Proceedings of DETC2000
Design Theory and Methodology Conference
September 10-13, 2000 – Baltimore, Maryland

DETC2000/DTM-14566

TOWARDS A GENERIC SYSTEMATIC PROBLEM SOLVING AND INNOVATIVE DESIGN METHODOLOGY

Darrell MANN
Systematic Innovation
5a Yeo-Bank Business Park, Kenn Road, Clevedon BS21 6UW
+44 (1275) 337500 FAX +44 (1275) 337509
Darrell.Mann@systematic-innovation.com

ABSTRACT

Constructed around the findings of over 1500 person years of research, and the systematic extraction of knowledge from nearly 3 million of the world's strongest patents, the Russian Theory of Inventive Problem Solving, TRIZ, is the most comprehensive systematic innovation and creativity methodology available to mankind. Powerful as it is, however, the method is not as yet comprehensive enough to permit successful use on all types of problem. The paper discusses pioneering work to integrate an upgraded version of TRIZ with other existing and newly derived problem definition and problem solving tools and strategies to create a uniquely powerful, generically applicable methodology. The paper goes on to describe how the new methodology has been successfully validated over a period of several years against a wide variety of real industry-based case study problems.

INTRODUCTION

Following the emergence of the TRIZ methodology from the former Soviet Union during the 1980s, much has been written on the subject (1), and a growing number of business and academic institutions have begun introducing the methods into their working practices. It would be fair to say that many of these organisations are struggling to use TRIZ with any great degree of tangible success despite its undoubted power relative to the best of the rest of mankind's systematic innovation and creativity methodologies. There are various factors which account for this effect. Not least of which is the existence of subtle but profound paradigm shifts between traditional occidental and Russian problem solving methods which the classic TRIZ texts (2,3) fail to appreciate fully. It would further be fair to note that there are a number of problem types to which TRIZ in its classical form is not well suited – for example in terms of reliability-based problems, constrained problems, or life-cycle design based problems. Taken together, the thinking paradigm shifts demanded by TRIZ, and the apparent shortfalls of the method, suggest the need for a new way of looking at TRIZ and its deployment.

The paper presents for the first time, a problem definition and problem solving methodology which integrates into a TRIZ-based framework a number of other existing and emerging problem strategies in order to achieve the solid foundations for a unified and generically applicable methodology. Such integration requires some reformulation and upgrading of the classical TRIZ methods.

The first section of the paper thus examines TRIZ from the perspective of the reformulation required for it to achieve the desired generic problem definition and problem solving capability. Subsequent sections then go on to describe the unified methodology built around this revised TRIZ core, and then to demonstrate how the method has been successfully deployed to examine a number of widely disparate problem types. A final section of the paper identifies certain areas in which work will allow the described generic methodology to be further enhanced.

No systematic innovation methodology can ever claim to be complete, and the one described here is no exception. One of the great beauties of the TRIZ method, however, is that it provides a framework amenable to expansion as mankind's knowledge base expands. The method described here seeks to achieve that same amenability to future growth.

A NEW PERSPECTIVE ON TRIZ

1500 person years of research has produced a lot of significant innovation tools and methods. TRIZ allows users to deploy each of these tools in either an individual or systematically sequenced manner. Experience using the method in real work environments has suggested that users often struggle with the various tools and techniques because it is difficult to set TRIZ in the context of 'traditional' problem solving strategies. With this in mind, the methodology proposed here re-casts TRIZ in order to strengthen awareness and understanding of the four main paradigm shifts which discriminate the methodology from other methods. The four paradigm shifts – Figure 1 – Contradiction, Ideality, Functionality, and Use Of Resources are discussed below in the context of the central role they each play in defining the new generic methodology.

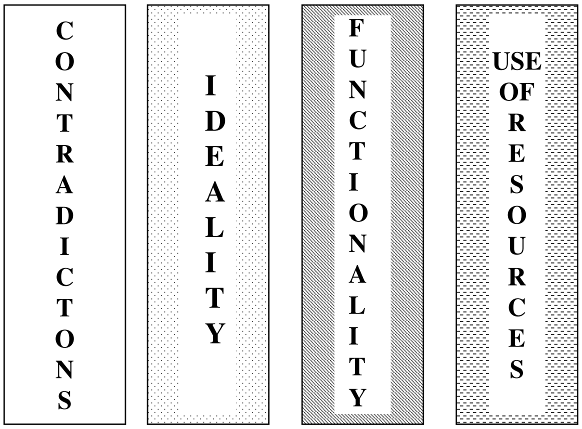

Figure 1: The Four Pillars of TRIZ

Contradictions

Although often the first of the TRIZ tools seen by newcomers to TRIZ, Contradictions is probably the tool which is deployed least well. At least part of the reason for this is that the main underlying principle of the Contradictions philosophy – that of seeking to identify and eliminate contradictions – is almost the complete opposite of traditional problem solving strategies - in which the emphasis is very firmly placed on the importance of achieving 'optimum' compromises between conflicting problem parameters.

