The TRIZ Route To Naturally Better System Design

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Abstract

The paper describes how an evolved version of the Theory of Inventive Problem Solving, TRIZ is being applied to help realise fundamentally better system design. The main theme of the paper is that it is not the components that make up a system, but the but the functional interactions connecting those components that dictate the success or otherwise of a system. The paper describes a law of system completeness and applies it to both technical and business system examples in order to demonstrate routes to better system design.

Introduction

At its highest level, TRIZ is about allowing users access to global excellence. It is about collecting the strongest ideas and concepts from all scientific, engineering, business, political, social and artistic disciplines, and abstracting them into a form relevant to all. It is about avoiding the re-inventing of wheels history tells us all industries spend a significant amount of their time doing. A key tenet of TRIZ, therefore, is that someone, somewhere has already solved a problem like yours.

In parallel with this overall philosophy, TRIZ has uncovered a number of high-level concepts that re-define what we might traditionally think of as excellence. These conceptual shifts include:-

- The recognition that function forms the over-riding essence and reason-for-being of a system, and that while the solutions developed to deliver a function change (usually putting companies unable to change out of business), the functions themselves stay largely constant.
- definition of a concept called ‘ideality’. Ideality is a measure of the benefits generated by a system divided by the negative aspects – like cost and harm. TRIZ research suggests that all systems evolve in the direction of increasing ideality. In the final analysis they evolve to an ‘ideal final result’ in which the benefits are delivered with zero cost or harm. If this is the case, the concept suggests, then when designing a system, why not start with the ideal final result definition rather than starting from the psychological inertia of today’s knowns. In specific terms, this viewing perspective leads to solutions which are able to deliver functions ‘by themselves’, and thus deliver self-organising, self-repairing, self-optimising, etc capabilities.
- The finding that the evolution towards ideality fundamentally involves the elimination of the conflicts and contradictions in a system that we normally take for granted.

- The recognition that we are traditionally very wasteful of resources, and that ultimately, even the things we think of as harmful in a system can actually be turned into useful resources.
- The recognition that what makes a system viable is not just the entity's from which it is constructed but crucially the form and manner in which those entities interface and relate to one another.

While considering all of these concept shifts, the paper focuses on the last one, and specifically the idea that 'it's not the things, but the connections between the things' that will ultimately determine whether a system is more or less successful than competing equivalents.

The paper takes as its start point the broadest possible definition of a system, such that an engineered product, a business process, an organisation structure, or just about any other form of human-configured, function-delivering entity is a 'system'.

The paper suggests that the predominant mode of thinking during execution of a traditional design process involves viewing 'the system' as a collection of 'objects'. These 'objects' might be nuts and bolts, they might be events in a sequence, or they might be people. This is an essentially Newtonian/Descartian worldview. While this 'collection of objects' perspective undoubtedly can and often does produce systems that are useful, the paper shows that it fundamentally limits the achievable level of ideality of the system. Simply put, you can optimise and re-optimise the objects in a system until the end of time and not be able to improve beyond a certain inherent level.

The shift to a worldview in which it is the relationships and interfaces between the objects, while having its roots in the writings of Einstein, is something which is firmly rooted in TRIZ and present in many of the tools, methods and strategies it contains.

The paper details some of these aspects of TRIZ and applies them to the design of both technical and business systems. Firstly, however, we examine an evolved amalgamation of two TRIZ tests of what makes a system 'viable':

System Viability

TRIZ contains two tests of system viability (Figure 1). The first, 'The Law of System Completeness' in its classic form dictates that a system requires four essential components engine, transmission, tool and control system before it is able to perform a function. The second test provided in the S-Field model on the other hand suggests that it is only possible for a system to perform a function if it contains two substances and a field.

The latter of the two tests is generally speaking the more useful (the idea of engine-transmission-tool-control being largely self-evident in most Western engineering education systems), although both have their uses.

