

Manufacturing Technology Evolution Trends

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Keywords: systematic innovation, creativity, S-curves, contradictions

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, has identified a number of design contradiction-eliminating strategies, and distinct and predictable technology evolution patterns. The paper discusses these patterns and their use in the context of current and projected future manufacturing methods and systems.

Introduction

Manufacturing technology R&D spend is inevitably limited by the financial constraints of an organisation. The drive to maximise manufacturing output benefit per dollar invested in manufacturing technology innovation has never been greater. Nor, seemingly, have the difficulties in identifying exactly where, how and when investments might most prudently be made. The problem definition and solving strategies contained in TRIZ provide powerful new ways of managing the risks associated with drives to continually improve existing or create new manufacturing capabilities.

The first section of the paper provides a brief outline of the TRIZ methodology, concentrating on the parts of the method most applicable in an innovative manufacturing context. The second section then illustrates how these tools can be deployed to help identify future manufacture system evolution directions.

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 1, 2) of Inventive Principles and that technology evolution trends follow predictable paths.

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.

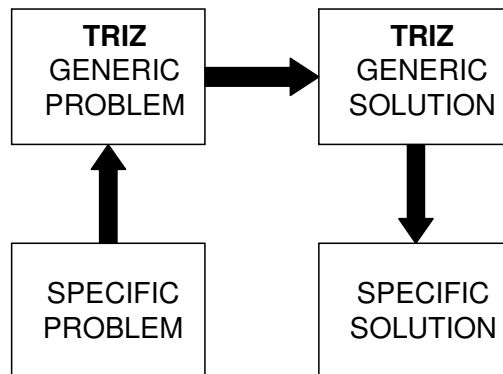


Figure 1: The Basic TRIZ Problem Solving Process

By using the global patent database as the foundation for the method, TRIZ effectively strips away all of the boundaries which exist between 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 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 description offered here re-casts TRIZ in order to strengthen awareness and understanding of the four main paradigm shifts – CONTRADICTIONS, IDEALITY, FUNCTIONALITY, and USE OF RESOURCES – which discriminate the methodology from other methods.

The four paradigm shifts 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. 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’ (3) the contradictions rather than to accept them. The principle tool used to assist in this contradiction-elimination process is the Contradiction Matrix (2). The Matrix has extracted the good contradiction-eliminating practices of the best inventions in the world and made them accessible to any other problem containing any pair of conflicting design parameters.

Ideality

TRIZ researchers have identified a trend whereby systems always evolve towards increasing ‘ideality’ through a series of evolutionary S-curve characteristics (1, 4). A key finding of TRIZ is that the steps denoting a shift from one S-curve to the next are predictable.

The essential paradigm shift between traditional evolution prediction approaches 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 first thinks about an ‘ideal final result’. TRIZ uses the ‘ideal final result’ to describe the situation where the system *performs its desired function without any resource, cost or harm*. From this ‘ideal final result’, the problem solver then works backwards, step-by-step, until a solution capable of being practically engineered is achieved (Figure 2). References 5 and 6 give examples of this strategy in operation.

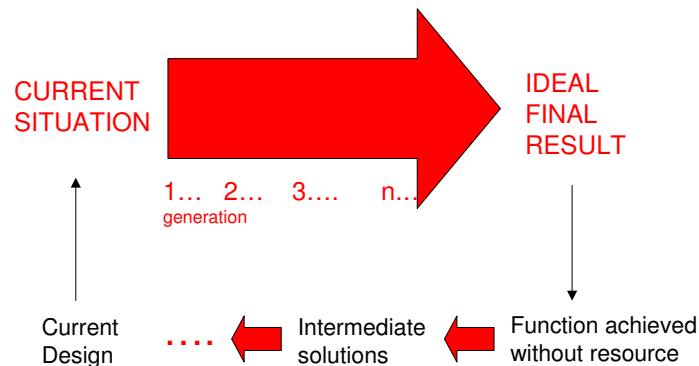


Figure 2: ‘Ideality-Based’ Improvement and Evolution Strategy

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 (7), 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 engineers 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 considerably more 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 general message which forms an important 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 appears to be 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.

