

TRIZ-BASED SYSTEMATIC INNOVATION: The Space Between Inventive Principle and Design Solution

Darrell MANN

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

Ellen DOMB

The PQR Group, 190 N. Mountain Ave., Upland, CA 91786 USA
+1(909)949-0857 FAX +1(909)949-2968
EllenDomb@compuserve.com

"First things first, but not necessarily in that order"
(Doctor Who)

Abstract

Since its introduction to the West around a decade ago, TRIZ has proved itself to be an extremely potent problem solving and product innovation method.

The key to successful problem solving with TRIZ usually starts with the definition of appropriate physical and technical contradictions. To a large extent it then ends with a number of candidate 'Inventive Principle' recommendations from the list of 40 possibilities.

The Inventive Principles - like for example the commonly used 'the other way around' principle - are necessarily generic in nature. Subsequent application of this type of generic statement to the inevitably specific conditions of a particular problem can often be a process fraught with uncertainty and unpredictability.

The paper takes a close look at what happens in this gap between Inventive Principle and specific problem solution in order to establish whether there might be some general rules applicable to a more automated systematic innovation process.

1.0 Introduction

The number of texts on human creativity and creative problem solving is vast (see Bibliography). Before TRIZ, the quantity of useful - i.e. in the context of the world of the engineer 'useable' - output from all of this activity amounts to little more than zero.

TRIZ research began in 1946 with Genrich Altshuller's hypothesis that there are universal principles of invention that are the basis for creative, technology advancing, innovations (1). Altshuller believed that if these principles could be identified and codified, they could be taught to people; and thus could make the process of invention more predictable. TRIZ research has proceeded in several stages over the last 50 years, now accumulating over 800 man-years of scientific study and going far beyond Altshuller's initial hypothesis. The three primary findings of the research are:

:

- 1. Problems and solutions were repeated across industries and sciences**
- 2. Patterns of technical evolution were repeated across industries and sciences**
- 3. Significant innovations used scientific effects outside the field where they were developed**

Much of the practice of TRIZ consists of learning these repeating patterns of problems-solutions and patterns of technical evolution, and methods of using scientific effects, and applying the general TRIZ patterns to the specific situation that confronts the developer. Figure 1 describes this process graphically.

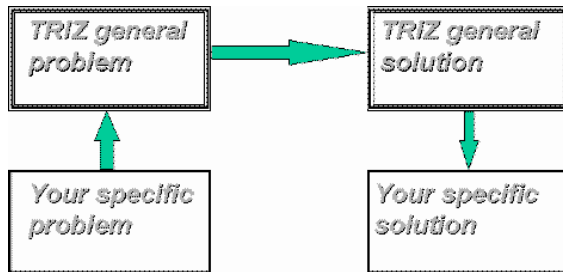


Figure 1: The General Model For TRIZ Problem Solving

Altshuller's work on problem classification and the discovery that there are only a very small number of Inventive Principles available to the engineer is already profoundly changing the systematic innovation picture. That there are only these small number of principles has, for example, meant their systemisation in software form has been relatively easy. The emergence of a number of commercial packages built around TRIZ ideas (3) is therefore not surprising.

Powerful as it is, however, the systemisation process unfortunately effectively ends with the 'TRIZ General Solution' and the output of Inventive Principles successfully used by others to solve the given TRIZ General Problem. True, other factors - like Altshuller's discoveries regarding the predictability of technology evolution trends, the Ideal Final Result concept, or Functional Analysis problem modelling methods – can provide engineers with useful problem solution clues, but there is nevertheless a distinct gap between TRIZ General Solution Inventive Principle and specific design solution:

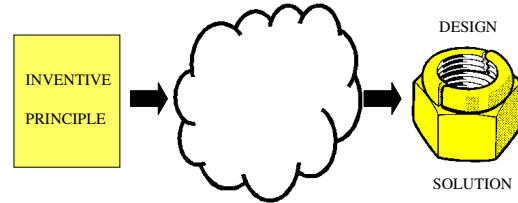


Figure 2: The Space Between Inventive Principle and Design Solution

Not least of the issues here can often be the problems associated with determining which of the 40 Inventive Principles is the 'right' one for the problem at hand. Altshuller's Contradiction Matrix is an undoubtedly elegant means of classifying how others have successfully solved the same TRIZ General Problem, but it was never intended to be a comprehensive one. It is in fact quite common that the 'right' solution to a specific problem comes from an Inventive Principle not recommended by the Matrix.

