Integration and Application of TRIZ and DFMA

Darrell L Mann

Systematic Innovation
5a Yeo-Bank Business Park, Kenn Road, Clevedon BS21 6UW
Darrell.mann@systematic-innovation.com

Abstract

DFMA offers users a tremendous level of capability in a host of different settings. Many of the techniques contained in the method also feature in some form in the Russian originated theory of inventive problem solving, TRIZ. TRIZ however also contains a number of additional strategies that can be usefully deployed to enhance the DFMA capability.

The paper describes work to integrate DFMA and TRIZ techniques to produce a method combining the best features of both. The paper also describes two case studies; one a simple system and the other a more complex aerospace system in order to highlight the differences in approach between the two techniques.

Introduction

DFMA and TRIZ share similar conceptual roots. Both represent the distillation of 'best practice' into a form that allows systematic transfer of that practice to other generically similar situations. In the case of DFMA this knowledge distillation process has focused on manufacturing industry and the 'best practices' identified after intensive periods of assessing and analyzing what defines an efficient manufacture or assembly operation over one that is less efficient. The method presents this knowledge in terms of quantified metrics that enable a user to assess how long a given series of tasks will take, rules that enable the user to improve the system, and then quantify the level of that improvement.

Within TRIZ, the knowledge base from which best practice has been extracted is somewhat broader and now comprises a substantial proportion of the world's most successful patents, taken from all fields of engineering endeavour. The main focus of TRIZ has been the creation of a systematic innovation capability.

The paper compares the two methods in light of the common conceptual ancestry. The first two parts of the paper examine TRIZ through the eyes of someone with a DFMA background, and then DFMA through the eyes of a TRIZ user. The aim in both cases has been to identify those elements of one method that may offer most benefit to the other. The paper then goes on to describe two case study applications to first highlight the philosophical differences, and then the opportunities for mutual benefit.

A DFMA Perspective of TRIZ

Newcomers most often view TRIZ as a somewhat complex looking entity. Certainly it contains a level of richness that is unique among creativity and innovation tools. The first misconception surrounding TRIZ is that it is necessary to master the whole before any benefits can be derived. The reality is that many of the tools within TRIZ can be used independently of the others. There are, however, a number of philosophical elements to TRIZ that it is helpful to be aware of. These pillars have been detailed elsewhere (Reference 1, 2), but for the benefit of the discussion here, it is worth re-emphasising some of those pillars from the perspective of how they might benefit a DFMA practitioner.

Ideality – ideality is defined in similar terms to 'value'. It is typically defined as benefits divided by cost and harm. In studying the patent database, TRIZ researchers uncovered the perhaps not unsurprising fact that as systems evolve, they move in the direction of increasing ideality – i.e. greater levels of benefit; less cost; less harm. The evolutionary end-point for a system – defined as 'Ideal Final Result' (IFR) – is thus the point where the benefit (function) is delivered without cost or harm. While this might appear to be somewhat abstract, examples of systems that have evolved to this point, especially at the sub-system level, are increasingly commonplace (Reference 3).

Use of Resources – TRIZ defines a resource as 'anything in or around a system which is not being used to its maximum potential', and encourages users to embark on a relentless search for things that can work harder in a system. In many senses, this philosophy is very similar to the underlying directions encouraged within DFMA. The major difference comes when the concept of resource maximization is combined with the trends of evolution uncovered by TRIZ researchers and the concept of 'evolutionary potential' (Reference 4) is introduced. Figure 4 illustrates one of the TRIZ trends 'Surface Segmentation' and the evolutionary stages that it contains. Systems evolve from left to right along the trend as designers uncover the benefits of shifting from one evolution stage to another. The evolutionary potential concept relates to systems that have not evolved to the end of a given trend. Thus, in terms of the example surface segmentation trend and the importance of resources, a smooth surface – having three unused evolutionary stages – should be thought of as a resource.