The keen emphasis on 'trade-off' solutions in traditional problem solving practice often means that designers are usually only vaguely aware that conflicts exist. The first major paradigm shift that takes place in the Contradictions part of TRIZ is the need for problem solvers to actively seek out the conflicts and contradictions inherent in all systems. The second paradigm shift then involves using the TRIZ methodology to try and 'eliminate' (4) the contradictions rather than to accept them.

A number of strategies are beneficial with regard to the first – contradiction identification – issue. In the new approach detailed here, two novel approaches in particular have been established. The first, relating to the use of function analysis mapping to help identify contradiction types, is discussed later in the lens-polishing case study. The second approach relates to the use of a graphical approach to help identify contradictions. In this regard, the two significant phenomena are illustrated in Figure 2.

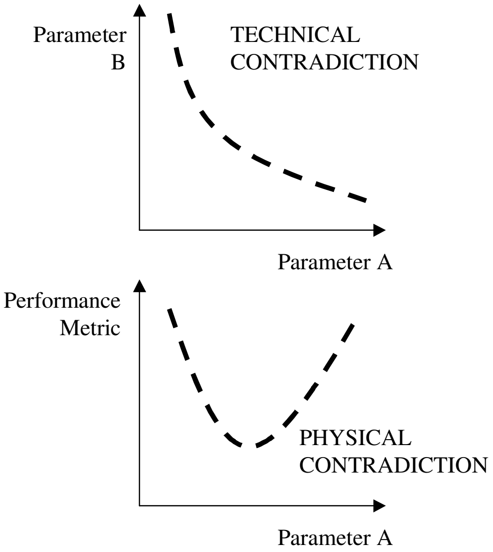

Figure 2: Graphical Representation of Technical and Physical Contradictions

With regard to the 'contradiction elimination' tools – primarily the Contradiction Matrix (3) – used to encapsulate how the best contradiction-eliminating practices may be deployed to help solve a problem, it is worth noting that experience derived during the validation of the new method shows that this part of TRIZ is applicable to widely varying degrees depending on the problem type – Figure 3.

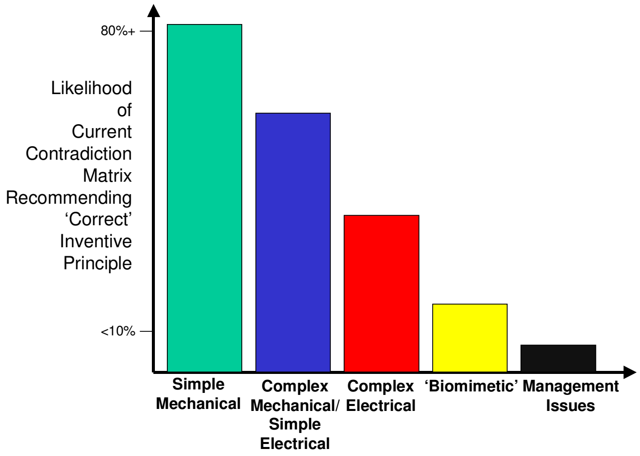

Figure 3: Relative Effectiveness Of Contradiction Matrix In Different Problem Arenas

Despite these findings, the Matrix remains a good starting point. In situations, however, where the Matrix is found to be deficient, alternative strategies are required. In their crudest form, this has typically meant that problem solvers attempt to systematically work through all 40 of the Inventive Principles currently in existence; trying to make connections with the problem at hand. Less crudely, the previously unseen problem segmentation method detailed in Table 1 has been found to be useful in limiting the required Inventive Principle search space.

