A Systematic Machine Maintenance Innovation Methodology

Darrell Mann BSc(Hons), MSc, MI Mech E, C Eng
Director
Systematic Innovation, Bristol, UK
darrell.mann@systematic-innovation.com

John Cooney
Academic Researcher
School of Business and Government
National University of Ireland, Cork
j.cooney@ucc.ie

Abstract

Constructed around the findings of over 1500 person years of research, and the systematic extraction of knowledge from nearly 3 million of the strongest solutions from all areas of science and technology, the Soviet originated Theory of Inventive Problem Solving, TRIZ (Teoriya Resheniya Izobreatatelskikh Zadatch), is the most comprehensive systematic innovation and creativity methodology ever developed. Its Soviet roots have undoubtedly slowed its spread into industries in the West, but recently published cases of Western companies using TRIZ to save many millions of pounds are promoting wider deployment. More recent research to incorporate best maintenance and design for maintenance practices looks set to provide engineers and technicians working in the machine maintenance arena with a similar capability to systematically access 'best practices' from the best solutions abstracted from all fields of human endeavour. The paper describes the overall structure of the TRIZ toolkit and provides details of the main tools.

Introduction

The TRIZ problem solving methodology has been designed to handle all known kinds of problem situation (Reference 1). It is able to achieve this capability by adopting a modular approach. The overall method thus contains a number of different tools to help, first, define what the problem actually is (very often 90% of the problem – or 'opportunity' for that matter – is defining what the problem is), and then a different set of tools to help generate solutions to the problem. In all there are around 20 different tools.

The key word in the TRIZ acronym is 'inventive': TRIZ is going to be most useful when we are seeking to do something better than we have previously done it.

Maintenance in its most general sense may be seen to fall into two main categories; scheduled and unscheduled. Unscheduled maintenance generally speaking means that something unexpected has happened. In the 'unscheduled' situation, there is very definitely a problem, and a need to do something to fix it. The TRIZ tool most useful in this situation is Subversion Analysis.

The other sort of maintenance is scheduled. In this case there are two possible scenarios. One, that we are happy to continue conducting the same maintenance actions as we always have, the other, that we would like to change what we do, reduce effort, or cost, or increase the time between maintenance actions. In certain situations, we may wish to take these wishes to the extreme and eliminate the maintenance action altogether. In the first of these instances – where we are happy with the maintenance as it is, then TRIZ will not be of any assistance; if no problem is seen, and there is no desire to improve what already exists, then there is no need for an inventive approach. If, on the other hand, there is a desire to improve something about the maintenance process, then TRIZ will most definitely be relevant. As indicated in Figure 1, there are several TRIZ tools that have been designed to help us depending on what precisely it is that we wish to improve. The 'desire to improve maintenance' route includes what we might typically think of as 'design for maintenance' and other reliability and maintenance improvement strategies. Thus, in many senses we can see TRIZ as being complementary to such tools.