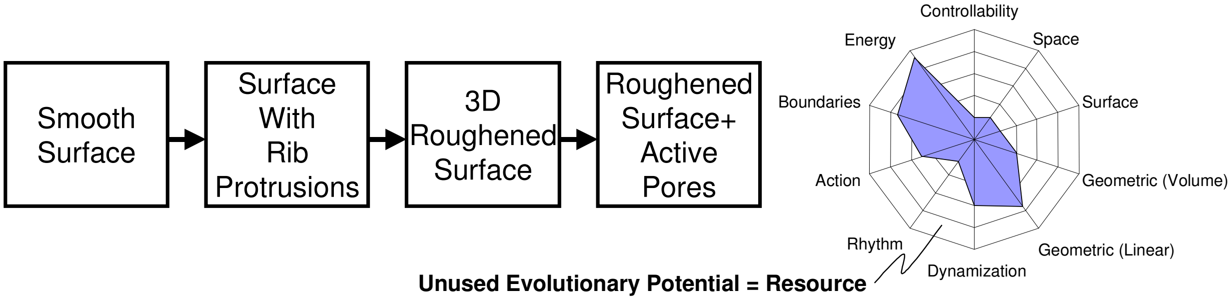


Figure 1: Surface Segmentation Trend and 'Evolutionary Potential' Concept in a Resources Context

Functionality – function and functionality are very important in the TRIZ context. Functions (benefits) are the things that customers want. TRIZ encourages users to focus on the functional relationships between the different components within and around a system. Typically this is done through an evolved version of the function analysis/value engineering methods originally developed by Miles (Reference 5). The innovation introduced by TRIZ has been the modelling of the negative as well as positive functional relationships in a system. This enables users to define both the problems present in a system and the most appropriate tools to help solve them. By forcing users to examine a system on a component by component basis, the tool enables systematic management of complexity. Latterly, the method has further advanced (Reference 6) to better take into account manufacture and assembly process systems. Another important aspect of TRIZ is that it uses function as the principle means of classifying knowledge (example in Reference 1). Knowledge classification by function enables users to access, for example, all known ways of 'moving liquids' or 'joining surfaces', etc very rapidly.

Contradiction – TRIZ researchers also uncovered the fact that the principle driver through which ideality is increased is the resolution or elimination of contradictions. In terms of evolutionary s-curves, the mechanism causing the leveling off of the top of the s-curve is some form of limiting contradiction. Improving a system beyond the fundamental limits imposed by a given s-curve demands the realisation of a new s-curve. By codifying the successful contradiction-eliminating strategies of others, TRIZ offers users systematic means of improving systems beyond the limits inherent to trade-off based approaches. Figure 1 illustrates a typical way of looking at the design process – a flexible bag filled with an incompressible fluid comprised of all the parameters it is necessary to take into consideration when designing a system. Conventional wisdom, and just about all engineering design methods tell designers that an attempt to improve one parameter (squeeze the bag in one place) will cause something else to get worse (bulge in another). This can often be seen to be the case in a DFMA (or indeed Design for X) context – where attempts to improve manufacturability or assembly time often result in adverse consequences elsewhere.

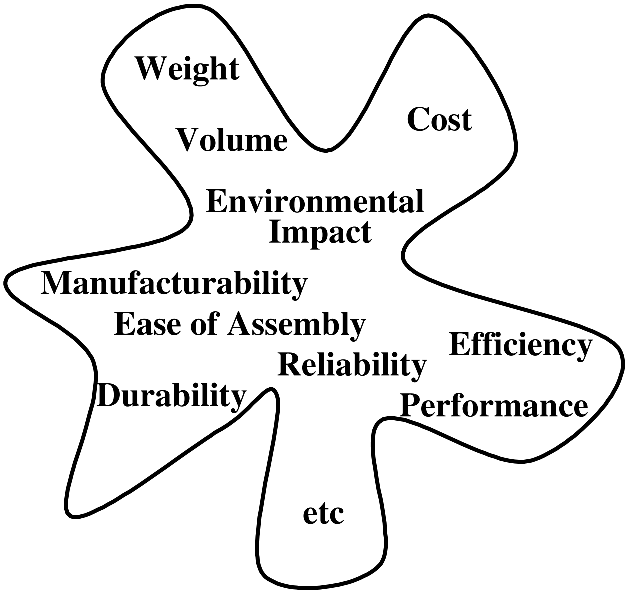


Figure 2: The Design Process as Fluid-Filled Bag

TRIZ researchers have configured a tool called a Contradiction Matrix which takes the list of parameters inside the fluid-filled bag and for each pair, identifies the strategies adopted by inventors who have refused to accept the conventional trade-off approach , and have instead achieved a design in which the trade-off has been successfully challenged. Included in the list of parameters considered by the TRIZ researchers have been 'manufacturability', 'device complexity' and 'level of automation' all of which have strong connections to the DFMA purpose. Analysing the strategies that inventors have used to improve these parameters without adverse affects on other design parameters (i.e. the contradiction-breaking strategies) results in the top-five list of Inventive Principles detailed in Table 1.