Problem Type	Inventive Principles[1]
All	1, 3, 4, 13, 15, 17, 22, 25
Improving Physical Attributes	2, 5, 7, 8, 10, 14, 28, 30, 35, 37, 40,
Improving Performance	9, 10, 16, 19, 21, 23,
Improving 'Ilities	11, 14, 18, 27, 35,
…If a solution still hasn't emerged	6, 12, 20, 24 26, 29, 31, 32, 33, 34, 36, 38, 39

Table 1: Inventive Principle Segmentation Strategy

Contradiction Solution Route	Inventive Principles[1]
Separation In Space	1, 2, 3, 4, 7, 13, 17, 24, 26, 30,
Separation In Time	9, 10, 11, 15, 16, 18, 19, 20, 21, 29, 34, 37
Satisfy Contradiction	12, 28, 31, 32, 35, 36, 38, 39, 40
Alternative Ways	
-Subsystem	1, 7, 25, 27
-Supersystem	5, 22, 23, 33
-Alternative	6, 8, 14, 25, 35
-Inverse	13

[1] - Numbers as per standard Principle conventions

Table 2: Relationship Between Inventive Principles and Physical Contradiction Solution Strategies

With regard to Physical Contradictions, where the Contradiction Matrix of no help, experience using TRIZ has permitted the creation of the Inventive Principle selection process illustrated in Table 2. The Table is a modified version of a similar method found in the latest version of the Invention Machine TechOptimizer® software.

Contradiction elimination is one of the most powerful of the TRIZ problem solving tools. A common phenomenon when problem contradictions are eliminated instead of traded-off is that the benefits tend to extend beyond those identified during the problem solving process (5, 6). The novel tools derived for the new method have been shown to increase this beneficial effect.

Ideality

Altshuller identified a trend in which systems always evolve towards increasing 'ideality' and that this evolution process takes place through a series of evolutionary S-curve characteristics. A key finding of TRIZ is that the steps denoting a shift from one S-curve to the next are predictable. This finding may be expected to play a significant role in helping organisations to predict how and when evolution steps are possible. This is an undoubtedly useful capability when seen from the normal context of how organisations innovate. Figure 4 illustrates a typical traditional system evolution path. According to TRIZ and other research (7), there is a very highly likelihood that the spark providing the major innovation will come from outside the existing industry.

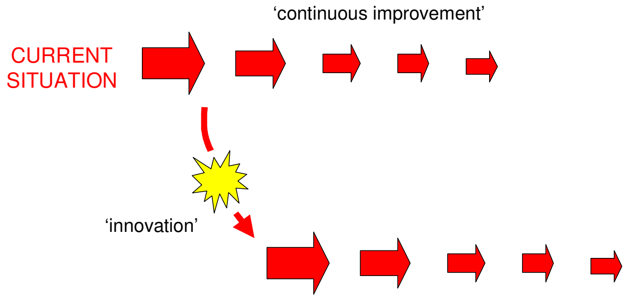

Figure 4: Traditional System Improvement and Evolution Strategy

The essential paradigm shift between this approach and the approach proposed here is that while traditionally, problem solvers start from the knowns of today, the concept of ideality, demands a strategy in which the problem solver is first asked to eliminate the constraints of today's solution, to then envisage the 'ideal final result' situation – in TRIZ terms where the function is performed without any resource, cost or harm – and to then use that as the basis from which a realisable solution is derived. The problem solver may thus be seen to be working back from the 'ideal' to something which is physically possible. This philosophy is illustrated in Figure 5. There are already several examples of this strategy in operation (8, 9).

As well as offering a successful evolution strategy and real problem solutions, it may also be noted that the proposed method also provides a considerable amount of valuable long-term strategy definition data.

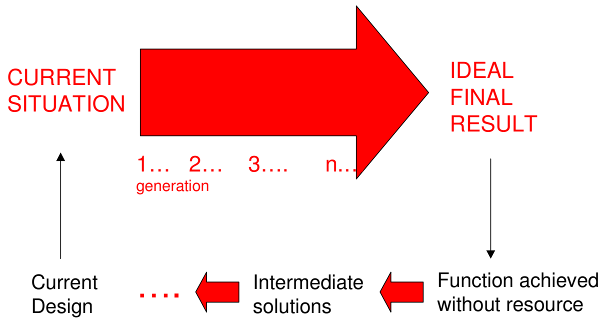

Figure 5: Proposed 'Ideality-Based' Improvement and Evolution Strategy

Functionality

Although the functionality aspects of TRIZ owe a significant debt to the pioneering work on Value Engineering by Miles (10), the method of defining and using functionality data is markedly different; sufficient at the very least to merit discussion as a distinct paradigm shift in thinking relative to traditional occidental thought processes. Three aspects are worthy of particular note:-