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 TRIZ also demands that the search for resources 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 viewed as something to be avoided if at all

possible. 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.

Applying TRIZ In A Manufacture Context

Every component within a system has a family of evolutionary S-curves associated with it. It may further be seen that every manufacture process associated with each of these individual components also possesses a family of S-curves. The position of a component or manufacture process on its current S-curve plays a large part in determining how improvements beyond the present capability may be realised. Generally speaking, the further down the system hierarchy a component is, the more likely it is that the designer will have pushed the component design to the top of its current S-curve – thus a bolt is much more likely to be designed at the limits of its potential than, say, the engine it holds together, or the motor vehicle into which the engine is fitted. Manufacture processes are in turn much more likely to be pushed to the top of their current S-curve than the components which they are designed to make. This characteristic is re-enforced by strong ‘continuous improvement’ initiatives to progressively squeeze as much output from the manufacture process as is possible.

At the top of an S-curve, the system or process has been pushed as far as it can and becomes *fundamentally* incapable of delivering additional ‘value’. The system has hit what is known in TRIZ as a ‘limiting contradiction’; that is, as attempts are made to improve one aspect of the system, another aspect immediately cancels out the benefit of the first such that there is no net increase in value. When a limiting contradiction has been reached, the only way of advancing the evolution of the system is to overcome that contradiction.

In a manufacture context, this limiting contradiction can usually be associated with the generic TRIZ parameter ‘SPEED’, as the most common goal in devising a manufacture system is to achieve the maximum throughput efficiency.

Given a limiting contradiction situation, the TRIZ toolbox offers two methods by which contradictions can be overcome:-

- 1) Contradiction Matrix/Inventive Principles
- 2) Trends of Evolution

Contradiction Matrix

For a manufacture process, the Contradiction Matrix is very likely to offer ‘good’ suggestions as to how a limiting contradiction may best be overcome. In terms of contradictions associated with the parameter SPEED, the Matrix identifies the following Inventive Principles as the ones most likely to help overcome the limiting contradiction:-

- 28 - **Mechanics Substitution**
(replace a mechanical solution with another physical principle – optical, acoustic, magnetic, electromagnetic, thermal, etc)
- 13 - **‘The Other Way Around’**
(perform the opposite action – e.g. heat instead of cool, make fixed parts movable, make movable parts fixed, turn the process upside-down)
- 35 - **Change of Physical and Chemical Parameters**
(change of aggregate state, change of concentration or consistency, change of flexibility, or change of temperature)
- 10 - **Prior Action**
(perform the required change of an object before it is needed, if the object is subject to harmful factors, create conditions that will prevent the harm beforehand)
- 19 - **Periodic Action**
(use pulsed actions, vary periodicity according to conditions, use pauses to perform another useful function)

Trends of Evolution

During the course of analysing the global patent database, TRIZ researchers identified a number of distinct patterns of system evolution. These trends have since been shown to be applicable at all levels of a system hierarchy and in both technical and non-technical contexts. The trends data has been abstracted in such a way that it illustrates key inventive steps between adjacent S-curves in a family. As with the Inventive Principles, the process of mapping from the specifics of a given manufacture problem onto the generic trends often requires a considerable amount of adaptability on the part of the problem solver.

Some of the trends are more obvious than others. Perhaps the trend which correlates most obviously with manufacturing operations is the one associated with the evolution of linear and volumetric structures – Figure 3.