Manufacturability	System Complexity	Level of Automation
1) Segmentation	1) Taking Out	1) Parameter Changes
2) Parameter Changes	2) Segmentation	2) Mechanics Substitution
3) Cheap Disposables	3) Copying	3) Other Way Around
4) Mechanics Substitution	4) Other Way Around	4) Taking Out
5) Other Way Around	5) Prior Action	5) Copying

Table 1: Inventive Strategies for DFMA-type Contradiction Elimination

A more comprehensive description of these Principles may be found in Reference 7. In the meantime it is worth noting some of the main points arising from the analysis. In the first instance, it may be noted that the Principle 'Other Way Around' ('turn the process the other way around or upside down') is commonly applied in a DFMA context. The Parameter Change and Mechanics Substitution principles on the other hand point to the shift from mechanical to fluid or (more usually) field-based solutions r when it comes to improving manufacturability and assembly issues. This is a feature not commonly found in DFMA practice. Likewise, the importance of the Segmentation, Copying and Taking Out ('separate out the harmful functions from the useful ones') in a TRIZ context appears to run counter to the conventional DFMA practice of reducing part count. The full implications of this contradictory advice requires further analysis.

Trimming - TRIZ contains a tool most commonly described as 'trimming'. The trimming tool is very close to the part count reduction rules contained in DFMA at the detail level. It differs at a higher level, however, due to the existence of a higher level trend of evolution collated from the patent research showing that there are times during the evolution of a system where the complexity (or part count) will inevitably have to rise, and then a time ('point of maximum viable complexity' – Reference 1) after which 'trimming' becomes both possible and necessary. The trend is illustrated in Figure 3 below.

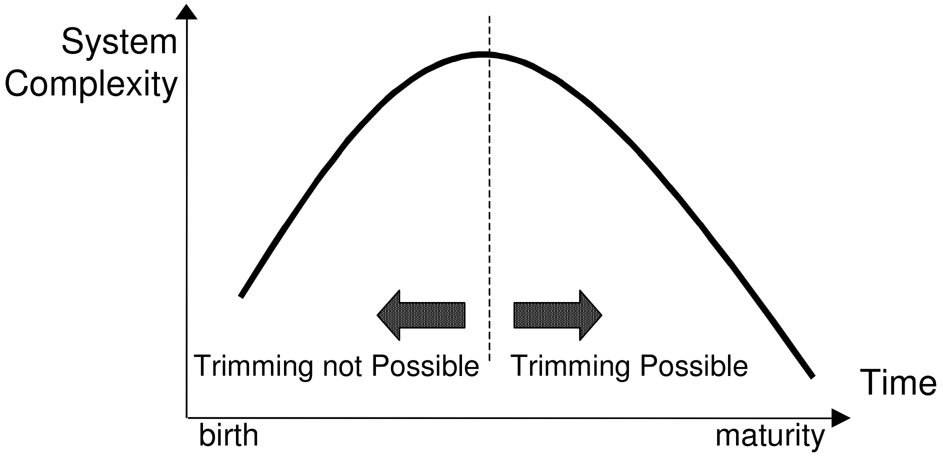


Figure 3: Trimming Evolution Trend

The trend has implications from a DFMA perspective because it suggests that it is not always possible to successfully reduce the complexity within a system. For simple systems, the shift from rising to falling complexity usually occurs at the mature end of the system s-curve. For more complex systems – example gas turbines – the shift occurs much earlier in the s-curve characteristic (Reference 8).

Bearing in mind the other similarities between Trimming and DFMA, it is useful to briefly compare the basic questions used to provoke designers into reducing the complexity of the systems they are responsible for. From a DFMA perspective, the three main provocation questions are - Must the part move relative to other parts; Must the part be of a different material or isolated from its mating parts; Must the part be separate from mating parts to facilitate assembly or dis-assembly. TRIZ offers a similar array of questions, albeit with a greater emphasis on the functionality provided by a given component or part of a process.