In looking at the gap between Inventive Principle and design solution, therefore, it will also be useful to look at the pre-cursor issue of understanding and identifying what the 'right' Principle actually is.

TRIZ is being used successfully in a wide and widening variety of fields. The space – this 'gap' – between Principles and specific design solutions is obviously therefore not a vacuum. Whatever it is, however, is at present obscured by clouds. The question is, what is behind those clouds, and whatever it is, is it in any way mappable?

2.0 The Irreversible Nature of Inventive Ideas

The best if not only way of usefully looking beyond the clouds is through examination of case study examples. Every successful patent and every successful innovation offers potential data. There is thus an awful lot of case study material from which to choose.

Unfortunately there is a problem. A fairly fundamental problem associated with each and every case. A problem of irreversibility:

Moving forwards from problem to solution – in effect the process hidden behind the cloud – is an often highly nebulous, highly intractable path. Before that moment when the light-bulb finally lights, the engineer is often literally as well as metaphorically in the dark.

The other way around – looking back at the problem after the solution has been discovered – however, is a completely different matter. In this situation, the solution is often seen as ‘obvious’ - to the point of being almost facile. The ‘why didn’t I think of that’ experience.

In fact the ‘obviousness’ of a solution is very often used as a test of how ‘right’ the solution is. Generally speaking, the more ‘obvious’ the answer is, the more elegant the solution is felt to be.

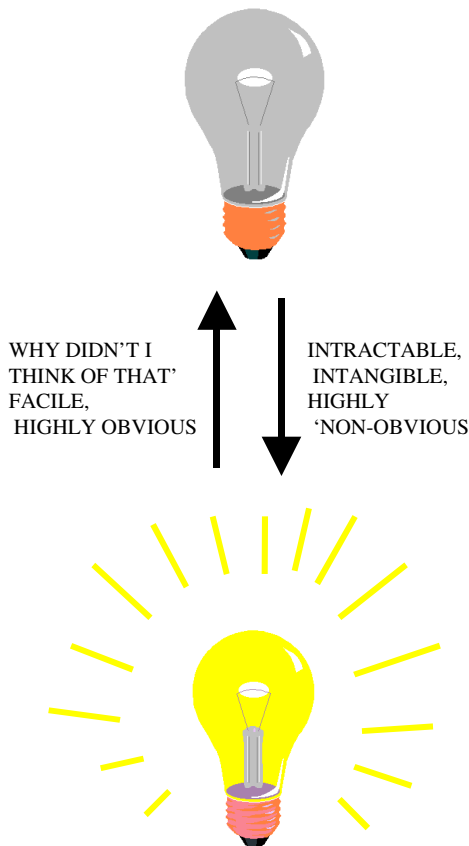


Figure 3: The Irreversible Nature Of Creative Ideas

Think, for example, of how obvious a solution the wheel is. Then think how non-obvious it was for the first 95% of human existence. Or think how it is now almost impossible to imagine that the molecular structure of Benzene could be anything other than a ring.

This ‘obviousness’ irreversibility and the speed with which the light gets turned on once the switch is found makes it extremely difficult to establish what the turning on process actually was. Most famously with Kekule and his solution of the Benzene ring problem, the solution process took the form of a dream about a snake chewing on its tail (reference 4). It is difficult to see how this might be a mappable process. Without direct access to the problem solver – as was the case with Altshuler looking at the patent database – likely as not the problem will be even greater.

In trying to get ‘behind the cloud’, the irreversibility problem can be expected to be a fairly major one.

