The Four Pillars of TRIZ

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Systematic Innovation

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 finest patents, the Russian Theory of Inventive Problem Solving, TRIZ, is the most comprehensive systematic innovation and creativity methodology available to mankind. From a distance, the various tools and methods contained in TRIZ can appear, particularly to occidental eyes, to be somewhat unnatural and non-instinctive. The paper examines TRIZ in the light of ongoing work at the University of Bath teaching the method and actively using TRIZ tools to solve problems across a wide range of industry sectors.

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 deploying 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 a TRIZ-based problem definition and problem solving methodology which is now being successfully deployed across a broad spectrum of fields and problem types.

The first section of the paper examines TRIZ from the perspective of the paradigm shifts and emphases which make it deployable in the context of a working environment previously unfamiliar with the method. Subsequent sections then go on to describe how TRIZ is being integrated with other systematic innovation methodologies, and how the combined methods are beginning to be applied successfully across a number of widely disparate problem types. A final section of the paper identifies current and planned future research activities which together point the way to a generic systematic creativity and innovation methodology.

TRIZ BASICS

The core findings of TRIZ research on the global patent database are that the world currently contains a very small number (40 – Reference 2, 3) of Inventive Principles and that all technology evolution trends are predictable.

TRIZ provides means for problem solvers to access the good solutions obtained by the world's finest inventive minds. The basic process by which this occurs is illustrated in Figure 1. Essentially, TRIZ researchers have encapsulated the principles of good inventive practice and set them into a generic problem-solving framework. The task of problem definers and problem solvers using the large majority of the TRIZ tools thus becomes one in which they have to map their specific problems and solutions to and from this generic framework.

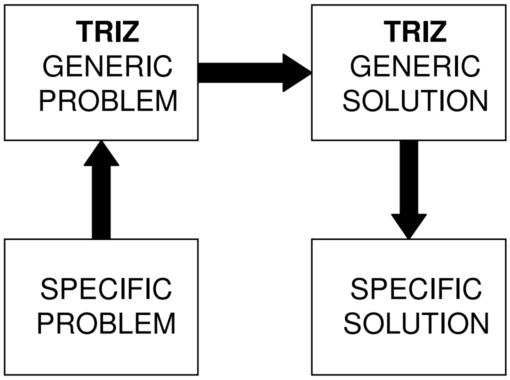

Figure 1: The Basic TRIZ Problem Solving Process

By using the global patent database as the foundation for the method, TRIZ effectively strips away all of the boundaries which exist between different industry sectors. The generic problem solving framework thus allows engineers and scientists working in any one field to access the good practices of everyone working in not just their own, but every other field of science and engineering.

THE FOUR PILLARS OF TRIZ

1500 person years of research have 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 non-Russian 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 description offered here re-casts TRIZ in order to strengthen awareness and understanding of the four main paradigm shifts which discriminate the methodology from other methods.

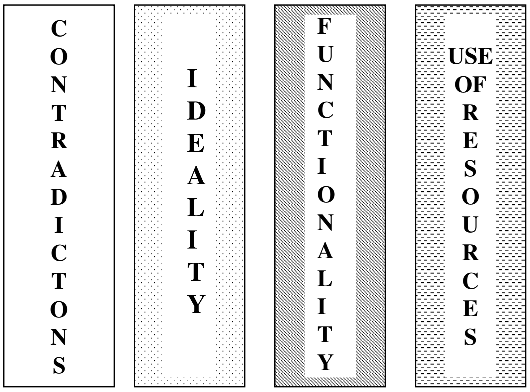

Figure 2: The Four Pillars of TRIZ

The four paradigm shifts – Contradiction, Ideality, Functionality, and Use Of Resources (Figure 2) - are discussed below in the context of the central role they each play in creating a deployable and effective problem definition and problem solution methodology.

Contradictions

Although often the first of the 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. There is a strong tendency in a traditional design approach, in fact, to think of the design process as an amorphous bag filled with an incompressible fluid made from the different design parameters – Figure 3 – in which, as the designer tries to squash the bag to improve one parameter, it bulges out somewhere else as a different parameter gets worse.