Figure 4 illustrates a combined list of DFMA/Trimming questions as have been used in the following case study investigations.

- Do I need the function offered by the part?
- Can something else in or around the system perform the function?
- Can an existing resource perform the function?
- Can a low cost alternative perform the function?
- Must the part move relative to other parts
- Must the part be of a different material or isolated from its mating parts?
- Must the part be separate from mating parts to facilitate assembly or dis-assembly

Figure 4: Combined TRIZ/DFMA 'Trimming' Rules

A TRIZ Perspective of DFMA

Beyond their similar distillation-of-best-practice conceptual roots, looked at from a TRIZ perspective, DFMA (and indeed all of the Design for X variants thereof) appears very strong in terms of knowledge structure and communication of benefits to potential users. In these areas, DFMA has much to contribute to the evolution of TRIZ. Elsewhere, however, the method is viewed in much the same way as many other creativity and innovation aids – that it is useful in terms of helping to define problems and opportunities, and even better at helping to analyse and rank solutions – thanks to the creation and validation of a comprehensive database of action metrics – but between the two falls into the usual 'now generate some good ideas' magic-button found in almost every other tool (Figure 5).

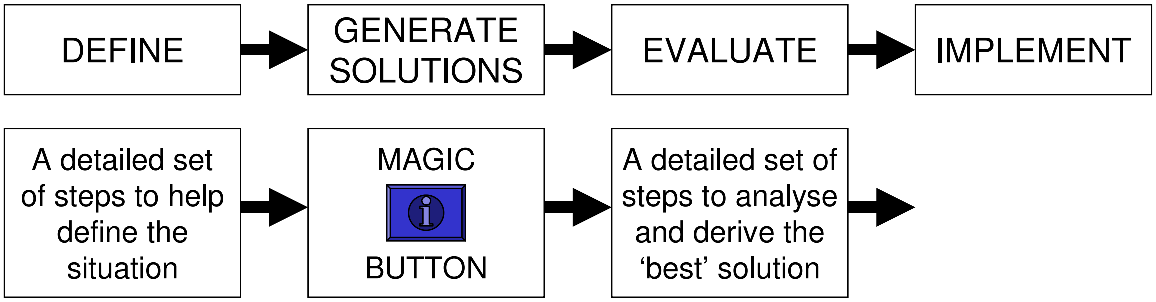


Figure 5: The 'Magic Button' Stage

The magic button is usually a signal to hand over responsibility to brainstorming techniques. The two main problems with this from the TRIZ perspective are, first, that no amount of favourable environment will elicit solutions that rely on knowledge that none of the participants are aware of, and second, that awareness of some of the TRIZ 'generate solutions' tools very often encourages definition of a very different problem than would otherwise have been the case. A particularly good example of this problem definition shift comes through awareness of the contradiction-breaking tools in TRIZ – the usual response of most problem solvers is to avoid contradictions, whereas within TRIZ, problem solvers tend to run towards a good contradiction.

Case Study 1 – Hand Stapler

With the two preceding sections comparing TRIZ and DFMA as background, a simple case study examining a typical hand-held paper stapler was constructed to compare the two approaches. From a TRIZ perspective, a usual first step in improving a system involves the construction of a function analysis diagram. This is usually done in three stages; the first describing the components in and around the system; the second detailing the useful relationships between each pair of components; the third then describing the negative (harmful, insufficient, missing or excessive) functions present in the system. In the case some systems it is common to re-draw the function map at different times during the assembly or operation of the system in order to capture how functionality changes with time. For the stapler example, this time element has been ignored. The resulting function analysis map for the stapler is reproduced in Figure 6.