1) The idea that a system possesses a Main Useful Function (MUF) and that any system component which does not contribute towards the achievement of this function is ultimately harmful. In a heat exchanger, for example, the MUF is to transfer heat to the working medium; everything else in the system is there solely because we don't yet know how to achieve the MUF without the support of the ancillary components. (Systems may of course perform several additional useful functions according to the requirements of the customer.)
2) In traditional function mapping, the emphasis is very much on the establishment of positive functional relationships between components. TRIZ and more so the method proposed here, places considerably more emphasis on plotting both the positive and the negative relationships contained in a system – see the lens polishing example later – and, more importantly, on using the function analysis as a means of identifying the contradictions in a system.
3) Functionality is the common thread by which it becomes possible to share knowledge between widely differing industries. A motor car is a specific solution to the generic function 'move people', just as a washing powder is a specific solution to the generic function 'remove solid object'. By classifying and arranging knowledge by function, it becomes possible for manufacturers of washing powder to examine how other industries have achieved the same basic 'remove solid object' function. 'Solutions change, functions stay the same' is a general message which forms a central thread in the new methodology.

Use Of Resources

The last of the four main paradigm shifts contained within TRIZ is the simplest, and relates to the unprecedented emphasis placed on the maximisation of use of everything contained within a system. In TRIZ terms, a resource is anything in the system which is not being used. TRIZ demands an aggressive and seemingly relentless pursuit of things in (and around) a system which are not being used to their maximum potential. Discovery of such resources then reveals opportunities through which the design of a system may be improved.

In addition to this relentless pursuit of resources, the method proposed here recommends that the search for resources also take due account of negative as well as the traditionally positive resources in a system. This is done because experience has demonstrated that the discovery of a negative resource coupled with application of the 'Blessing In Disguise' Inventive Principle can often lead to significant design improvements.

A NEW GENERIC SYSTEMATIC PROBLEM SOLVING AND INNOVATIVE DESIGN METHODOLOGY

The new methodology proposed here is built solidly around the existing tools and methods of TRIZ as well as the including the four paradigm shifts discussed above. The method also includes a number of existing and emerging tools and methods to be found outside the TRIZ boundaries.

The method – summarised in Figure 6 - is constructed on the basis of deployable benefit rather than collection of features. In other words, the method is arranged on the basis that users arrive at the method with a certain type of problem to solve rather than with a pre-determined knowledge that they wish to use a certain problem definition or problem solving tool.

In instances where the problem owner is uncertain as to the type of problem at hand, and in any event an important first part of the method, the first part of the process involves analysis of the current situation. The tools contained in the 'analyse system' part of the overall process are detailed in the top right hand leg of Figure 6.

Figure 6: Schematic Of Proposed New Methodology

Following this analysis stage, the problem owner is directed towards different parts of the armoury of problem definition and solving tools depending on the type of problem at hand. The five basic problem types demanding distinctly different problem solving strategies have thus far been determined to be:-

a) problems in which a **new function** is sought
b) problems in which we wish to **improve** some aspect of an **existing** system,
c) problems where we wish to make a step change **evolutionary improvement** to an existing system,
d) problems which relate to **reliability**-type issues
e) problems which relate to **mature systems** in which there are **cost** reduction type drivers

There is undoubtedly some degree of overlap potential between these problem types, and it is not yet possible to say with absolute certainty which path is most appropriate for a given specific problem. This is particularly apparent in situations where the problem owner has a problem with potentially more than one of the above attributes. The most effective solution route determination method discovered involves examination of the current position system under consideration on its evolutionary S-curve. The principal different stages on the S-Curve are illustrated in Figure 7.

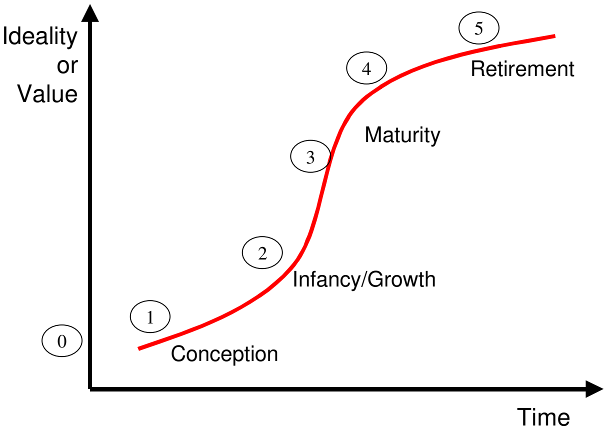

Figure 7: Using S-Curves To Determine Problem Solution Route

(NB: The S-Curve characteristic can be applied at various levels in a system hierarchy – from the total system, looking right down to the smallest sub-system.)