First, however, it is necessary to have a look at a number of case studies in order to gain a more specific feel for the size of the unknown behind the cloud:-

3.0 Case Study 1: Flanged Joint

Flange joints are used widely across a number of industry sectors for joining adjacent sections of pipe or casings. In the aerospace gas-turbine industry, flange joints are expected to seal high temperature, high pressure gases at quite large diameters. A typical flange joint for the powerplant in a large civil airliner may well require over a hundred bolts to achieve adequate sealing performance. From the perspective of reducing weight and improving maintainability of the engines, it is desirable to reduce the number of bolts required. ‘Halving the number of bolts on a flange joint’ was a TRIZ case study described in Reference 5. The solution to the problem was patented in the US as patent number

5,230,540 and is reproduced here in Figure 4.

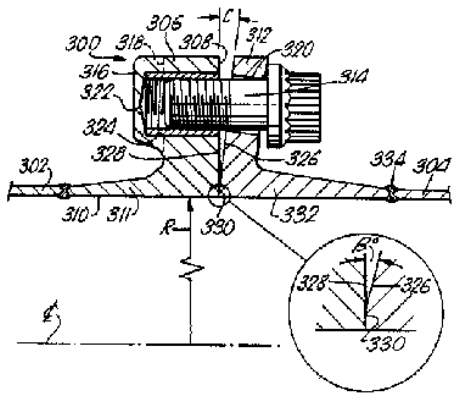


Figure 4: Fluid-Tight Joint With Inclined Flange Face, US Patent 5,230,540

The Inventive Principle used to derive this highly elegant and simple solution was ‘Another Dimension’.

Case Study 1 then leaves us with ‘Another Dimension’ and patent number 5,230,540 as the entry and exit points respectively of any process that may exist behind the cloud.

4.0 Case Study 2: Bicycle Seat

Bicycle seats are, generally speaking, uncomfortable things to sit on. The bifurcated bicycle seat (Figure 5) is conceptually at least, a means of achieving both comfortable sitting position and freedom to pedal.



Figure 5: ABS Sports Bifurcated Saddle

While not a new idea, the bifurcated seat does offer an effective demonstration

of the power of TRIZ and the Contradiction Matrix (reference 6).

Case Study 2 sees the bifurcated bicycle seat as the specific design solution emerging from simultaneous application of two Inventive Principles; ‘The Other Way Round’ and ‘Dynamic Parts’.

5.0 Case Study 3: Particle Separator

Reference 7 describes a more complex problem concerning a novel design solution to the problem of particle separator systems for helicopter engines.

There are a number of separator types available. Engine mounted forms are probably the most common. All current engine mounted separators look like the device illustrated in Figure 5; essentially an axi-symmetric, bifurcated duct taking clean air around a sharp bend into the engine, and using the inertia of contaminants to expel them through a scavenge duct.

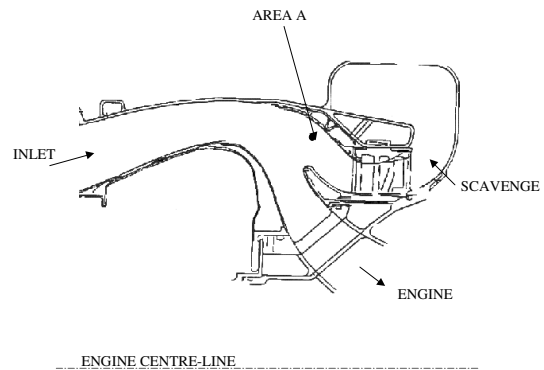


Figure 6: Typical Engine Mounted Particle Separator

Much effort has been expended trying to improve the performance of these designs. Reference 7 describes the background to the realisation of the novel solution shown in Figure 7. This new design offers the potential to not only double contaminant separation efficiency, but also to offer significant reductions in volume, weight, aerodynamic losses, and power requirement.

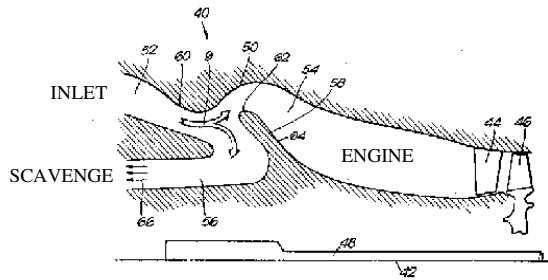


Figure 7: US Patent 5,139,545 Particle Separator

While the improved design may be seen to be relatively simple – the innovation comes about by simply transposing the position of the engine and scavenger ducts - the process of deriving it was rather more complex. Most significantly as far as this analysis is concerned, the Inventive Principle used ('The Other Way Round') was not one of the ones recommended when the problem (problems) were set in the context of the TRIZ Contradiction Matrix.