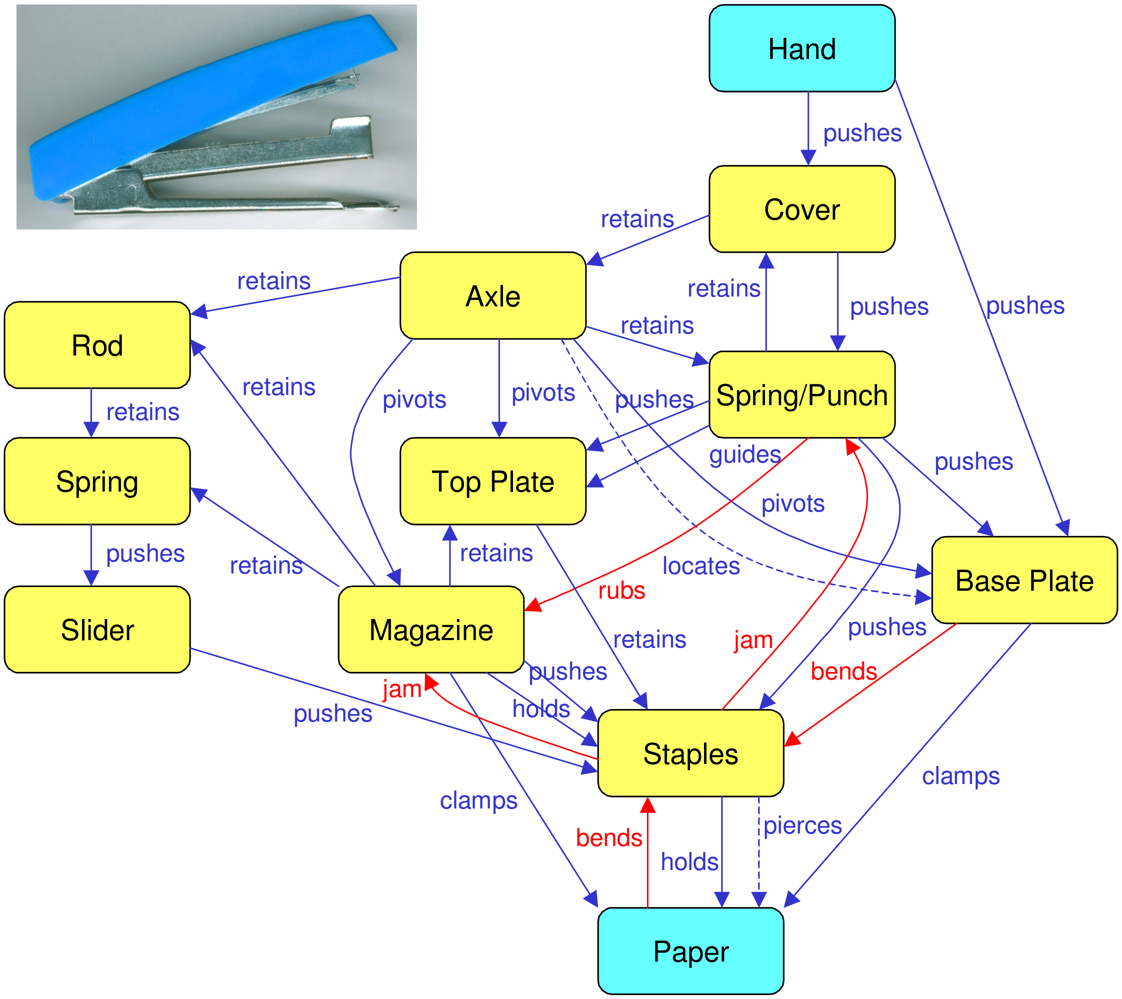


Figure 6: Functional Analysis Model of Typical Hand-Held Stapler

Typically, this picture would then be expanded to include the key attributes of the components present – most commonly in a Trimming context, cost and assembly time. Although DFMA would not construct a picture of this nature, it would identify components and their attributes and use the attribute information as the basis for focusing the part-count reduction activities. While TRIZ would do a similar thing, it would encourage designers to focus first on the elimination of the negative functions in the system.

Given that in this case the large majority of the negative functions are connected to the staple, TRIZ would encourage users to consider focus in this area. Thus an immediate difference between TRIZ and DFMA becomes apparent; from the DFMA perspective 'elimination of the staple' would be very unlikely to be considered due to the fundamental change in the functioning of the system that this implies. TRIZ, on the other hand would identify a series of contradictions associated with the staples (the staple should be 'flexible and stiff', 'joined and not joined' and 'present and absent'). Solution of one or more of these contradictions leads to a novel system that retains the function 'hold paper' but no longer requires staples. Further, it also requires about 50% less components than the original design.