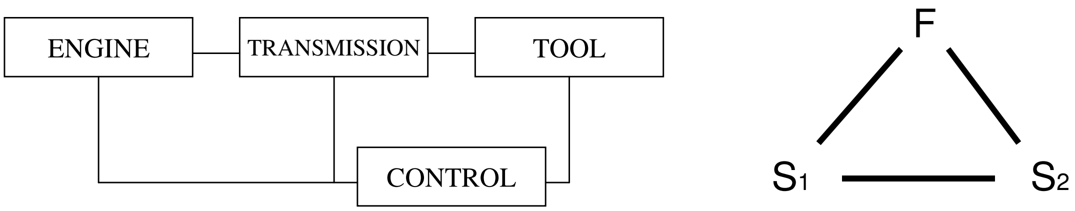


Figure 1: The 4 Essential Elements of a Technical System and S-Field Model (as defined in classical TRIZ)

By way of example, a technical system to achieve the function ‘clean teeth’ requires a working unit (or ‘tool’ in several texts) – the tooth-brush; an engine – our muscles; a transmission – our arm/hand/etc; and a control unit – in this case a combination of our brain, our nervous system and our view in the mirror. Take any one of the four away, and we are no longer able to deliver the required function.

More recent work reported by Savransky (Reference 3) has implied that actually the system is not complete with just the four elements, and that a fifth essential element is required. Savransky calls this fifth element ‘casing’. Incidentally, both Stafford Beer’s ‘Viable System Model’ (Reference 4) and Game Theory (Reference 5) both also describe the need for five elements to define a complete and viable system. Reference 6 discusses the three different perspectives in more detail for those interested in gaining a broader perspective. We might interpret this description more evocatively as a connection between the defined system and its surroundings. In keeping with other conventions developed throughout this paper, we will use ‘interface’ as a suitably descriptive name. By way of example of what we mean by this fifth essential system element, in the case of the above ‘clean teeth’ example, we see that we are only able to successfully achieve the function because of the presence of teeth and thus there has to be an interface between the tool and those teeth. There is considerable commonality with the substance-field model concept here, of course, and the definitive law of system completeness rule we will recommend here combines all of these elements.

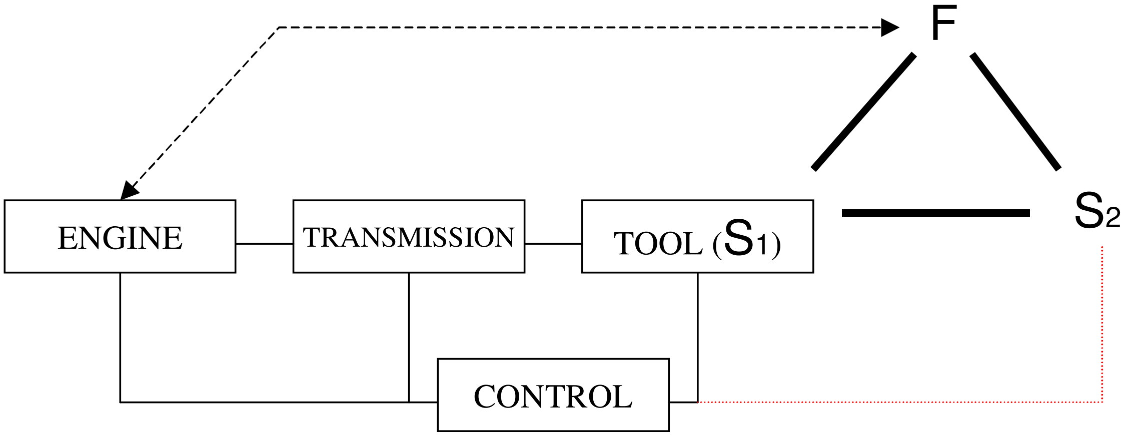


Figure 2: The Complete Viable System Model

The picture illustrated in Figure 2 highlights the tool and ‘S1’ as the common link between the Law of system Completeness and the Substance-Field Model; the two things are in fact the same. There is a similar link between the engine and the field required to make the function happening.

The net effect of this combination is that the Law of System Completeness is only strictly speaking correct if S2 – ‘the object’ or ‘interface’ is present. This is consistent with the above description of the need for a fifth essential element.