Case Study 3, therefore, comes with the added issue of knowing first of all which Inventive Principle is the 'right' one.

6.0 Mechanisms of Mind: Pattern Recognition

To solve the mystery of what lies behind the cloud, would be to solve a problem that has confounded many hundreds of man-years of effort. To suggest that a solution exists here, therefore, would be an action of extreme folly.

That being said, it is apparent that TRIZ has already done much to de-mystify the creative process. Wonder, for example, whether Kekule might have discovered the ring structure of Benzene any quicker if he had been aware that there were Inventive Principles called 'Merging', or 'Self-Service', or 'Curvature Increase'? The Inventive Principles of TRIZ provide 40 very good start points from which to search for problem solutions – see reference 6.

TRIZ provides a powerful foundation point. A pointer to how the steps between Inventive Principle and design solution

might then be plotted perhaps comes from some of the research on how the human brain functions and, particularly, on its pattern recognition capabilities.

By way of demonstration, and adapting the 'Connect-Up' idea first written about by Edward de Bono (9), if any two words are picked at random, the brain will almost without fail manage to come up with another word which connects them. The process is often expressed in a manner like that shown in Figure 8. Here the two chosen random words are DOG and WING – at first glance neither word has anything at all to do with the other, but the brain will almost inevitably make some kind of connection. Indeed, given a couple of minutes, most people will be able to make associations with ten or more connecting words.

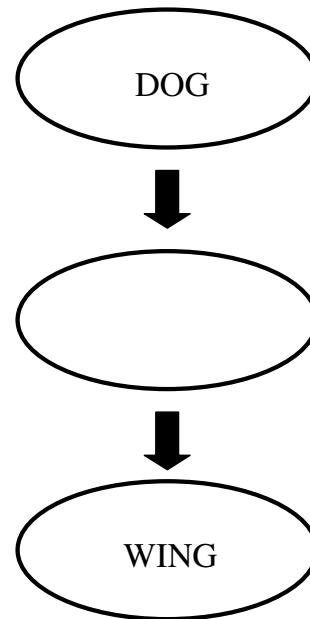


Figure 7: Connecting Words

This pattern making capability is an undoubtedly powerful one. Perhaps not so powerful, however, that some kind of mammoth artificial intelligence computer-code might be constructed to mimic the process? Even with only ten words connecting any pair and a typical individual's word vocabulary, though, mammoth would certainly be the word.

Unfortunately, the situation becomes even more complicated if a number of people are asked to perform the same exercise. Research in this field (10) suggests that if ten people are asked to write down ten connecting words each, the level of duplication of words between individuals would be very small. On average, the number of duplicated words would be around 5%. In other words, ten people writing down ten connecting words each would tend to produce a total of over 90 different connecting words.

Knowing there to be a finite number of words, maybe some people can still imagine this being a situation amenable to a software implementation – albeit one in which we might hope the software itself does the large majority of the ‘learning’/programming.

Unfortunately, even this scenario is a very long way away from the full story. A very long way because given a series of pictorial images to connect, one brain is usually capable of making even more connections. Take a population of brains and the number of connections may well be as close to infinite as makes any difference to even the biggest imaginable computer code.

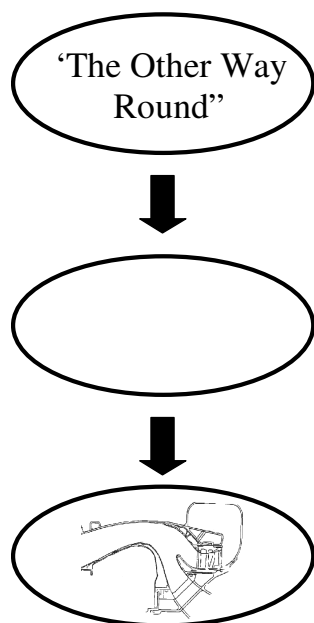


Figure 8: Case Study 3 Connections

So what does this mean from the perspective of TRIZ and the need to solve problems?