Case Study 2 – Helicopter Engine Particle Separator

The stapler example serves to highlight one of the alternative perspectives presented to designers relative to DFMA. A recent analysis of a more complex system – an inlet particle separator for a helicopter engine (Figure 7 illustrates a generic example) serves to both elaborate on this difference and suggest other areas for mutual benefit between TRIZ and DFMA.

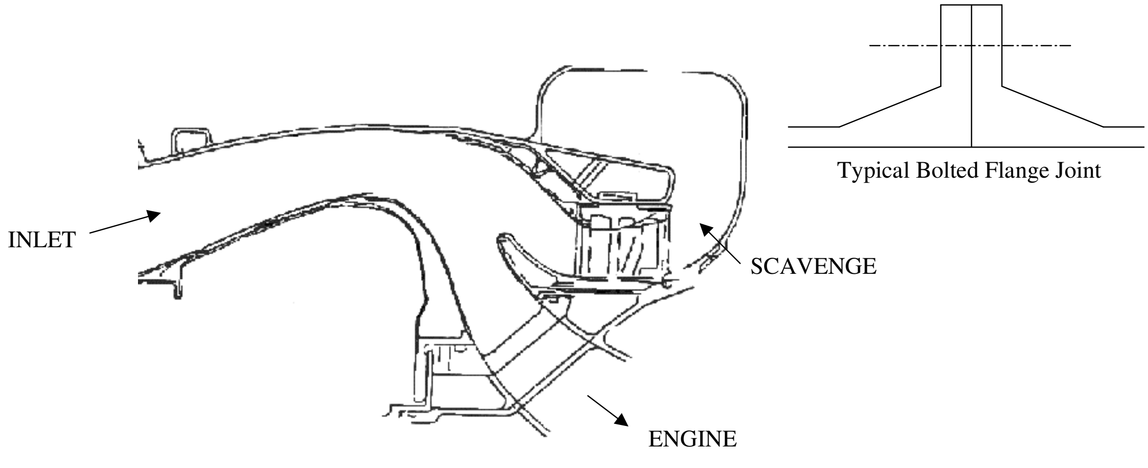


Figure 7: Typical Helicopter Gas-Turbine Engine Particle Separator

Being a design that has existed for several years, the separator under evaluation had already been the subject of some prior part-count reduction activities. Although DFMA had not been a part of this prior activity, when it came to apply the DFMA/Trimming questions described in Figure 4, it soon became clear that there was not much scope for improvement. Attention soon focused on the multiple bolted flange joints contained in the design. While it was shown that all of the joints were required (for reasons of dis-assembly and differences in function between adjacent parts), it was felt that the number of fasteners required was somewhat higher than desirable. This was the prompt to conduct a search of knowledge databases containing alternative solutions to the 'join' functional requirement. One possible solution was the inclined face flange design concept illustrated in Figure 8. This design, being located via the patent database, offered the potential for reducing the number of bolts required in the separator by a factor of two (Reference 9).

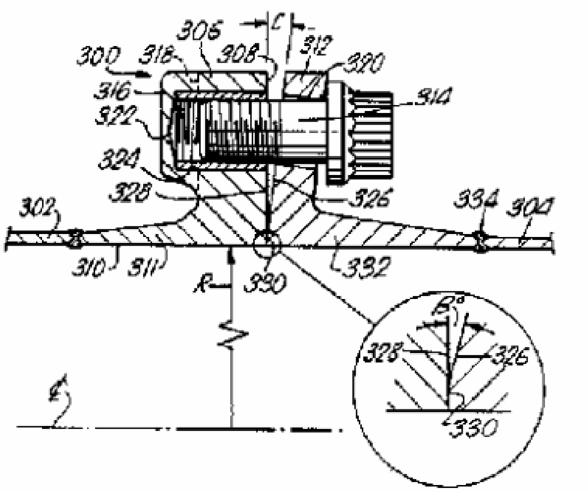


Figure 8: US Patent 5,230,540 Inclined Face Flange Joint

Further searches revealed opportunities to reduce the number of bolts still further, thus affirming the value of the TRIZ statement that someone, somewhere has already solved a problem something like the one you are currently facing. Access to the patent and other solution databases is consequently highly recommended during any kind of DFMA activity.