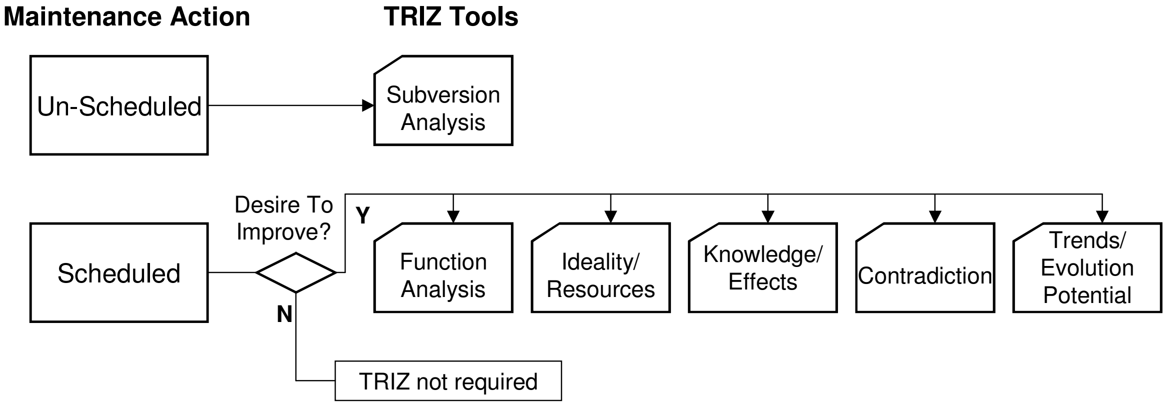


Figure 1: TRIZ Tools Relevant To Different Maintenance Situations

The paper now briefly examines each of these different tools individually before bringing them together to see the whole structure again.

Principle TRIZ for Maintenance Tools

1) Function Analysis

Function Analysis is a problem definition tool. It seeks to examine the totality of a system by breaking it down into its constituent elements and then considering the relationships between those elements. In many senses, function analysis is about managing complexity. The tool has its roots in value engineering, but has added the concept of describing not only the useful functional relationships that exist within a system but also the negative relationships. The functional analysis process has three main steps:-

1) Identify the different components within the system at each of the different time steps of the process deemed to be important
2) For each pair of components, at each of the different stages, establish what *useful* functional relationship exists between them.
3) For each pair of components identify what *negative* functional relationship exists. Negative relationships include harmful actions, actions that are insufficient, actions that are excessive and actions that are missing.

Figure 2 illustrates a typical function analysis diagram. The diagrams serve a number of useful purposes. Most significant of these purposes is that for any of the different possible combinations of useful and negative functions, the TRIZ method has codified what tools will best help to solve that particular problem. For example, any relationship denoting an ‘insufficient’ action means use the knowledge or trends part of the toolkit. Similarly, the combined presence of both useful and negative relationships means a conflict exists and that therefore the contradiction tool should be employed.