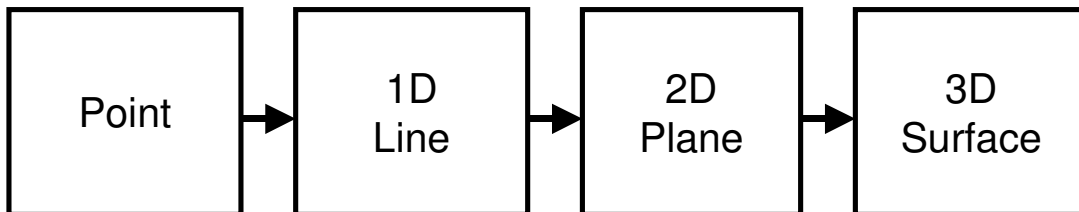


Figure 3: Geometric Evolution Trend

The trend data is expressed as a left-to-right progression of increasing benefits. Thus, the majority of systems may be seen to evolve from left to right. (Exceptions usually occur in circumstances where ‘costs’ and ‘harms’ become more important than ‘benefits’; in which case, the evolution trend can become right-to-left.)

Where the current state of the art sits at the right hand end of the evolution trends, either a new discovery is required in order for the evolution to progress, or – far more likely – the need for the system disappears. Where the current state of the art lies at the left hand end of the trends, there is seen to be the potential for considerable improvement in the current system, and also the creation of a considerable amount of intellectual property.

In the case of the geometric evolution trend, the large number of manufacturing systems already operating at the right hand end of the trend indicates little future evolution potential in this area. Other trends, on the other hand, suggest considerably more improvement potential:-

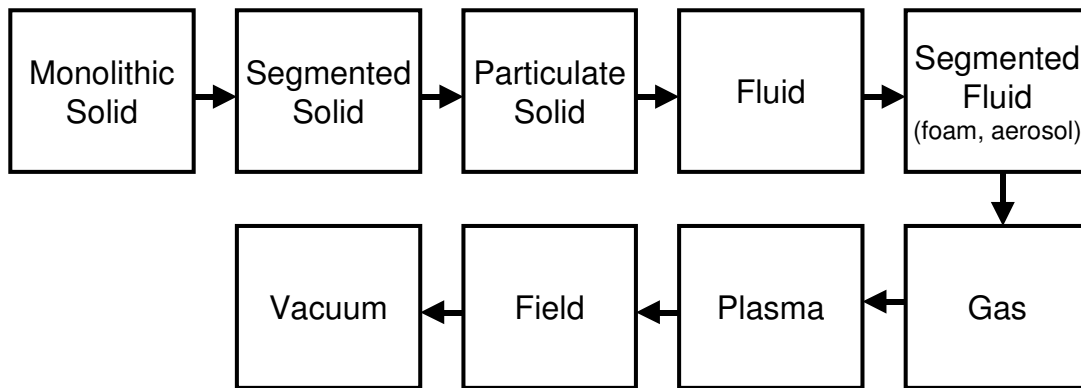


Figure 4: Object Segmentation Evolution Trend

The segmentation trend fits in with both the Inventive Principle suggestions ‘Mechanics Substitution’ and ‘Parameter Changes’ from above, and with the TRIZ concept of Ideality, and the idea of ‘doing more with less’. The transitions from mechanical to powder to liquid to gaseous to field based manufacture solutions are very important paradigm-shifting steps with potent applicability in a manufacture evolution context.

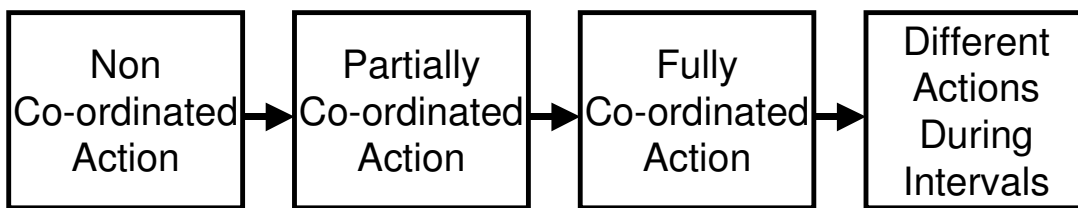


Figure 5: Action Co-ordination Evolution Trend

The action co-ordination trend – Figure 5 – is another with potentially significant implications in a manufacturing systems context. Many systems may already exist at the ‘co-ordinated actions’ stage, while very few appear to have exploited the ‘actions during intervals’ step to a significant extent. The action co-ordination trend also links closely with the ‘controllability’ trend, in which systems are seen to evolve from open loop to closed loop control, to intelligent/adaptable control systems, to, ultimately, self-controlling systems.