Given the incorporation of these changes, the separator had evolved closer to its maximum achievable part-count for the given design style. In terms of the ratio of parts to number of useful functions delivered (a Trimming metric analogous to the Boothroyd & Dewhurst 'Complexity Factor') the design was nevertheless felt to be some way short of its ultimate evolutionary potential. This belief was the prompt to construct a detailed function and attribute analysis model. A partial version of this model examining just the splitter lip component is reproduced in Figure 9 below.

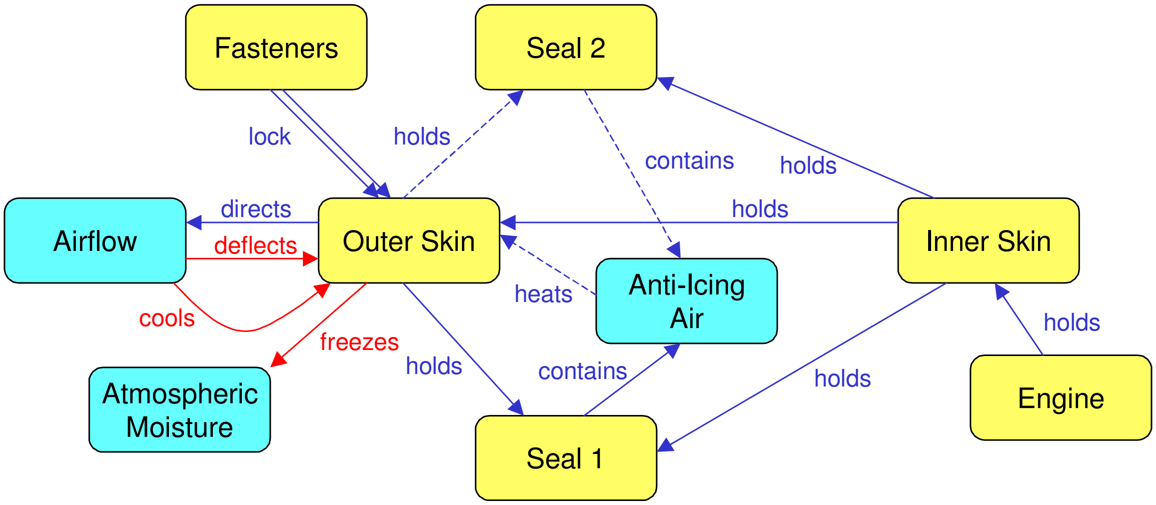
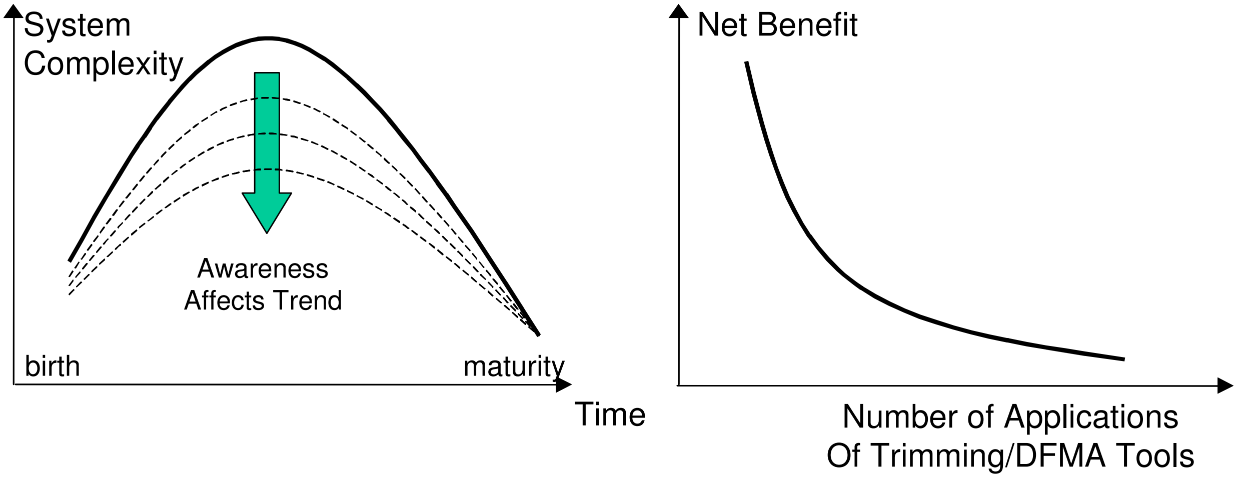


