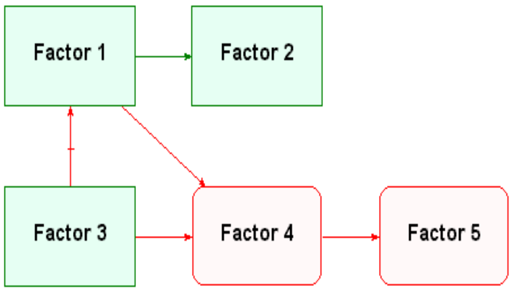
$$\text{Ideality} = \frac{\text{Sum of Useful Functions}}{\text{Sum of Harmful Functions}} \rightarrow \infty$$

where the ideal system would be a hypothetical system whose functions are performed without the system even existing. Next seek to formulate an ideal vision of the system by asking the following questions:

1. What functions do we want to maximize? (improving useful functions)

2. What functions do we want to minimize? (counteract harmful functions)
3. What contradiction do we have to try to apply a known solution?

To help understand the useful and harmful functions and the contradictions that exist in any given problem, it is very helpful to develop functions models to graphically show these relationships. In Figure 5 below a function model is shown linking useful and harmful functions:



[Useful] Factor 1	produces	[Useful] Factor 2
[Useful] Factor 1	produces	[Harmful] Factor 4
[Useful] Factor 3	counteracts	[Useful] Factor 1
[Useful] Factor 3	produces	[Harmful] Factor 4
[Harmful] Factor 4	produces	[Harmful] Factor 5

Figure 5

Functions in **Green Boxes** are considered useful functions and functions in **Red Boxes** are considered harmful functions. If a **useful function** (Factor 1) *produces* another **useful function** (Factor 2), then the arrow connecting these two functions is **green** with the arrowhead pointing towards the second function. If a **useful function** (Factor 1) *produces* a **harmful function** (Factor 4), then the arrow going from the **useful function** to the **harmful function** is **red.** If a **useful function** (Factor 3) *counteracts* another **useful function** (Factor 1), then the arrow connecting these functions is **red** with a **red line** through it. Likewise if a **harmful function** (Factor 4) *produces* a **harmful function** (Factor 5), a **red** arrow will connect the two **harmful functions**.

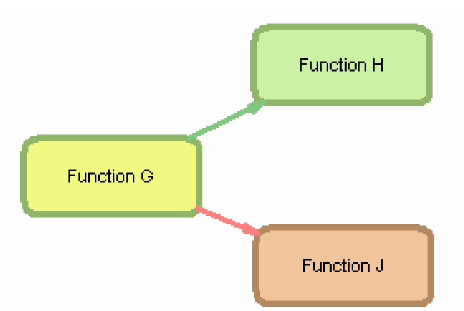


Figure 6

Figure 6 to the left shows a contradiction where a **useful function (G)** produces both a **useful function (H)** and a **harmful function (J).** When this occurs, the function model changes the inside fill color of the **useful function** from **green** to **yellow** to show that a contradiction exists. There are only three ways to improve system ideality:
- find a way to improve the **useful function** (H in this case)
- find a way to counteract the **harmful function** (J) or
- resolve the contradiction that **Function G** should produce **Function H** and not produce **Function J.**

By completing this functional block diagram on the problem to be studied, various issues and technical contradictions can be visually identified for the most challenging of problems. Functional block diagramming performed as a team exercise may actually result in a solution that can be achieved at a lower level of invention than originally thought thus reducing the complexity and length of the study.

The second fundamental principle of TRIZ is that of understanding the resources that are available. TRIZ utilizes resources that are often overlooked with traditional brainstorming and similar techniques. These resources are **S**pace, **I**nformation, **T**ime**,** **E**nergy, and **S**ubstances as defined below:

Space – Free, unoccupied space existing in a system or its surroundings.

Information – Any additional information about the system which can be obtained through interaction with fields and substances.