Relating this figure to the different problem solution path scenarios, it has been found that:-

New Function type problems occur at positions 0 and possibly 1.

Improve Existing type problems occur at positions 1 through 4. This is generally the type of problem with the greatest scope for flexibility in terms of solution approach.

Evolutionary improvement problems can occur at all points through the S-curve; at positions 0 and 1, consideration of evolution is probably premature; at positions 4 and 5, the situation may for commercial reasons already be too late. Consideration of this approach at the position 3 point – where the rate of achievable ideality increase has begun to decline – offers the greatest benefit potential. This problem solution strategy is also beginning to be used widely in an R&D strategy planning capacity.

Reliability problems usually emerge at point 4 (although it is worth noting that it is often very difficult to 'build in' reliability to a system once it has already been commercialised).

Mature system cost problems fundamentally occur at position 5; where the system functional benefits have been improved as much as is possible, and the only further improvement potential left to the problem owner is to reduce system costs.

Case study examples of each of these problem types will be discussed briefly in the next section.

Before then, it is necessary to return to Figure 6 in order to examine some of the main additions and changes made to the basic collection of TRIZ tools which make up the basic core of the new generic method:

Physical Laws

TRIZ places surprisingly little emphasis on the need to understand the mathematical relationships usually present in a system. Experience has, however, demonstrated that during the analysis part of any problem situation, it is vital to understand – at least qualitatively – the relationships governing the operation of the system. The necessary form of this 'physical law' analysis depends on the problem type, but is usually instinctive: A heat balance is a necessary step in understanding an overheating problem (as in the lens polishing example later); an energy balance in the analysis of a locomotive braking system; a chemistry balance in a chemical reaction, etc.

QFD/TRIZ/Taguchi

It has been suggested that a combined QFD/TRIZ/Taguchi innovation strategy offers the ultimate in 'systematic innovation' capability. The theory behind the words sounds highly logical; use QFD to capture the customer requirement, use TRIZ to translate that requirement into a concept design, and then use Taguchi methods to help turn that concept design into a 'robust' product'. The practice is, however, somewhat different and there has been little tangible evidence that the trio of techniques works well together. All three are included in some form or other in the methodology proposed here. Whether any one, or part of one, method is employed in a given problem depends very specifically on the individual circumstances of the problem in hand. Two areas in which the proposed method employs the three tools in a generic and novel form are:-

1) Use of the QFD house of quality matrix as a means of identifying specific contradictions in order to then use the Contradictions tools of TRIZ to help overcome the conflicts. Such a method requires that the parameters used in the House of Quality be tailored to fit with the parameters used in the TRIZ Contradiction Matrix.
2) Use of the Evolution Trends tools within TRIZ to help customers to see the solutions that don't yet exist ('helping to write the sales brochure of x years hence') in order to improve the quality of the QFD analysis. This idea fits very much into the concept from 'ideality' of helping customers to break out of the paradigm of incrementing solutions from the known, to envisioning solutions which don't yet exist.

Axiomatic Design

Work examining synergies between TRIZ and Axiomatic Design has established a useful link in terms of a) the definition of functional requirements required of a system, and, b) use of the axiomatic design system of mapping between Functional Requirement, Design Parameter and Process Parameter domains to ease the transition from TRIZ concept design to subsequent detail design phases (11). In essence, TRIZ provides the 'ideate and create' capabilities shown in Suh's definition of the design process (12) – Figure 8.