The keen emphasis on ‘trade-off’ solutions in traditional problem solving practice often means that designers are rarely explicitly aware that conflicts exist. The first major part of the 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 part then involves using the TRIZ methodology to try and ‘eliminate’ (4) those contradictions rather than to accept them. Or, in terms of the incompressible-fluid filled bag analogy, to attach a valve of some kind which allows the amount of fluid in the bag to be altered.

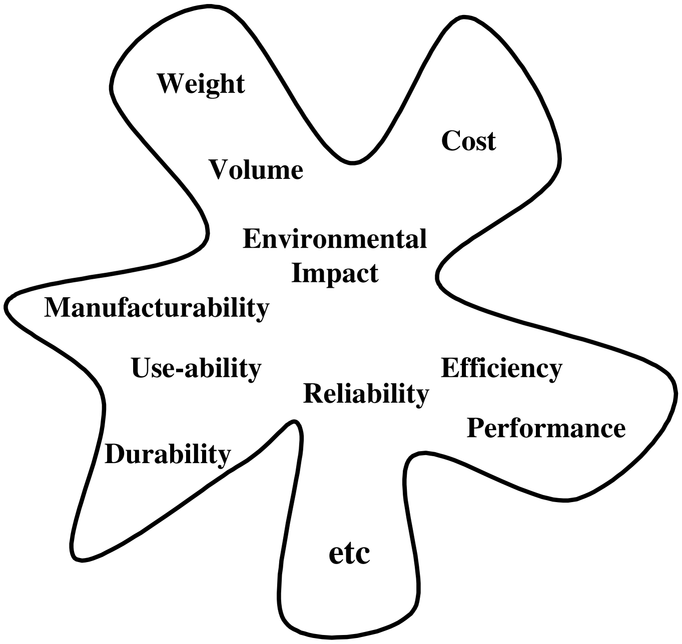

Figure 3: The Design Process As An Incompressible-Fluid Filled Bag

A number of strategies are beneficial with regard to the first – contradiction identification – issue. In the approach detailed here, two novel ideas in particular have been established. The first relates to the use of function analysis mapping to help identify contradiction types. The second relates to the use of a graphical approach to help identify contradictions. In this regard, the two significant discoveries are illustrated in Figure 4.

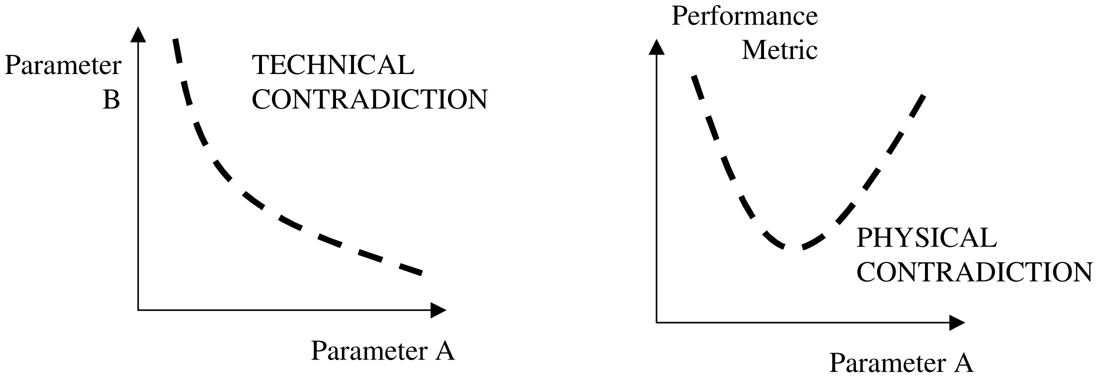

Figure 4: Graphical Representation of Physical And Technical Contradictions

Once contradictions have been identified, TRIZ contains a number of ‘contradiction elimination’ tools – primarily the Contradiction Matrix (3) – which encapsulate how others have successfully solved similar problems. At this point in time, TRIZ has identified 40 Inventive Principles which might apply in any given contradiction situation. The Contradiction Matrix allows problem solvers to narrow down that list of 40 to three or four Principles which might apply to an individual contradiction type. Experience using the Matrix has shown its capability to be widely variable depending on the type of problem being solved – Figure 5.