On the positive side, it means that given a problem and an Inventive Principle – for example the Case Study 3 scenario as re-drawn in Connect-Up form (Figure 8) – the brain **will** make interesting connections.

Knowing the eventual solution to Case Study 3 and seeing this picture, it is already extremely easy to see how the solution came about. Recognising the Irreversibility phenomenon described in Section 2.0, perhaps it is too easy to be believable?

The same may be seen to apply to the other two Case Study examples.

So what about another case study? One where the ‘answer’ has not previously been seen?

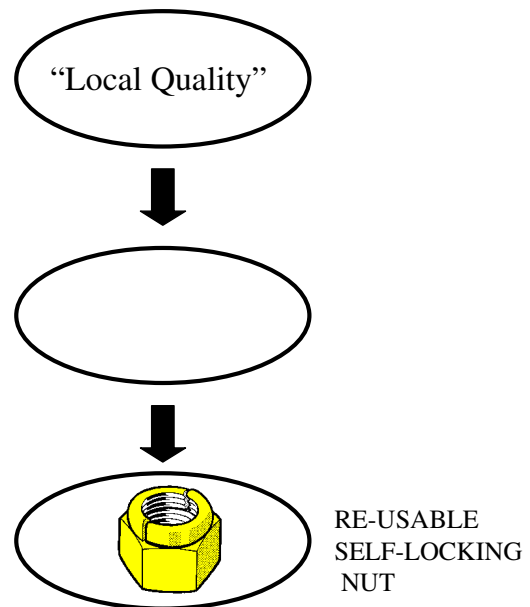


Figure 9: Connecting Inventive Principle and Desired Design Outcome

The (an?) answer to this one can be found in Reference 11.

Of course, even this example is over-simplistic. Over-simplistic in two important ways:-

1) There are 40 Inventive Principles. ‘Local Quality’ happened to be the one that gave the answer to this problem, but

that was not known a priori. In reality, there will have been at least three – and quite possibly all 39 – other Inventive Principles to also try to connect.

2) More significantly, who is to say that the picture and its corresponding problem definition ('re-usable self-locking nut') is either the 'right' picture or the 'right' definition?

In other words, although it is possible to demonstrate that the brain is able to make the right connections, the 'Connect-Up' idea is still some considerable distance from being a systematic procedure.

7.0 Use of Analogies

In many respects, the Connect-Up idea works in a manner similar to the analogies used by Altshuller (1), by Invention Machine in the TechOptimizer software (2), and by Domb (12) to assist designers in relating the TRIZ General Solution to their own specific problem circumstance.

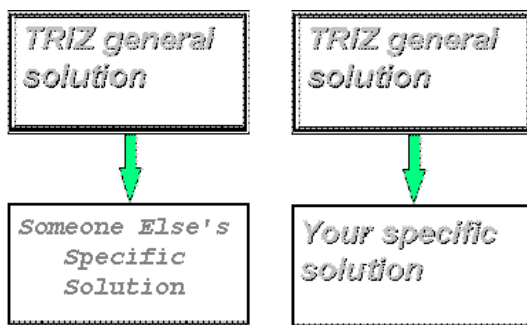


Figure 10: Use of Analogy to Help Connect General to Specific Solution

The analogies take the form of worked examples illustrating how other inventors have applied the Inventive Principles to their particular problems. In this sense, while often useful, they provide little scope for incorporation into an automated problem solving methodology.

The Altshuller approach (1) adopted by Domb (13), however, in which problem solvers are required to divide problems into:-

- Object
- Tool
- Energy Source
- Transmission means, and
- Guidance & Control

elements does perhaps offer more scope for systemisation; if only because dividing a problem into these functional elements, the approach provides a basis for identifying which element(s) of the system the solution should focus on.

For example, in Case Study 1 the approach can be used to show that the problem solution is most likely to emerge through consideration of the flange faces (tool) rather than the need to form a seal (object), or the bolts (energy source), or wrench (transmission means), or the human operator (guidance and control).