Time – Time intervals before the start, after the finish, and between the cycles of a technological process, which are partially or completely unused.

Energy – Any kind of energy, action, force, etc. available in the system or its environment such as mechanical, thermal, chemical, electrical, magnetic or electromagnetic.

Substances – All of the materials in the system or its surroundings.

There are generally many more resources available for any given problem then first realized. It is important to take the time to thoroughly identify and evaluate all of the resources that are available in and around the problem being studied including those that may be combined or derived from the basic resources. Many times these combined or derived resources may be the key to resolving the problem or contradiction that initially exists or it may allow a solution to resolved at a lower level of invention thus simplifying the problem and shortening the length of time to study the problem.

The third phase of the TRIZ methodology involves finding possible ways to resolve conflicting functions or contradictions as demonstrated in the functional block diagram of useful and harmful functions. After studying over 1.5 million patents worldwide, Altshuller extracted 95 standard principles that were used over and over again to resolve a wide range of problems from business processes to organizational to intellectual property to sales etc. Thus the third fundamental principle of TRIZ is to apply these inventive principles by analogical thinking. The inventive principles are abstract suggestions which may be applied using analogical thinking to the specific problem being studied. There are three steps to the analogical thinking process as follows:

1. Read the Inventive Principle and associated examples trying to understand their relevance to the Inventive Principle
2. Map the Inventive Principle to your system by creating a series of mental images. Simply imagine that it can be implemented, and focus on whether or not it would be helpful.
3. If one image doesn't work, choose another, then another and write down all ideas.

Below are just a few examples of the 95 inventive principles and how they may be analogically applied to solve real world problems. Thousands of problems may be solved by applying these inventive principles to new problems as shown here:

1. **Use a model or copy:**
   a. *Example 1:* Logs transported in open rail cars must be measured so that their volumes can be calculated.
   b. *Solution:* Photographs are taken of the logs on the rail car. The dimensions of the logs are then calculated by measuring the images of the logs.
   c. *Example:* Buildings near the Arctic Circle must be constructed on piles. The positions of the piles must be measured manually using geodetic devices.
   d. *Solution:* Take photographs of the piles then measure the images of the piles.

2. **Use separation in space:**
   a. *Example:* Military vehicles carrying fuel must be protected from inflammation when struck by enemy fire.
   b. *Solution:* Protect the vehicle by filling the fuel tank with a honeycomb that divides it into many small compartments which prevents inflammation and yet does not restrict the flow of fuel.

3. **Use separation in time:**
   a. *Example:* Farmers must plow each furrow so that the soil lays in the same direction in adjacent rows, however, with standard plows, they must make an idle run the complete length of the field or circle the field thus wasting time.
   b. *Solution:* Use the time for the return run as a resource by equipping the plow with both right-hand and left-hand blades. The operator presses a button to switch blades at the end of a row; then plows the next row. The soil then lies on the correct side of the furrow in adjacent rows.

The final TRIZ fundamental principle that needs to be mentioned is that of how to resolve contradictions. A contradiction is a situation where an attempt to improve one feature of a system leads to a degradation in another feature. Finding the optimum trade off in a contradiction can improve performance, however, resolving the contradiction can lead to a breakthrough. Below are some real world examples of contradictions and how the TRIZ principles can be utilized to resolve these contradictions which results not in compromise, but in real optimization of the final product.

1. **Separation on Condition:**
   a. *Principle:* A characteristic is *present* under one condition and *absent* under another
   b. *Example 1:* A sieve is porous for liquids but solid for solid materials.
   c. *Example 2:* A light-sensitive circuit is open in the presence of light and closed in the dark

2. **Separation in Time:**
   a. *Principle:* A characteristic is *present* during one time and *absent* during another time
   b. *Example1:* The landing wings on a military aircraft can extend to provide a large area during landing and retract during high speed flight.
   c. *Example 2:* A staple is pointed when piecing the papers and flat when holding the papers together.