The rhythm co-ordination trend illustrated in Figure 6, is also a particularly interesting one in a manufacturing context, as many manufacturing systems are not very far advanced along the predicted evolution path. This suggests significant scope for enhancement of manufacture operations. The earlier paint stripping example provides a good case of the rhythm co-ordination trend in action; the majority of current water-based systems use a constant water jet; second generation systems use a pulsed jet; and future generations will see advantageous use being made of resonance (e.g. water jet pulsed at local resonant frequency of the ship hull), dual actions (introduction of particulates into the jet – e.g. (existing resource) ice), and, ultimately, use of a standing wave based system.

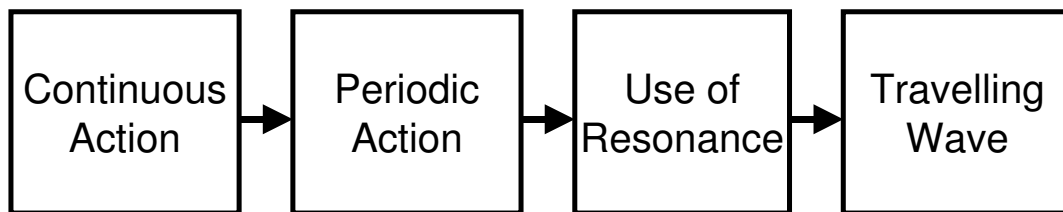


Figure 6: Rhythm Co-ordination Evolution Trend

TRIZ As A Strategic Investment Appraisal Tool

Since the large majority of manufacture systems and methods are pushed as hard as possible in the direction of maximum output efficiency, many find themselves approaching fundamental operation limits. TRIZ research has shown that the only way to move beyond such limits is to move to a new operating paradigm. New operating paradigms arise from the ‘elimination’ of design contradictions. TRIZ provides systematic means of achieving the elimination of such contradictions through either specific Contradictions tools, or established patterns of evolution.

The paper has discussed some of these tools from a manufacture perspective. While other business-related issues may dominate investment decisions on novel manufacture methods, TRIZ provides very powerful data on the technical possibilities. Few if any exceptions to the trends have been observed in all examined sectors of industry. The trends may thus be expected to be highly relevant in a manufacture context. Investment appraisal decisions which fail to take due account of the technical possibilities – and limitations – identified through TRIZ research, do so at considerable risk.

References

- 1) Altshuller, G., (1984), *Creativity As An Exact Science*, Gordon & Breach, New York.
- 2) Salamatov, Y., (1999), *TRIZ: The Right Solution At The Right Time*, Insytec BV, The Netherlands.
- 3) Mann, D.L., (2000), ‘Contradiction Chains’, *TRIZ Journal*, January.

- 4) Mann, D.L., (1999), 'Using S-Curves and Trends of Evolution in R&D Strategy Planning', *TRIZ Journal*, July.
- 5) Mann, D.L., (1999), 'Case Studies In TRIZ: A Self-Locking Nut', *TRIZ Journal*, April.
- 6) Busov, B., Mann, D.L., Jirman, P. (1999), 'TRIZ and Invention Machine: Methods and Systems For Creative Engineering and Education in the 21st Century', paper presented at 1st Int'l Conf. on Advanced Engineering Design, Prague, May 1999.
- 7) Miles, L., (1961), *Value Engineering*, McGraw-Hill, New York.