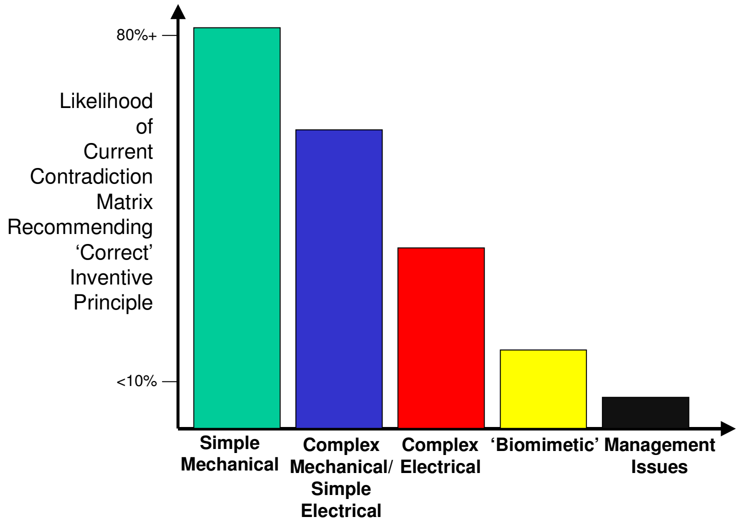

Figure 5: Relative Effectiveness Of Contradiction Matrix In Different Problem Arenas

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

With regard to Contradictions in which different attributes are required from the same parameter (e.g. the object should be big AND small), where the Contradiction Matrix does not apply, 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.

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 Solution 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

Table 2: Relation Between Principles And Physical Contradiction Solution Strategies

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 initially targeted during the problem solving process (5, 6).

In terms of evolutionary S-curves, it is the emergence of limiting contradictions (7) that ultimately restrict the ability of systems to give all of the benefits that customers desire and give the S-curve its characteristic flattened profile at the mature end of the curve. The TRIZ contradiction elimination tools thus have a very important role to play in allowing systems to transition from one S-curve to another.

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 (2, 8). 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 relative to the way in which organisations have traditionally viewed the innovation process. Figure 6 illustrates a typical traditional system evolution path. The improvement of systems using this method of operating is very much rooted in the existence of the current situation, and all improvement initiatives use the current design as their foundation. The large-scale innovations then usually appear through what is usually perceived as a highly random process. According to TRIZ and other research, there is a very highly likelihood that these major innovations will come from outside the existing industry. In fact, the likelihood is close to 100% (9).

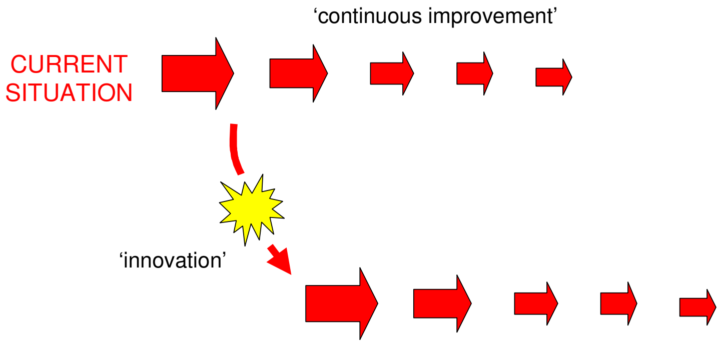

Figure 6: Traditional System Improvement and Evolution Strategy

The essential paradigm shift between this approach and the TRIZ approach 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 then physically capable of being engineered. This philosophy is illustrated in Figure 7. There are already several examples of this strategy in operation (10, 11).

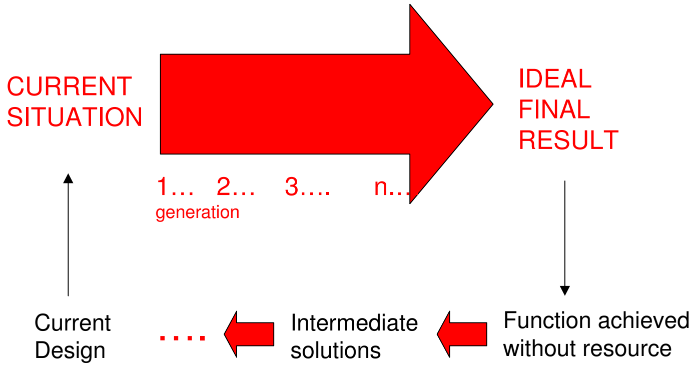

Figure 7: Proposed 'Ideality-Based' Improvement and Evolution Strategy

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

Functionality

Although the functionality aspects of TRIZ owe a significant debt to the pioneering work on Value Engineering by Miles (12), 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 places considerable emphasis on plotting both the positive and the negative relationships contained in a system, 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 message which forms a central thread in the TRIZ methodology: People want a hole not a drill.