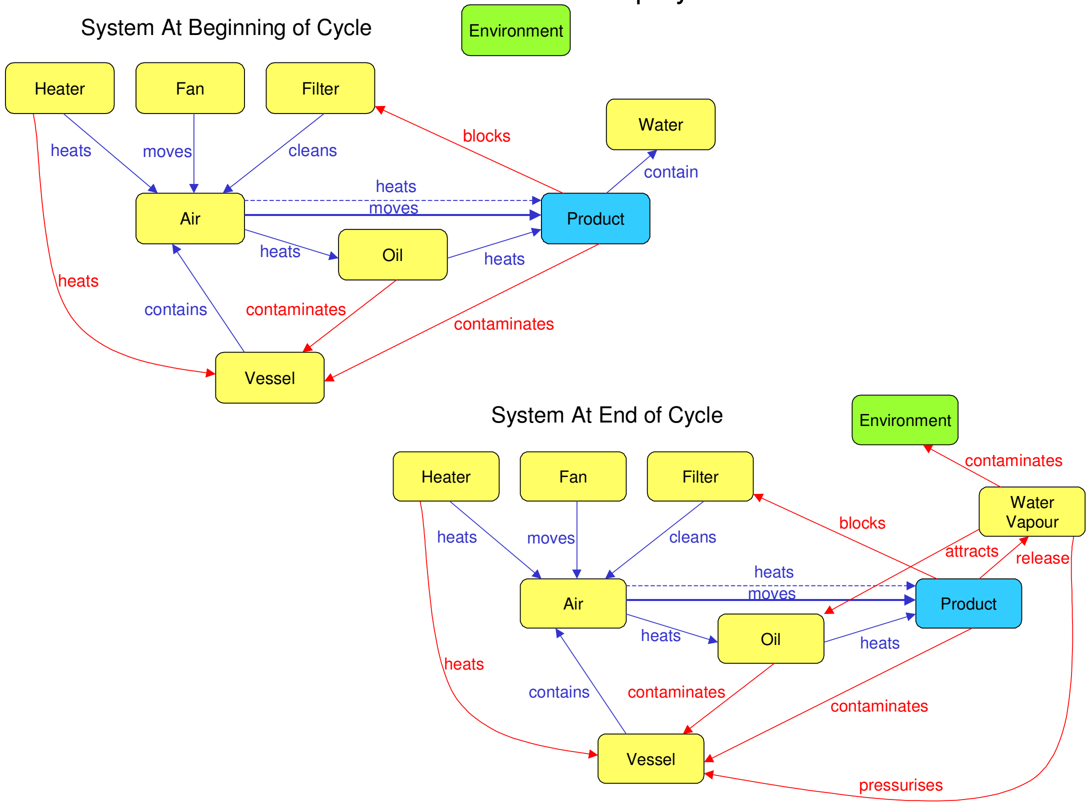


Figure 2: Typical Function Analysis Diagram

The Function Analysis part of TRIZ may be seen as a means of identifying and prioritising opportunities for improving the maintainability and maintenance of a system.

2) Ideality/Resources

The Ideality and Resources parts of TRIZ help to bridge the gap between problem definition/opportunity identification and solution generation. The ideality part of TRIZ emerges from analysis of successful innovations and the discovery that one thing all had in common was that they delivered one or more of a) greater functionality/customer benefit, b) lower cost, or c) lower harmful effect. In addition to suggesting this (hopefully obvious) direction of success, the ideality concept also contains the idea of a destination point for that direction. This destination is typically known as the Ideal Final Result or IFR state. As suggested by Figure 3, different parts of a value chain are likely to have different perspectives of what this IFR might be.

In this rapidly globalising world, it seems that customers are ever more likely to get the IFR that they want; if one provider is unwilling to provide it, then another increasingly is. In any case, the conflict that often arises between what the provider wishes to supply and what the customer wants is an issue that the Contradiction part of the toolkit is often used to resolve.