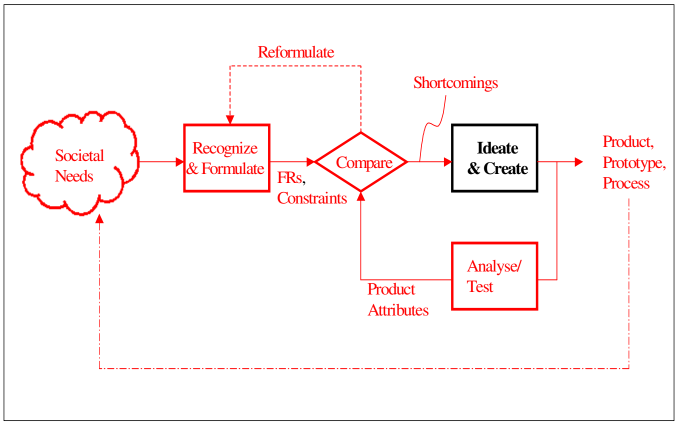

Figure 8: Role Of TRIZ in the (AD-based) Design Process

Theory of Constraints

TRIZ and TOC have much in common, albeit that research to date has really just been touching at the surface of the potential for interaction between the two methods. The first area of mutual benefit has emerged through integration of the 'Evaporating Cloud' problem solving strategy of TOC into the new problem-solving framework.

The basis of the interaction possibilities is essentially two-fold. Firstly, referring to the basic structure of the Evaporating Cloud model – Figure 9 – it is evident that a key part of constructing the cloud is the identification of a physical contradiction (prerequisites 'D' and 'not D'). TOC thus helps to define physical contradictions. The physical contradiction solution strategies contained in TRIZ then offer powerful means of 'evaporating' the cloud.

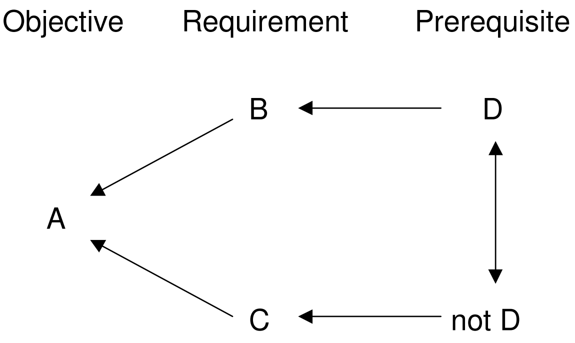

Figure 9: TOC Evaporating Cloud Model

Secondly, the TOC process through which the model is constructed, is amenable to integration with a function analysis model. In this role it encourages a much more profound understanding of the function analysis, and, further, then encourages problem solvers to challenge the assumptions (arrows in the figure) upon which the physical contradiction has been identified (13).

CASE STUDY EXAMPLES

All of the following case study examples are simplified accounts of real problem situations. Names have been omitted and details changed in order to permit more focused attention on the pertinent conceptual ideas in operation. More detailed information on each of the cases can be found in the relevant references.

1) New Requirement – Self Cleaning Hydraulic Filter

The self-cleaning filter for hydraulic systems is a concept which does not yet exist in the market. The idea is at the zero-stage in the S-Curve evolution path. Customers have no expectations in this area because the concept is so different from the current disposable filter convention. Presented with the idea, however, it is difficult to find a customer who would not buy such a product if it were available at the right price.

The idea of a self-cleaning filter is one of the products being developed at the University of Bath (5). The definition of the problem and its subsequent solution were achieved by using the 'New Requirement' tools shown in the proposed methodology.

The key to the definition of the problem came from some DeBono-driven Concept R&D work. The key to the solution came through recognition that the *function* of the self-cleaning filter was to 'move particles relative to flow', discovering through use of a functionally organised knowledge-base, how engineers in other fields had already successfully achieved the function (in this case, the solution came from work originating in the medical engineering sector) and then translating that solution – using Resources in the existing systems – into the hydraulics context.

2) Improve Existing System – Lens Polishing

This example concerns an established, working system, which develops an overheating problem after attempts are made to operate the process more quickly than was anticipated in the original design specification. The basic system involves a lens and a polishing stick comprising abrasive particles and a binding agent – Figure 10.

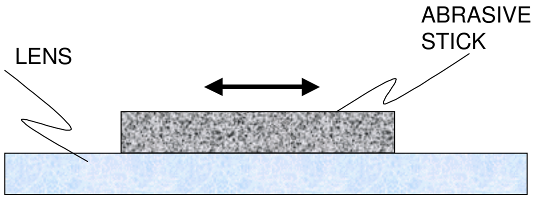

Figure 10: Lens Polishing Problem

The problem is typical of many where there has been little previous effort to improve the system. The current level of system maturity could be anywhere between the 1 to 4 positions in the Figure 6 S-Curve. Problems of this type permit the broadest range of solution approaches. The reason for including the example here is to demonstrate a common trend with this type of problem; that of being able to use a variety of different TRIZ tools to arrive at the same end point.