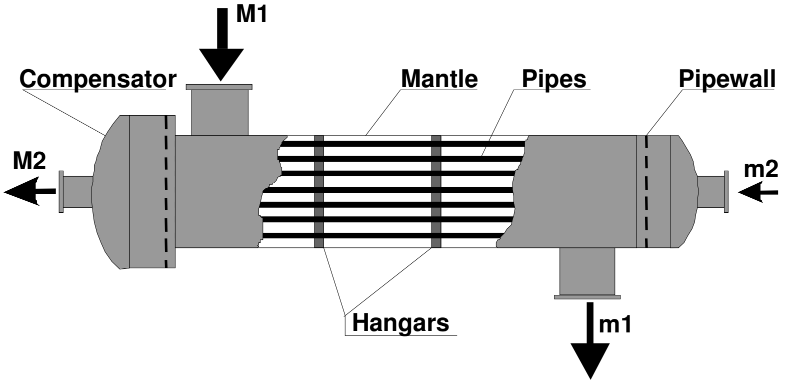
The essential ‘field’ element of the model may come from the ‘engine’, but not always. In the teeth-cleaning example, with the toothbrush as S1 and the tooth as S2, the field connecting them is a mechanical field producing relative motion. While at source the energy providing this relative motion is coming from human muscle, it is still useful to think of the two as ‘possibly’ rather than ‘definitively’ connected.

The ‘control’ element is interesting also with regard to the way it gets us to think about its relationship with S2: Returning to the cleaning teeth example, it should be evident that while it is perfectly possible to deliver the function without any connection between the teeth (S2) and the control system – most teeth cleaning systems exhibit precisely this disconnection such that we don't know other than by visual or tactile examination after the event whether we have clean teeth or not – a far more effective solution emerges when the object (S2) is included in the control loop – as shown by the dotted red line. This line is in fact the 'feedback' line suggested by the controllability trend. Either way, this final picture should give us a useful image of what actually defines a viable and effective system.

So, taking the combined Law of Completeness and S-Field model test illustrated in Figure 2 as our start point, the paper now examines implications for the modelling and design of both technical and business systems.

Technical Application

In the case of technical systems, a typical heat exchanger design is used as a start-point from which to compare traditional and TRIZ-based approaches. The exemplar case study uses third generation, TRIZ-based function analysis modelling methods to illustrate a generic technique for defining and using the inter-component relationships to define a better – contradiction-breaking – product than would otherwise have been possible.



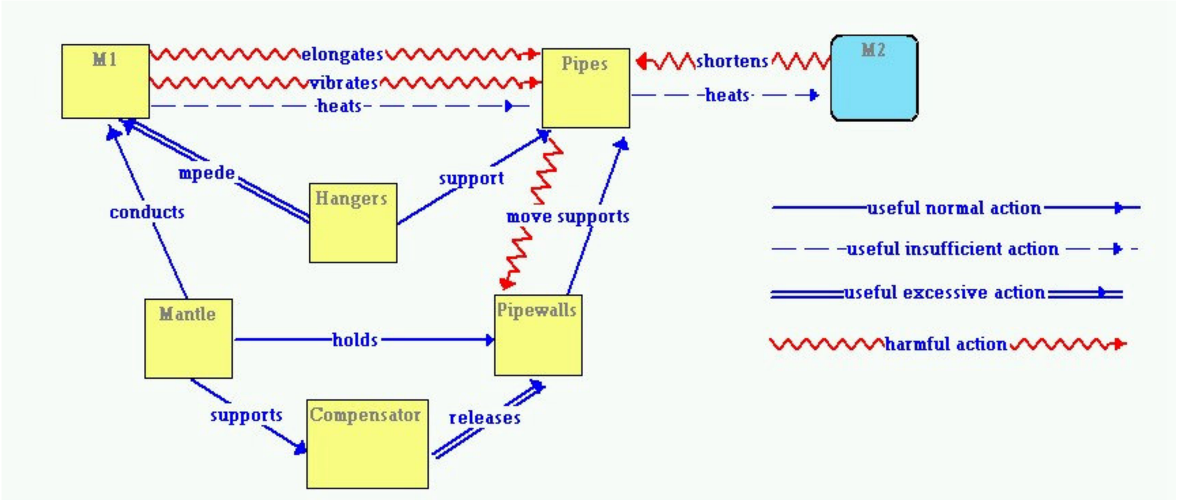


Figure 3: Initial Function Analysis Model of Heat Exchanger

This kind of function and attribute analysis (FAA) model is often helpful in managing the complexity surrounding system design and, more importantly, the improvement of that system. The method is discussed further in Reference 7.