The emphasis TRIZ places on functionality demands that engineers and scientists adopt a much more flexible approach to the way in which they look for solutions to problems. The age of the specialist is coming to an end; it is no longer sufficient for mechanical engineers to only look for mechanical solutions to their problems when someone from, say, the chemical sector may already have discovered a better way of achieving the function being sought – Figure 8.

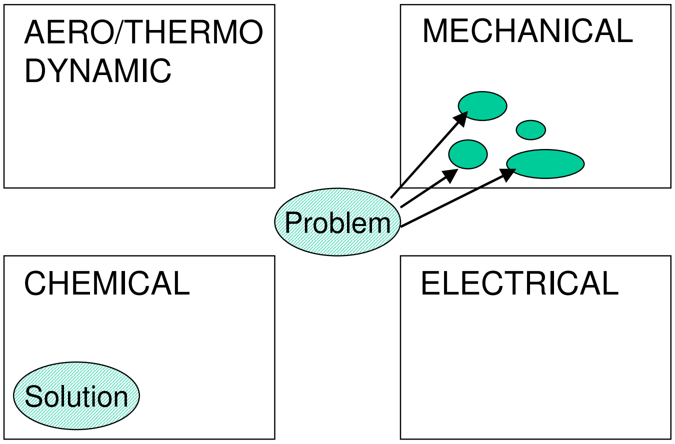

Figure 8: Solution Spaces

A number of functionally classified knowledge databases are now becoming commercially available. Probably the most comprehensive – currently containing around 6000 effects and examples – comes from Invention Machine (13).

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, TRIZ demands 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.

By way of an example of this 'turning lemons into lemonade' concept, Russian engineers often think of resonance as a resource. This is in direct contradiction to most Western practice, where resonance is commonly viewed as something to be avoided at all costs. TRIZ says that somewhere, somehow, resonance in a system can be used to beneficial effect. In effect, resonance is a potent force lever capable of amplifying small inputs into large outputs.

Resonance is currently being used to generate beneficial effects in a number of new product developments from vacuum cleaners (resonating carpet fibres to enhance extraction of dust particles), paint stripping systems on ships (firing a pulsed jet of water – existing resource! – at the local resonant frequency of the hull), and in helping to empty trucks carrying powder-based substances more quickly.

OTHER TRIZ TOOLS

S-Fields

Opinion over the importance of S-Fields in the TRIZ methodology varies considerably across the TRIZ community. While the problem solving tool is probably not a 'pillar' of the overall method, certainly no discussion of TRIZ can ignore the existence of S-Fields.

The S-Fields tool is built on Altshuller's discovery that a viable system must contain a minimum of two substances ('substance' being the 'S' in S-Fields) and a field. The terms 'substance' and 'field' are used as highly generic triggers, such that a measurement, a molecule or a complex bridge can all be interpreted as 'substances'. By way of example of the system viability test, consider a functional requirement to hammer nails into a block of wood. Here the system comprises two substances – hammer and nail – which does not become complete until we add gravity (a field) as a means of allowing one substance to act on the other.

The two substances and field in an S-Field may interact in various ways; the interactions may be effective, insufficient, excessive, or harmful. Depending on the combination of relationships in a given S-Field (usually established through a function analysis model), TRIZ then offers 76 Standard Inventive Solutions (3) providing means of transforming an incomplete or inadequate S-Field into a complete and effective S-Field.

Trends Of Evolution

One of Altshuller's key findings was that all technology evolution trends are predictable. The 76 Standard Inventive Solutions include solution triggers which build on some of these findings. It is becoming more common for the identified trends – of which there are 8 (Reference 2) to 20 (Reference 13) depending on how the same results are interpreted – to be used as problem solving tools in their own right.

Trimming

TRIZ contains a number of tools to help problem solvers eliminate components from a system, while simultaneously aiming to maintain functionality. Again there are strong links to function analysis modelling, but Trimming tools are beginning to be used as independent entities. Trimming has much in common with DFM/A approaches, albeit with a much stronger emphasis on component functions (both negative and positive).