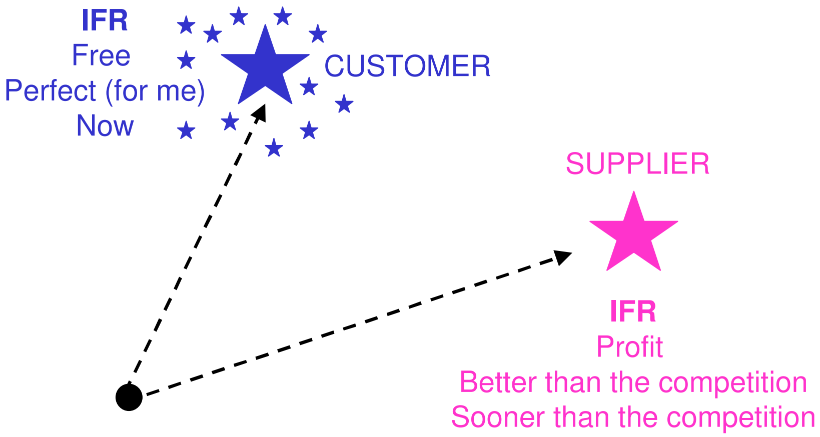


Figure 3: Successful Systems Evolve Towards An Ideal Final Result End State

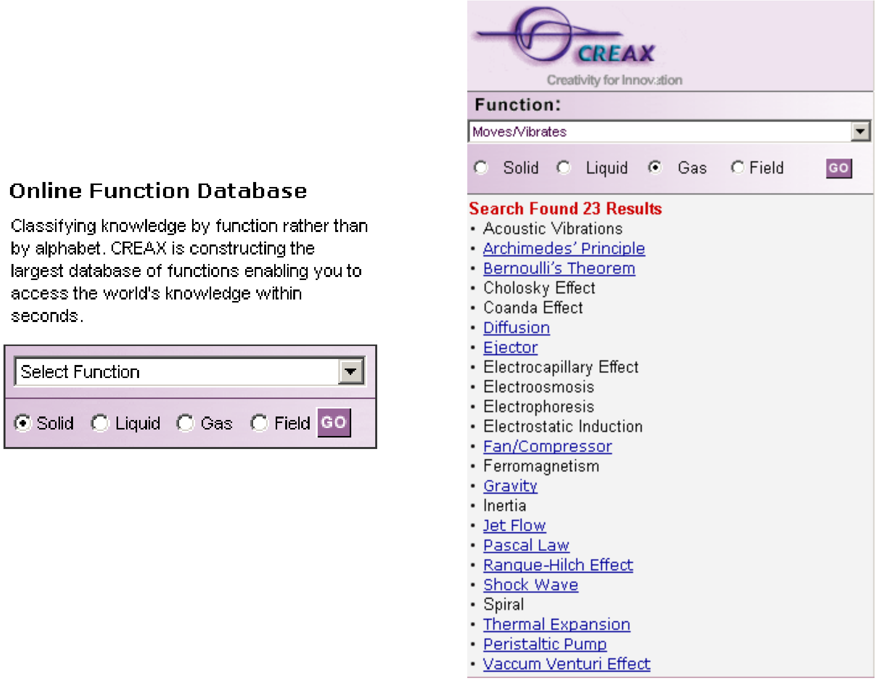
Although the IFR concept of ‘achieve the benefits with zero cost or harm’ might sound somewhat hypothetical, there are actually many examples of systems that have achieved precisely this end state. Key to achieving this is the word ‘self’ and the concept of systems delivering functions by themselves – self-cleaning, self balancing, self-aligning, etc (see Reference 1 for examples). Thus, in the maintenance context, the concept of ‘systems that maintain themselves’ is something we might see as an likely evolutionary end-state.

Closely related to the Ideality concept is Resource. In TRIZ terms a resource is defined as anything in or around a system that is not being used to its maximum potential. As will be suggested in the later section on Trends of Evolution, few if any current systems will meet this definition. According to TRIZ, a primary dynamic of more ideal systems is that they will progressively make better and better use of the available resources. In this part of the discussion, that definition is extended to include even those things in or around a system that are currently seen as harmful.

To take an example of ideality and resources in action together, we recently had occasion to work on a filter system for a water treatment plant. The filter was used to remove large contaminants and debris from the water before it was allowed to enter pumps and other components vulnerable to damage from foreign objects. At certain times of the year, the filter required maintenance action three times a day to remove debris that had become entangled on the grid structure of the main working elements. Maintaining the system three times per day was both expensive for the water company and tedious for the maintenance crews – who often had to visit the filter site during highly unsociable hours. The main problem with the filters appeared to be the fact that certain types of debris – plastic bags, grasses and hairs mainly – tended to loop around the grids and become stuck, pinned in place by the force of the water passing through the filter. In the terms of the designer of the filter and the maintenance crews, the force of the water was a harmful thing. In the terms of TRIZ, on the other hand, that force was an untapped resource. In the ideal final result state, the filter would clean ‘itself’. A simple re-design of the cross-sectional profile of the grids enabled the force of the water to be transformed from something that acted harmfully to something that became a useful resource. In other words, by harnessing the force of the water rather than trying to fight it, debris could be washed across and out of the filter instead of being pinned in a place where it would cause blockage.

3) Knowledge/Effects

In a typical problem situation, the usual technique for generating solution ideas is brainstorming. This method undoubtedly works, but it is inevitably limited by the scope of the knowledge of the people present within the session. One of the TRIZ objectives is to effectively allow groups to brainstorm using all of the knowledge of the world. One of the most readily used parts of the TRIZ toolkit is the knowledge/effects database. This is essentially a collection of all of the known ways of delivering different functions – moving things, separating things, removing things, accelerating things, etc – compiled from every field of human endeavour. This knowledge is constantly being expanded as new solutions emerge. It is available on-line at Reference 2. Details of the database and its role in knowledge management processes within organisations are described in Reference 3. Figure 4 illustrates a typical screen from the database – in this case the list of known ways of moving a gas.