The point at issue relating to the 'its not the things but the connections between the things' theme of this paper is that it is the functional relationships drawn between the components in the heat exchanger that will ultimately determine the overall function and successful evolution of the design, and not the components themselves.

The FAA model essentially comprises definitions of useful, insufficient, excessive and harmful functions. The evolution of the system will be guided by the removal of the harmful, and improvement of the insufficient/excessive relationships in the system, such that eventually the system will comprise only the useful functions – actually, the ideality concept within TRIZ suggests that the eventual system will comprise only the main useful function – which, in this case, is the heating of the fluid, M2.

The combined law of system completeness illustrated in Figure 2 must apply not only to the system as a whole, but also to the functional relationships linking any of the pairs of components. This recursive application of the law is something discussed in more detail in Reference 4. The main point of discussion here, however is that it is possible to extract any single functional relationship from the overall model, and use the law to help improve that relationship.

Two examples should serve to illustrate the relevance of the system completeness law to improving the design of the heat exchanger. In the first instance, there is the functional relationship 'heats' between the pipes of the heat exchanger and the fluid, M2. This relationship might be drawn as an S-Field model as illustrated in Figure 4.

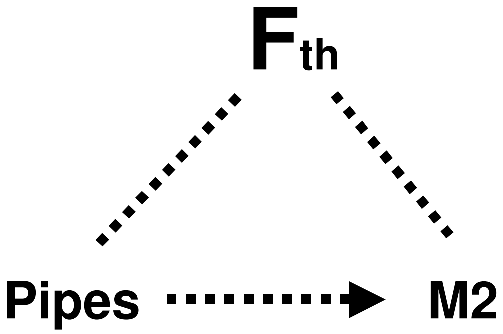


Figure 4: 'Pipes Heat M2' S-Field Model

In this situation – where the main useful function of the system is under consideration – it is common to describe the functional relationship as insufficient. The driving field (Fth) in delivering the 'heats' function is a thermal potential between a pipe with a high temperature attribute and the fluid, M2 with a lower temperature attribute. In order to transform the 'insufficient' action into a 'sufficient' one, the s-field model and the combined law of system completeness are intended to direct designers towards the good solutions of others. In the case of the s-field model, TRIZ contains a series of Inventive Standards – which describe generic solutions obtained by anyone who has successfully solved a problem situation where there is an insufficient field connecting two components. More directly, TRIZ also encourages classification of knowledge by function (as opposed to traditional classification strategies). The big benefit of functional classification is that it registers the importance of 'connection between things' and provides users with ready access to means through which others have delivered similar functions. In the case of the 'pipes heat M2' function, the functional classification model quickly allows designers to identify many other ways to deliver the function 'heats' – Figure 5.

- Turbulization
- Bulk flow Direction Change
- Fluid Vibration – Ultrasonic
- Magnetic Control
- Use of Spiral Geometry Features
- Gravity Assistance
- Transpiration Cooling
- Regenerative Systems
- Ejection Effect
- Droplet Magnetic-Deformation Effect
- Use of Elliptic Parabolic Geometry
- Dufour Effect
- Finned Surfaces
- Fluid Vibration – Mechanical
- Acoustic Vibration
- ‘Wavy’ Walls
- Flow Swirling
- Porous Metal Construction Method
- Resonance Effects
- Range Effect
- Magneto-Active Bubbling
- Drop-wise Condensation
- Capillary Grooves
- Gregorig Effect

Figure 5: Sample Functional Classification ‘Heats Fluid’

A second example viable system extractable from the heat exchanger system is the harmful relationship between M1 and the pipes – Figure 6.