The basic starting point for the problem was to develop the function analysis model shown in Figure 11. As previously stated, the main aim here is to plot the negative as well as the positive functional relationships between the different system components.

Unlike classical TRIZ – or its software implementations, in the new method, this function analysis model is used as a means of identifying contradictions and S-Fields.

From a Contradictions perspective, it is possible to identify a physical contradiction through the presence of both useful and harmful functional relationships emerging from the same component. In this case, a physical contradiction relating to the abrasive particles can be observed, in that the particles both polish and heat the lens. This physical contradiction in this case may be expressed as a need to have 'friction and not friction'. This contradiction cannot be separated in either space or time, and so if the contradiction is to be eliminated, the 'satisfied' option in Table 2 will offer the most likely solution path. One of the Inventive Principles suggested from this table is Principle 36, 'Phase Transitions'.

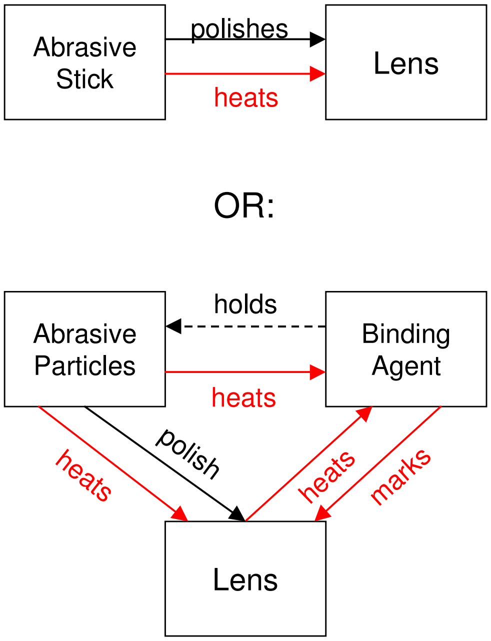

Figure 11: Lens Polishing Problem –Function Analysis Model

Alternatively, the same useful and harmful functions emerging from a single component characteristic can be used to formulate a technical contradiction by relating the problem situation to the overall improvement aim – in this case, the desire to improve the speed of operation of the system. In this sense, increasing speed will increase the useful polishing action, but will also increase the heat generation. In other words as speed is increased, temperature will become worse. The Contradiction Matrix lists Inventive Principle 36, 'Phase Transition' as one of those recommended for this type of speed/temperature contradiction.

The function analysis picture can also be used to identify S-Fields. Here an S-Field with a useful and a harmful interaction between two substances suggests application of Inventive Standard 1.2.4; *'If contact between the two substances must be maintained, transition to a dual S-Field by introducing an additional field'* also suggests possible introduction of a phase transition, which in turn realised the eventual solution illustrated in Figure 12.

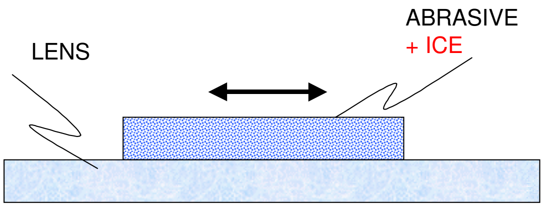

Figure 12: Lens Polishing Solution

3) Evolve Existing System – Mobile Hydraulics

The 'evolution' family of problems often start out as 'improvement' problems, which turn into evolution issues because the system is further up it's S-Curve and the system begins to exhibit the emergence of one or more limiting contradictions.

Taking a more pro-active position – at position 2 rather than 3 or 4 on the Figure 6 S-Curve – the new method allows problem solvers to anticipate the emergence of such limiting contradictions at an early stage.

The example used here is an example of a relatively mature mobile hydraulics system application typical of a mechanical shovel.

The evolution of such systems can be predicted through examination of commercial and technical trends.

The novel aspect here is to translate often quite instinctively obvious trends into the specific frame of the problem. In this case, 'instinctively obvious' trends include:-

Increases in:-
- load carrying capability
- speed of operation
- accuracy of operation
- system efficiency
- driver comfort
- reliability
- maintainability

Decreases in:-
- use of materials
- system weight
- system volume
- cost

Collectively, then, these demand directions may be integrated in order to identify the when different parts of the system become unable to sustain further change.

The approach draws from some of the TOC tools and techniques for identifying the constraint in a system (14).