Online Function Database

Classifying knowledge by function rather than by alphabet. CREAX is constructing the largest database of functions enabling you to access the world's knowledge within seconds.

Select Function

● Solid ○ Liquid ○ Gas ○ Field

Function:

Moves/Vibrates

○ Solid ○ Liquid ● Gas ○ Field

Search Found 23 Results

- Acoustic Vibrations
- Archimedes' Principle
- Bernoulli's Theorem
- Cholosky Effect
- Coanda Effect
- Diffusion
- Ejector
- Electrocapillary Effect
- Electroosmosis
- Electrophoresis
- Electrostatic Induction
- Fan/Compressor
- Ferromagnetism
- Gravity
- Inertia
- Jet Flow
- Pascal Law
- Ranque-Hilch Effect
- Shock Wave
- Spiral
- Thermal Expansion
- Peristaltic Pump
- Vaccum Venturi Effect

Figure 4: CREAX Knowledge/Effects Database – Move Gas Function Classification

This database has a role in the maintenance context in those situations where our attempts to improve the performance of an aspect of a system have hit certain fundamental limits that mean a different way of achieving a given function is required.

Reference 4 contains a case study involving a maintenance problem involving attempts to improve the time between overhauls of a troublesome mixer in a photographic chemical manufacture process. The ideal final result solution was deemed to be a mixer that required no maintenance. The knowledge/effects database was used to show that the mechanical mixer being used was just one of over 40 ways of delivering the desired mixing function. Choosing one of the other 39 presented a solution that has since not only eliminated the maintenance action, but has also enhanced the quality of mixing. The knowledge database bridges the gaps that traditionally exist between different industry sectors. One of the principle tenets of TRIZ is that someone, somewhere has already solved your problem. The knowledge/effects database is an effective way of accessing the best of those solutions.

4) Contradiction

Another – slightly more abstracted – means of accessing the good solutions of others is found in the Contradiction part of the TRIZ toolkit. The fundamental underlying concept behind this part of TRIZ is that in addition to heading in a direction of increasing ideality, successful innovations also challenge the trade-offs and compromise that usually come to dominate during the design of any system. That there might be systematic ways of eliminating trade-offs and compromises is often hard to believe for someone that has been through a traditional engineering education, since much of this education consists of teaching ways of optimising the outcome of those very same trade-offs. The Contradiction part of TRIZ is thus very much about challenging the status quo and seeking to achieve breakthrough solutions. The principle tool to help achieve these breakthroughs is the Contradiction Matrix (Reference 5). The Matrix represents the distillation of the world's best win-win, no compromise solutions to conflict problems. The Matrix (excerpt shown in Figure 5) comprises a list of parameters that are of interest to engineers when trying to improve something about a system. Several of these parameters – reliability, repairability, system complexity, control complexity for example – are closely connected to maintenance issues. The same parameters are then repeated across the top of the Matrix, but this time relate to things that get worse or stop us from making the improvement we desire. So, in order to use the Matrix, it is necessary to find pairs of parameters in conflict with one another. 'We wish to improve the repairability of the system, but unfortunately when we do that, the complexity gets worse, or the efficiency drops' would be a typical problem statement.