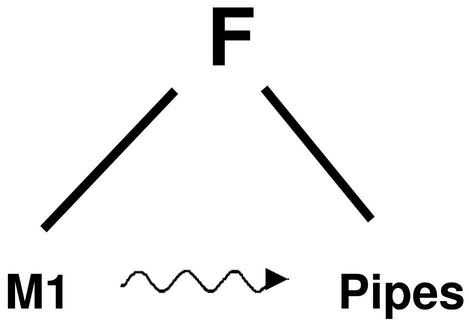


Figure 6: ‘M1 Vibrates Pipes’ S-Field Model

‘Harmful’ functions are interesting in the context of the combined law of system completeness, because they too must satisfy that law. This is important from a system improvement perspective, because it means that removal of the harmful function means eliminating at least one of the elements necessary to complete the system.

This means either eliminating one or both of the components – neither option looking very practical in this instance – or the field. In this sense, the law of system completeness and s-field models provide new perspectives on the problem; firstly it encourages understanding of the field (relationship) between the two components, and second it suggests that it is possible to eliminate the harmful relationship if we can eliminate the field.

Again, TRIZ provides a number of possibilities for achieving this – firstly, the Inventive Standards provide suggestions as to how other problem solvers have successfully tackled the s-field model situation where there is a harmful interaction between the two components – for example Inventive Standard 1.2.4 states “if useful and harmful functions appear between the substances, and the two must remain in contact, solve the problem by adding a new field”. Secondly, by forcing the problem solver to think about the evolution of systems towards increasing ideality through more effective use of resources, it encourages problem solvers to think about other components and fields present in the system and whether they can be harnessed to solve the problem. In the case of this particular M1 vibrates pipes' problem, the traditional response would be to add components to stop the vibration (see the plethora of 'vibration dampers' and related components on the market by way of evidence). The problem was actually solved using TRIZ by arranging the pipes in a manner that meant they were self-supporting – one pipe physically supporting the next – and hence the required 'additional field' was a mechanical field (see Reference 6 for a complete list of possible field types). By focusing on the 'field' (i.e. not the components), it was possible to generate a solution which ran counter to the traditional 'solve by adding things' strategy. The result was a significantly simpler and more cost-effective design.

Again, the main point is that improvement of the system emerges from understanding the connections between the components rather than the components themselves.

Business Applications

In the case of business systems, in a similarly generic fashion, we take an exemplar organisation structure as the basis for examining, firstly the inherent merits of an ideality-driven, self-organising, self-optimising, self-correcting structure over traditional top-down command-and-control designs, and secondly, the fundamental need to start from the relationships and interfaces and not the 'objects' if such systems are to become a practical reality.

With respect to the idea of 'self-x' as an evolutionary direction in organisations, it is necessary to return to the TRIZ concept of ideality – and the definition of an Ideal Final Result in which the system delivers all of the required functionality with none of the cost or harm. In other words, the function is delivered but the system does not exist. If this sounds implausible, think of the 'Quality' department present in most organisations. In TRIZ terms, the function of this department is usually described as 'improve quality' or 'reduce defects'. In ideality terms, the overall system would deliver these functions without the need for a Quality department. There have been many references to the Toyota system of manufacture, and its employment of essentially natural structures – nature is full of examples of self-x systems (reference 9) –which are 'self-improving' and 'self-optimising' (Reference 10). In such situations, the Quality department no longer needs to exist since the function is delivered by the system without the need for additional resource. Delivery of all functions in this 'self-x' manner is a dominant trend of evolution across all forms of system; whether technical or business (Reference 11).

It is possible to achieve this kind of self-x system either by designing a system with the 'achieve the function without the system' aim in mind from day one, or, more practically since most systems have not been designed with this goal in mind, by working from a functional model of an existing system and employing the principles described for the heat exchanger system in the previous section. Figure 7 illustrates a typical system model highlighting the positive and negative functional relationships between the different 'components' for a hypothetical supply organisation.

In the majority of instances at this point in time, such a functional map is a very novel way of describing what happens in organisations. As such, problem solving sessions involving the construction of these models reveal that it is often the first time that people have been asked to think about functional relationships – especially the 'what are the bad connections in the system' perspective. The usual outcome of this encounter is that there is considerable disagreement concerning what the relationships actually are. From a TRIZ perspective, this represents significant scope for designing improved systems.