8.0 Connections With Automated Mechanism Design Software

Whether it will ever be possible for a piece of computer software to automatically perform the actions necessary to achieve the answers to any of the Case Study examples – or indeed **any generic** problem – currently appears to be highly unlikely

Whether or not it might be possible for **particular** types or groups of problem, to be solved automatically, however, may be a different matter.

Recent work at the University of Bath on mechanism design (14) may be one area where such a formal link between algorithms based on TRIZ principles and automated mechanism design software (e.g. CAMFORD) may produce a powerful design capability:

The Beginnings of a Systematic Methodology? - Mechanism design is amenable to an automated design approach in areas where design rules are able to be described in a logical, mathematical form.

The bicycle seat example described in Case Study 2 may be just such an example:

The bicycle seat has a number of functional requirements which, in the context of configuration design (as opposed to detail design), may be expressed mathematically:-

- range of positions at which the human frame is designed to carry seating loads,
- range of loads at these positions,
- range of torque (cornering) loads,
- range of seat/bicycle connection positions,
- range of relative positions between seat loading points and pedals,
- range of leg movements associated with pedalling action,
- etc.

Figure 11 illustrates these loads and loading positions in diagrammatic form.

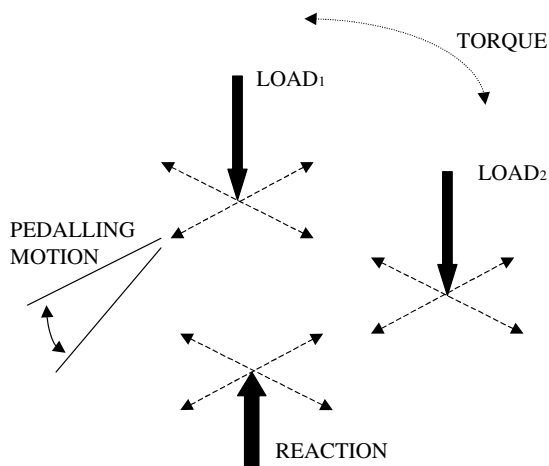


Figure 11: Example Bicycle Seat Design Domain Knowledge

In terms of a cognitive design approach (15), this information represents *domain knowledge*; the knowledge which provides the functional boundary conditions within which the design solution must lie.

The cognitive approach also requires *inference knowledge* – the ‘how’ rules (e.g. ‘carry load using cantilever’) and *strategic knowledge* – how the ‘how’ rules

may be applied. In the ongoing automated design approach developments at Bath, this *strategic knowledge* set is the one in which the Inventive Principles of TRIZ are being projected. At least those amenable to mathematical (software implementable) interpretation in the mechanism design context. For example:-

- | | |
|-------------------|---------------------|
| * Segmentation | * Extraction |
| * Asymmetry | * Merging |
| * Nested Doll | * Counterweight |
| * Prior Action | * Other Way Round |
| * Spheroidality | * Dynamics |
| * Partial Action | * Another Dimension |
| * Periodic Action | * Intermediary |
| * Self-Service | |

The work is some way from complete for even this simple case, not least because of the difficulties associated with the systemisation of *working knowledge* – i.e. the rules used by designer’s when gauging whether a candidate solution is successful or not.

In this regard, the current research philosophy, is pointing towards use of an evolutionary design approach (16) in which the designer manually applies this *working knowledge* to select the ‘fittest’ solution from a series of algorithm generated mutations.

Despite such shortfalls and deficiencies in the method, preliminary evidence suggests it is possible to generate the bi-furcated bicycle seat solution from such an approach.

9.0 Conclusions

- 1) The space between Inventive Principle and problem solution is not a vacuum. If a formal route between the two exists, it is very unlikely to ever be mappable (software implementable) in a generic sense.
- 2) For specific problem types – such as mechanism design – a formalised, mappable systematic innovation tool based on TRIZ principles may well be constructable.

- 3) Meanwhile, the 40 Inventive Principles of TRIZ provide a very powerful tool for breaking out of existing design paradigms and into new and exciting ones.
- 4) The de Bono based 'Connect-Up' idea – getting engineers to find connections between Inventive Principles and the problem at hand – and use of analogies, are also both very powerful means of deriving inventive problem solutions.

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<p><i>"If you can define a problem, it can be solved"</i> (Edwin Land)</p>
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