Subversion Analysis

A late addition to the armoury of TRIZ tools, created specifically to improve design robustness. The principal subversion analysis strategy is to force designers and problem solvers to systematically and pro-actively ask the question '*how can I destroy this system?*' The tool is beginning to be beneficially combined with FMEA and similar techniques.

COMBINING TRIZ WITH OTHER METHODOLOGIES

While undoubtedly powerful, TRIZ is not yet comprehensive enough to tackle all types of problems. Since its emergence in the West, the method has begun to be integrated with a number of established and emerging problem definition and problem solving tools and strategies. Most notable among these are illustrated in Figure 10.

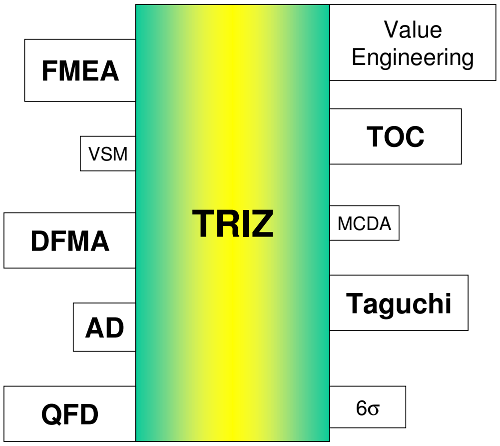

Figure 10: Integration of TRIZ With Other Systematic Innovation Tools

A combined systematic innovation and creativity methodology featuring TRIZ and other tools needs to be constructed on the basis of deployable benefit rather than collection of features. In other words, a combined methodology needs to be 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.

With this in mind, five basic problem types, each demanding different problem solving tools and strategies, have thus far been determined:-

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 to date involves examination of the current position of the system under consideration on its evolutionary S-curve. The principal different stages on the S-Curve are illustrated in Figure 11.

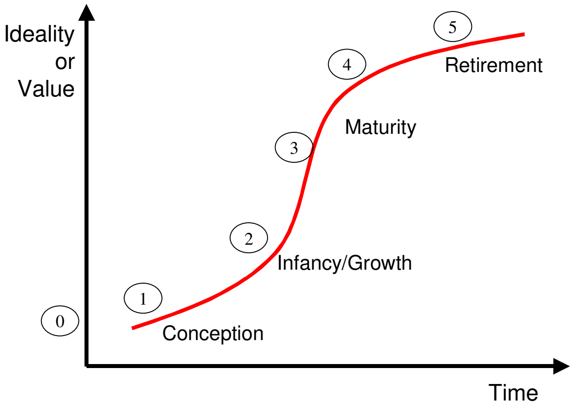

Figure 11: Using S-Curves To Determine Problem Solution Route

(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. Every component in a system ultimately has its own family of S-curves.)

New Function type problems occur at positions 0 and possibly 1. This type of problem is most amenable to solution using functional effects databases and S-Fields tools.

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, and all tools can apply. The specific solution route here is usually best determined following the completion of a rigorous function analysis of the current system. Reference 14 presents such a strategy in action for a novel heat exchanger design.

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 (albeit that systems at this stage are commonly at their most profitable). Evolutionary improvement problems will usually be most amenable to solution through either the Contradictions or Trends of Evolution tools.

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). Subversion Analysis and Contradictions are the two TRIZ tools most likely to be of help.

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. Trimming is the most effective TRIZ tool in such instances. Due consideration of Function Analysis and Use of Resources will also be beneficial.

More details on the operation of a generic problem definition and problem solving methodology, and the integration of TRIZ with other innovation tools may be found in Reference 15.

SUMMARY

1) The systematic innovation and creativity methodology, TRIZ, is formed around four main pillars, contradictions, ideality, functionality and use of resources.
2) TRIZ contains a broad spectrum of problem definition and problem solving tools. Selection of the most appropriate tool for a given problem is best performed on the basis of where the existing system lies on its family of evolutionary S-Curves.
3) TRIZ is the most comprehensive systematic innovation and creativity method known to man. It offers a generic problem-solving framework into which other tools have already begun to be successfully integrated.
4) 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 all TRIZ tools to include new patent and biological data
    - more comprehensive integration with non-Russian innovation 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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