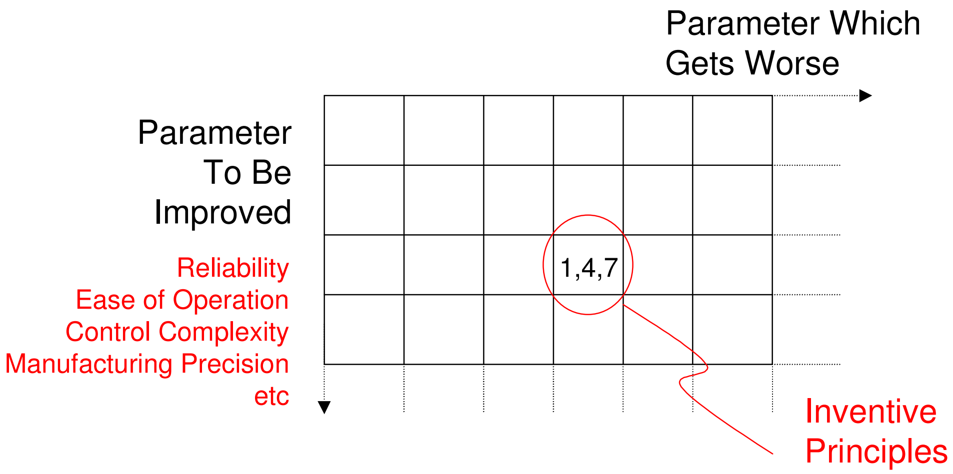


Figure 5: Segment Of Contradiction Matrix Highlighting Specific Relevance To Maintenance

Looking up the intersection of the improving and worsening parameters in the Matrix then points us towards the Inventive Principles or strategies that other people have successfully employed to successfully eliminate our contradiction. The companion paper to this one (Reference 6) contains a detailed example of the Contradiction part of TRIZ in action on a maintenance problem.

5) Trends of Evolution/Evolutionary Potential

The Trends of Evolution part of the TRIZ toolkit builds on both Ideality and Contradiction. TRIZ research has shown that all successful systems evolve towards the IFR end state through repeating cycles of emergence and resolution of contradictions. Evolution is thus observed as a series of discontinuous steps. The Trends part of TRIZ has thus sought to identify and map what these discontinuous steps look like, and to gather together those steps that are generically applicable across systems of all descriptions. To date 35 such trends have been uncovered (Reference 1). They are typically presented as left-to-right progressions towards increasing ideality, with each step representing a predictable disruptive jump. Figure 6 provides an example of one of the trends – dynamization – in action. This is a trend with a particular relevance to engineering and manufacture systems. Reference 1 offers more detail on the reasons behind the trend and examples of systems that have followed it.

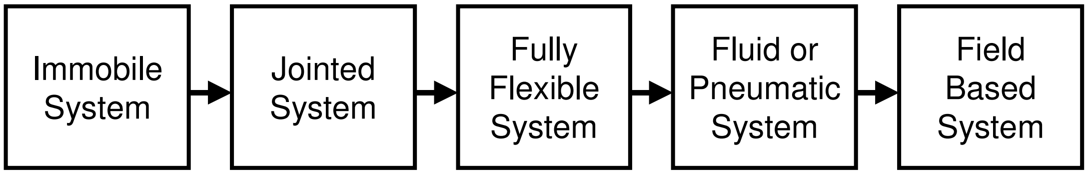


Figure 6: Typical Trend of Evolution - Dynamization

The primary use of the trends is in either strategic or problem solving roles. In this latter role, it is often possible to overcome the limitations of a current system by evolving it (or some part of it) to a more ideal stage. In this sense, the trends may be seen as *signposts* towards more ideal systems.

The dynamization trend also has a direct relevance to maintenance of machinery systems; flexible systems often being capable of responding to or adapting to changing external conditions whereas immobile systems are not (see this increasing flexibility trend in action in the design of tall buildings, bridges and an increasing number of automotive and aerospace systems). Similarly, the shift away from mechanical to hydraulic and then field-based systems is often done for reasons of increasing operational adaptiveness, controllability and improved maintainability. Reference 7 contains a more detailed example of the Trends part of TRIZ being used to solve real maintenance problems.

The last part of the Trends story involves the concept of evolution potential. In simple terms this involves comparing a system and the elements from which it is assembled with each of the trends and identifying how far along each the system has evolved. The evolutionary potential™ radar plot is a simple means of presenting the results of this analysis. As shown in Figure 7, the radar plots offer a graphic representation of the current evolutionary state of a system compared to where it would be if it took advantage of all of the disruptive jumps towards ideal final result identified from other systems.