In the case of this – and several other hydraulic applications – the limiting factor turns out to be heat dissipation rate, and more specifically the performance of the oil cooling system. The limiting contradiction in this case occurs between the ability to dissipate heat and the reducing available installation volume in which to achieve the necessary dissipation.

In order to evolve the system beyond this point, it is necessary to either advance to a new sub-system S-curve by 'eliminating' the heat versus volume contradiction – Reference 15 describes how this was achieved for one particular heat exchanger design – or to directly apply the TRIZ trends of evolution. For example, the 'Surface Segmentation' trend – Figure 13 – might be applied to evolve the heat exchange surface design from one generation to another.

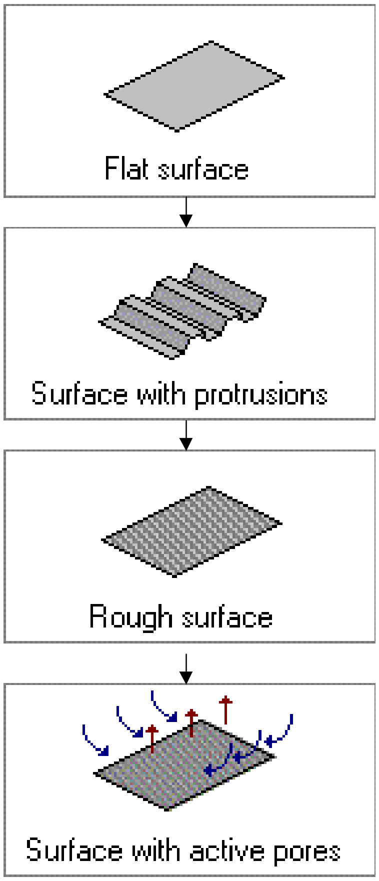

Figure 13: Surface Segmentation Evolution Trend

4) Reliability Problem – Gas-Turbine Blade Failure

The difficulties of designing-in reliability into a system after it has been productionised are well recognised, and much effort now goes into designing reliability into a system at the earliest possible stages of R&D activities. This is of little comfort, however, if reliability problems become apparent only after a system has been in operation for a prolonged period – in extreme cases, possibly several years.

Reliability issues have traditionally only begun to be taken seriously when a system is at the mature (position 4) end of its S-Curve. At this stage, the problems of improving reliability performance are made worse by the fact that the system is approaching the limits of its evolutionary capability. Another common phenomenon present in systems at this end of the evolution curve is that R&D funds have typically disappeared (even though this is a time in the system life at which profitability is usually at its highest). This places special limitations on the scope for change in the system.

In the case study in question, a series of similar and unexpected blade-failures began to occur on an engine type that had seen over 15 years of previously trouble-free operation. The problem brief demanded that the problem be eliminated with minimal changes to the blade, and zero changes to any other components in the engine.

This type of problem demands a rigorous constraint management approach, coupled with a significant amount of detailed subversion analysis. Subversion analysis is a particularly useful technique in situations where – as in this case – the engine was operating within all the limits set by previous FMEA analysis.

The new methodology was able to solve this highly constrained problem through a rigorous root-cause failure subversion analysis (16), and transition of the problem to the manufacturing level – where a local contradiction was identified and eliminated to both solve the problem, and produce a manufacture cost benefit to offset the modification certification costs.

CONCLUSIONS

1) A generic, systematic, problem solving and innovative design methodology has been derived.
2) The methodology is formed around a revised version of TRIZ, in which four major paradigm shifts – contradictions, ideality, functionality and use of resources – have been formulated. Novel modifications to the TRIZ methods and integration with other existing and novel problem solving methods have been necessary to create the desired generic applicability of the method.
3) The method has been successfully validated against a range of real-life problems covering a broad spectrum of problem types.
4) The method has been shown to provide a suitable framework into which new knowledge, tools and methods can be integrated as they emerge.
5) No systematic innovation methodology can ever claim to be complete. Areas into which the current method may be expanded in future evolution steps, include:-
    - update of TRIZ Contradiction Matrix to include new patent and biological data
    - more comprehensive integration of Theory of Constraints methods
    - improved knowledge base of non-technical problem solving strategies
    - improved integration with multi-criteria decision analysis methods to facilitate better solution down-select operation
    - integration of tools and strategies to facilitate improved use of the method in a team environment – paying specific attention to consensus management issues.

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