3. **Separation in Structure:**
   a. *Principle:* A characteristic which *exists* at the system level but *does not exist* at the component level (or visa versa).
   b. *Example 1:* A bicycle chain is made up of many multiple rigid sections, yet is flexible overall.
   c. *Example 2:* Epoxy resin and hardener are liquids, yet become solid when mixed.

4. **Separation in Space:**
   a. *Principle:* A characteristic is *present* in one place and *absent* in another.
   b. *Example 1:* One end of a funnel is wide so that material can be easily poured into it and yet the other end is narrow so that it can fit into a small opening.
   c. *Example 2:* The lower part of bifocal glasses serve as reading glasses while the upper portion provides correction for long distance vision.

Continue to review the various 95 TRIZ inventive principles and seek to apply that principle to the specific problem which is under study. To gain additional ideas, try also to review these principles in combination with each other to generate a new idea. Document all of the ideas and then combine ideas into workable solutions or concepts as needed. There are various TRIZ software tools available to help develop and document the TRIZ process, but whether software tools are used or not, TRIZ allows one to channel creativity by reviewing multiple solutions for a particular problem that most likely has already been encountered by someone at some previous point in time.

How TRIZ can Optimize a Design which has completed a DFMA Analysis:

Although a DFMA analysis can greatly improve the design and manufacturing concept for a new product, if the overall target cost can't be achieved after multiple DFMA iterations, then an inventive solution may be needed to meet the business plan for the new product. This is where TRIZ may be applied to help find an inventive solution that the current design and manufacturing team may not be able to generate without this outside support. An expert in TRIZ can lead a team to identify the problem, to develop an idea vision for the new concept, evaluate all of the available resources and then help them develop a function model will identify the specific useful and harmful functions involved with the problem including the contradictions. Once the function model is agreed upon by the team, then the various 95 TRIZ inventive principles may be applied to help resolve the contradictions and generate new ideas. It is important to note that for each new idea generated, there may be subsequent problems, however, these problems may be at a lower lever of invention and therefore may be able to be solved with other standard known engineering techniques. Each new idea may not work by itself, however when combined with other new ideas, they may be able to generate a new concept that is very plausible. Don't initially throw out an idea just due to the fact that it causes another technical problem or challenge, because potentially there is a way with further evaluation of the 95 TRIZ inventive principles, to resolve this problem with a known solution. After a new concept is generated with the best combined ideas generated from reviewing the 95 TRIZ principles, then re-evaluate the new concept with the DFMA analysis tool for total product cost. This iterative process between DFMA and TRIZ may continue until an ultimate solution is achieved that will meet the business plan for any given product.

Summary and Conclusion

In summary, the combination of DFMA with TRIZ can be a very powerful tool for any manufacturing organization in developing new products or optimizing existing products. As stated earlier, it is best to utilize the DFMA tool as early as possible in the design development process for any given product such that the best designs may be developed with optimized materials and processes when considering manufacturability. The TRIZ tool may be used on a variety of problems or when a new inventive solution is necessary and it has evolved into a system that can be the cornerstone of a company's innovation practice. It can be used effectively as an iterative tool with DFMA when the initial analysis does not meet the cost target for a given product as set either internally, by the customer, or by market conditions. Manufacturing organizations today need to be able to apply new technology to their products and processes to be successful in the highly competitive global marketplace, and the usage of TRIZ in combination with DFMA can help them meet this objective. TRW has a VE department that specializes in the utilization of these tools along with function analysis to maximize the value of our new products globally and bring added benefit to our customers. The link of the DFMA and TRIZ tools with the value methodology is particularly strong, therefore, our VE group trains our organization to utilize these tools for new product development. An additional benefit of utilizing these tools has been the improvement of communication between our product design department, our advanced manufacturing engineering department, our quality department, and our suppliers in the early stage of development of a new product. If your organization could use a boost in optimizing new products before they are tooled, then you may want to seriously investigate the use of DFMA in combination with TRIZ as an iterative process to maximize value for your customers.