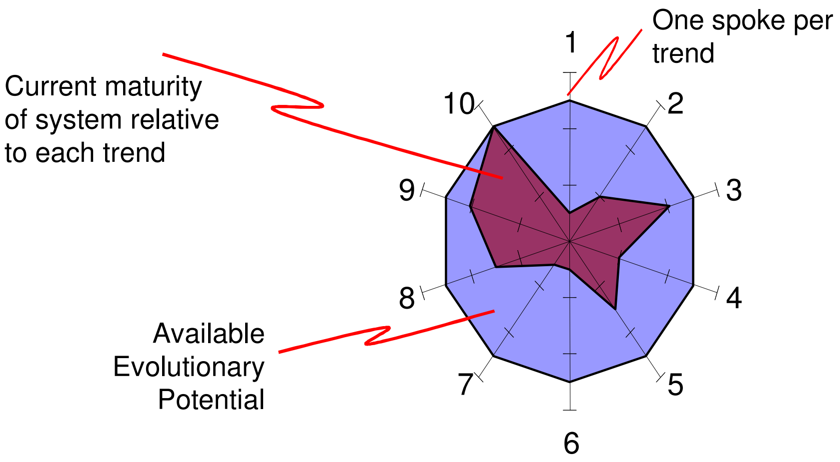


Figure 7: Typical Evolution Potential Radar Plot

The main function of these plots from the maintenance context is to identify all of the untapped resources existing within a system. Evolutionary potential, in other words, is untapped resource. Similarly, if the constructed radar plot for a system shows that most or all of the evolution potential has been used, it is indicating to us that our system really has hit a fundamental limit. Fundamental in this case unfortunately means precisely that. When we reach this state, we will need to use a different part of the toolkit to help us to generate further improvements. Fortunately, the vast majority of existing systems have used on average less than 50% of their potential. This is the case because the trends have been compiled by looking across all industries, whereas very few organisations have the time or inclination to do the same.

6) Subversion Analysis

Last but no means least of the TRIZ tools for maintenance problems is Subversion Analysis. This is the TRIZ tool designed to help in those situations where an unexpected problem has occurred, and where we don't know the source or cause of the problem. Subversion Analysis (Reference 1) or Anticipatory Failure Determination (AFD, Reference 8), as it is sometimes known, has several parallels with established methods like FMEA, HAZOP, or fault-tree analysis. It differs in that it forces users to take a much more pro-active approach to finding causes of problems or, increasingly, designing systems that are invulnerable to failure. The key Subversion Analysis question is 'how can I destroy this system?' The theory is that by identifying ways of destroying a system we can then design it so that the possibility of that mode of failure is eliminated.

There is insufficient space here to go into all the details of how Subversion Analysis works. Interested readers are invited to examine References 1 and 8. One fundamental aspect of the method that ought to be introduced here, however, is the concept of system completeness. TRIZ research has identified certain tests that will determine whether a system is viable or not. It must, for example, have an energy source, a means of transmitting that energy to a working 'tool', the tool itself, and then some form of control system. A viable system requires these resources to be present. By turning this idea around, TRIZ has also demonstrated that the failure of a system will also require the presence of these resources. Thus an important part of the Subversion Analysis method is identifying what resources exist in and around a system, and then examining how these resources might be able to combine to deliver a system failure. Subversion Analysis is about inventing failures. In this sense it has simply turned the inventive problem solving idea through 180° - if we can invent a failure then we can use the other TRIZ tools to eliminate it. Subversion Analysis is typically carried out as a systematic process. A typical process is illustrated in Figure 8.