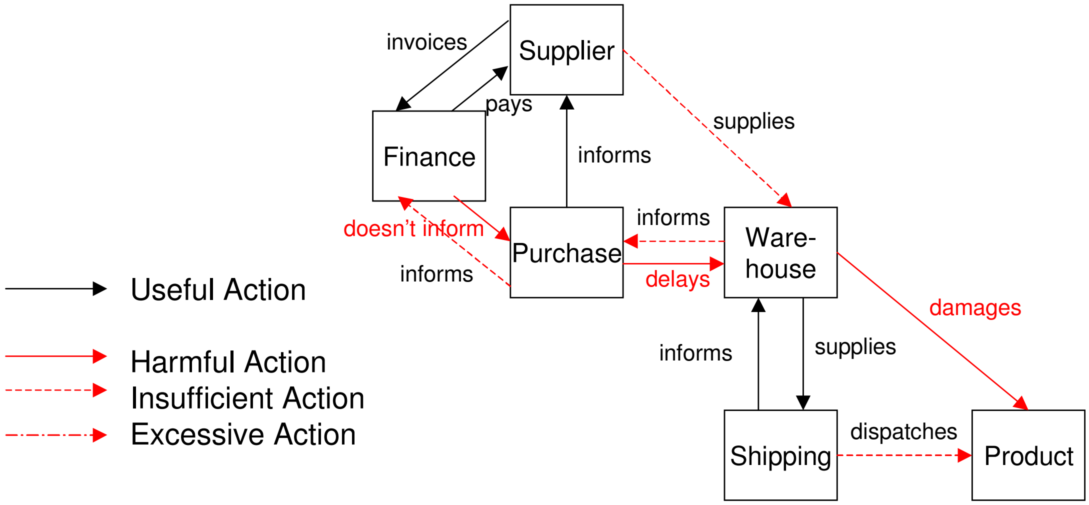


Figure 7: Typical FAA Model For Organisation Structure

As with the technical example earlier, the business FAA model exists primarily to manage complexity; breaking the whole down into constituent functionally related parts. The idea of recursion means that every pair of 'components' in the model linked by a functional relationship must satisfy the law of system completeness. Reference 4 suggests this, but the TRIZ law makes it more specific to the smallest possible viable system within the whole. At this point in time, due to the novelty of the thinking approach, it is probably dangerous to use the 'law' descriptor; rather that it should be interpreted as a useful working hypothesis.

If we take just one example from the Figure – the relationships that exist between 'Purchase' and 'Warehouse' for example – the combined law of system completeness offers the suggestion that, like the 'M1 vibrates pipes' function from the previous example, the removal of the harmful effect 'Purchase delays Warehouse' requires the addition of a field not the addition of more 'components'. 'Field' in the organisational sense is often interpreted as 'communication'. Communication, like other 'fields' tends to be rather cheaper to implement than additional 'things'.

Summary

TRIZ encourages three-dimensional thinking – this means thinking spatially and temporally, but also in interfacial terms – where the connections that exist between components and systems are shown to be essential.

In the design of technical systems, designers traditionally concern themselves with the components that make up the system. What TRIZ and the evolved laws of system completeness described in the paper show is that the improvement and evolution of those systems is critically dependent not just on the components, but the way the components interact with one another functionally. A viable system requires a 'field' to exist between any pair of interacting components. The common failure to register the importance of these 'fields' – and particularly the ones associated with negative functions – can have a marked impact on the way the system functions. The route to better technical system design demands better understanding of interfacial functional relationships between components and their attributes.

The law of system completeness – in particular the requirement for a field to be present – can be seen to apply to organisational and business models as well as technical systems. The concepts of function and attribute mapping of organisations and the 'it's not the things but the connections between the things that matter' model are still relatively new in a business systems context. As such, the 'law' can be said to be just a working hypothesis at this stage. The use of TRIZ-based function and attribute analysis for business systems has however already been shown to generate fundamentally better understanding of both what happens in systems and how to make them better.

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