Figure 9: Simplified Function Analysis Model of Particle Separator

What the function analysis revealed was that a large proportion of the negative functions present in the design (inadequate seals, excessive deflections, inadequate anti-icing heating) were attributable to the use of pumping hot air into a double skin metallic construction. The 'inadequate heating' function identified at certain operating conditions was the prompt to examine other means of delivering the heating function. A TRIZ-based knowledge database then revealed the existence of a novel electrically conducting paint system that not only offered the opportunity to improve the heating capability, but also upon subsequent analysis enabled the elimination of the double skin arrangement and all of the seals that had been necessary to try and keep the hot air within the system. Taken together, the revised system offered the opportunity to reduce the net weight of the system by over 25%, reduce the cost of manufacture and assembly by over 30% and because the electrical heating system was so much more controllable than the hot air version, to reduce the anti-icing heating power input by over 70%. These benefits coming on a system that conventional thinking had suggested was optimal.

Conclusions

The two case studies suggest that TRIZ and DFMA are philosophical quite different in outlook when considering the high-level design of a system, but then very similar when it comes to the job of getting the fine detail right. The two techniques have been shown to integrate and operate well together. Awareness of DFMA and TRIZ Trimming techniques is already beginning to affect the system complexity trend of Figure 3 in a way that encourages designers to think harder before they add components to a system (Figure 10a). The emerging consequence of this awareness is that the benefits of applying either technique are reducing. As illustrated in Figure 10b, if a system has not been through a DFMA/Trimming process before, the likely benefits in terms of complexity reduction are high. The s-curve/limiting contradiction effect, however, dictates that subsequent initiatives will produce markedly reduced benefits. The only means of obtaining additional benefits in these circumstances is to shift to a new s-curve (design paradigm). This type of jump requires other TRIZ tools.



a) **b)**

Figure 9: Law of Diminishing Returns in Complexity Reduction Initiatives

In TRIZ terms, as systems evolve towards their Ideal Final Result, the ratio of parts contained within the system per useful function delivered tends to unity and beyond. Any DFMA or Trimming activity that begins to run out of steam at ratios significantly higher than this value are suggesting the need for a shift to a new paradigm. Various TRIZ tools can be deployed to help identify what such a shift will be.

In terms of benefits to TRIZ, DFMA offers two main opportunities. The first relates to the use of information that enables engineers (and probably more importantly, their managers) to quantify the benefits of applying DFMA techniques. The second, technically more important, reason relates to the potential benefits of incorporating the DFMA best practice knowledge base into the TRIZ framework.

References

1) Mann, D.L., 'Hands-On Systematic Innovation', CREAX Press, Belgium, www.creax.com, April 2002,
2) Mann, D.L., 'The Four Pillars of TRIZ', invited paper at International Design Conference, Brunel, June 2000.
3) Mann, D.L., 'Ideality and Self-X', Creativity and Innovation Management Journal, Blackwell Publishers, Vol 11, No2, May 2002.
4) Mann, D.L., 'Evolutionary Potential in Complex Systems', paper presented at CIRP2002, Hong Kong, May 2002.
5) Miles, L.D., 'Techniques of Value Analysis and Engineering', McGraw-Hill Book Company, New York, NY, 1961.
6) Dewulf, S., Mann, D.L., 'Improved Function and Attribute Modelling Techniques and their Role in the Problem Management Process', paper presented at TRIZ Future conference, Bath, November 2001.
7) Domb, E., '40 Inventive Principles With Examples', TRIZ Journal, www.triz-journal.com, July 1997.
8) Mann, D.L., 'Trimming Evolution Patterns in Complex Systems', TRIZ Journal, February 2000.
9) Mann, D.L., 'Case Studies in TRIZ: Halving The Number of Bolts Around a Flange Joint', TRIZ Journal, November 1998.