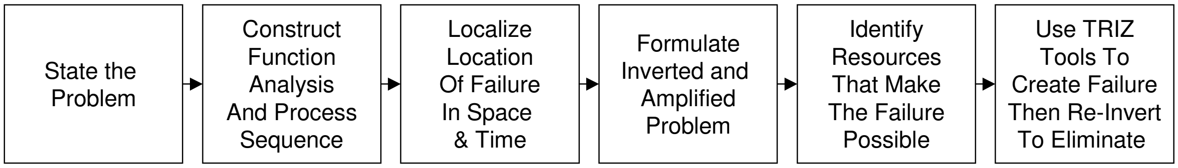


Figure 8: Subversion Analysis Process Flow Chart

The key steps in the process involve the two inversions of the problem; firstly to allow us to 'invent the failure' (how would I design a system that failed in the way my system actually has), and then to re-transform the invented failure into a means of preventing the failure in the future. Reference 9 contains several examples of the process in action.

Putting It All Together

The aim of this paper has been to introduce the TRIZ tools in the maintenance context.

The database of case studies of TRIZ being used to generate tangible maintenance improvement benefits is increasing. Several cases have been referenced here. What seems to be the most difficult part of TRIZ is knowing which of the rich array of different tools should be used under which circumstances. The Table below represents a summary attempting to manage the complexity and allow new users to make the best choices for their particular maintenance situation. Wherever possible, TRIZ recognises that not everyone will have the time or inclination to learn every tool, and as a consequence contains some overlap that enables different tools to get to the same solutions. The first column denotes scheduled (S) or unscheduled (U) maintenance scenarios.

S/U	**Problem Type**	**1st Choice Tool**	**2nd Choice Tool**	**3rd Choice Tool**
U	Unexpected Failure	Subversion Analysis	Contradiction	
S	Don’t Know What To Improve	Function Analysis	Ideality/ Resources	Contradiction
S	Desire to Improve TBO	Function Analysis	Trends	Contradiction
S	Reduce Cost of Maintenance	Function Analysis	Contradiction	Knowledge/ Effects
S	Eliminate Maintenance	Ideality/ Resources	Trends	Contradiction
S	System Has Hit Fundamental Limit	Function Analysis	Knowledge/ Effects	Trends
S	Heavily Constrained System	Function Analysis	Contradiction	Trends
S	System Integration/Combination Issues	Ideality/ Resources	Function Analysis	Contradiction

Summary

TRIZ and maintenance are two words that have only just started to be used together. We have presented here an overview of how we see the former benefiting the latter. TRIZ offers new and systematic means of improving and evolving systems in more ideal directions. It does this by distilling best practices from all fields of human endeavour and presenting them in a form that enables everyone else to deploy them. Although it is still early days for TRIZ in the maintenance innovation context, early evidence appears to suggest that the relationship will be both long and productive.

References

1) Mann, D.L., ‘Hands-On Systematic Innovation’, CREAX Press, April 2002.
2) CREAX Function Database, www.creax.com.
3) Mann, D.L., Hey, J., ‘TRIZ As A Global And Local Knowledge Framework’, paper presented at ISPE, CE2003 Conference, Madeira, July 2003.
4) Mitchell, I., Mann, D.L., ‘Constraint-Dominated Breakthrough Innovation in a Manufacturing Process Situation (A Case Study From the Photographic Paper Manufacture Industry)’, paper presented at TRIZ Future conference, Aachen, November 2003.
5) Mann, D.L., Dewulf, S., Zlotin, B., Zusman, A., ‘Matrix 2003: Updating The TRIZ Contradiction Matrix’, CREAX Press, July 2003.

6) Cooney, J., Mann, D.L., Winkless, B., ‘Case Study Applying the TRIZ Methodology to Machine Maintenance’, TRIZ Journal, August 2003.
7) Winkless, B., Mann, D.L., O’Connor, B., ‘Product and Process Improvement Using TRIZ: A Case Study In Increasing Innovative Options’, paper presented at TRIZ Future conference, Strasbourg, November 2002.
8) Kaplan, S., Visnepolschi, S., Zlotin, B., Zusman, A., ‘New Tools For Failure and Risk Analysis; Anticipatory Failure Determination™’, Ideation International Inc, Detroit, 1999.
9) TRIZ Journal, www.triz-journal.com, 1998-present.