Integration of TRIZ and roadmapping for innovation, strategy, and problem solving

Phase 1 – TRIZ, roadmapping and proposed integrations

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July 2011

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This is a collaborative research initiative between the Centre for Technology Management, University of Cambridge, UK, and Dux Diligens, Mexico.

EXECUTIVE SUMMARY

This document reports the first phase of an ongoing project aimed at combining technology roadmapping (TRM), a methodology for technology and innovation planning, and TRIZ, an approach for systematic inventive problem solving. The overall objective is to develop an enhanced methodology for systematic innovation planning, strategy and problem solving. This report is focussed on providing an understanding of TRM and TRIZ, and conceptualising ways in which they can be combined. These conceptualised combinations will be further investigated, tested and applied in subsequent phases of this project and results will be presented in subsequent reports.

This report is organised into 4 major parts. The first part introduces the TRIZ methodology, its basic concepts and its major tools and techniques. It highlights the benefits of the method and how it can be applied. The second part focuses on TRM, explaining its background, framework and process. The third part highlights suggestions from literature on how to combine these methodologies and then proposes three different modes of combination of TRM and TRIZ based on their individual strengths and features. These three modes of combination have advantages over the lone application of the methods. The fourth part of the report briefly highlights other planning methods that have been combined with TRM and TRIZ, showing how other benefits may be reaped in the application of these methods. The planning methods highlighted include Quality Function Deployment (QFD) and Six Sigma.

TABLE OF CONTENT

PART 1 –TRIZ

1.1 Introduction

What is TRIZ?

TRIZ comes from the Russian phrase "teorija rezhenija izobretatelskih zadach", which means the "theory of inventive problem solving"(Rantanen & Domb, 2008). It was developed by Genrich Altshuller (a Russian scientist and engineer, 1926-1998), who studied about 400,000 technology patents[1], and from them drew out certain regularities and basic patterns which governed the process of solving problems, creating new ideas and innovation. This provided an understanding for the creation of a systematic process for invention of new systems and the refinement of existing ones.

Savransky (2000) defines TRIZ as "a human-oriented knowledge-based systematic methodology of inventive problem solving". Similarly, Souchkov (1997) explains that TRIZ is based on three pillars: analytical logic, knowledge based philosophy and a systematic way of thinking. This systematic approach of TRIZ provides a structure for the use of tools and techniques according to desired outcomes. It offers a comprehensive toolkit with simple tools for understanding problems and detailed techniques for system analysis to arrive at solutions and stimulate new ideas for purposes ranging from simple improvements to radical inventions.

As a generic problem solving method, TRIZ is not based on trial and error, but on established principles (Savransky, 2000). Also, it shows that the evolution of technology is not a random process, but one governed by a number of 'laws' (Souchkov, 1997).

What does TRIZ offer?

The traditional area of application of TRIZ is in technical and engineering problems, i.e. technical systems and technological processes. However, it is also now being applied to 'softer' non-technical problem areas such as management, public relations and investment (Savransky 2000).

TRIZ has considerable advantage over other methods applied for problem solving such as brainstorming, mind mapping, lateral thinking, morphological analysis, etc, which do not point clearly to ways of solving problems, or highlight the right solutions (Savransky, 2000). These methods usually have the ability of identifying or uncovering the problem and its root cause, but lack the capability to actually solve those problems. On the other hand, TRIZ offers the delivery of systematic innovation, acceleration of problem solving in creative ways, confidence that all possibilities of new solutions have been covered, and breaks up mental inhibitors (psychological inertia) to innovation and inventive problem solving (Gadd, 2011).

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[1] Presently, more than three million patents have been analyzed so far by TRIZ experts and researchers to discover patters that predict breakthrough solutions to problems (What is TRIZ? by Barry, Domb & Slocum, http://www.triz-journal.com/archives/what_is_triz/)

Main tools and techniques in TRIZ

The main tools within TRIZ (which will be discussed in further detail in subsequent parts of this report) include the following:

- 40 inventive principles, for solving *contradictions* (the term 'contradiction' will be explained later).
- 8 trends of evolution of technical systems, for identifying directions of technology development.
- 76 Standard solutions, for solving system problems.
- 2500 Effects, which are concepts extracted from the body of engineering and scientific knowledge and used for inventive problem solving.
- Function analysis and substance field analysis.
- Nine windows (or thinking in time and scale), for understanding the context of a problem and finding solutions.
- Creativity tools, for overcoming psychological inertia.
- ARIZ (the Algorithm for Inventive Problem Solving.)

The application of these tools leads to innovative solutions which would usually fall into one of the following classes (Savransky 2000):

- Improvement or perfection of both quality and quantity of technical systems (contradiction problems in TRIZ).
- Search for, and prevention of shortcomings (diagnostics).
- Cost reduction of existing technique (trimming).
- New use of known processes and systems (analogy).
- Generation of new "mixtures" of existing elements (synthesis).
- Creation of a fundamentally new technical system to fit a new need (genesis).

1.2 How TRIZ works – the TRIZ prism

Central to TRIZ methodology are the conceptual solutions for engineering problems. These are about 100 in number, derived from the overlap of the 40 inventive principles, 8 trends of technical evolution and 76 standard solutions (Gadd, 2011). To apply these, a specific and factual technical problem would need to be reduced to its essentials and stated in a conceptual or generic format. The conceptual problem can afterwards be matched with one of the 100 conceptual solutions. The important aspect of translating the specific and factual problem into its conceptual format is achieved by asking the right questions and drawing out its key functions and features. The second important stage is the translation of the found conceptual solution into specific, factual solutions.

This approach to problem solving provides a summary of the systematic methodology followed by TRIZ and has been termed TRIZ prism by Gadd (2011). It is a distinctive feature of TRIZ, distinguishing it from other conventional problem solving methods (e.g. brainstorming) which try to find specific factual solutions to factual problems directly (see Figure 1.1).

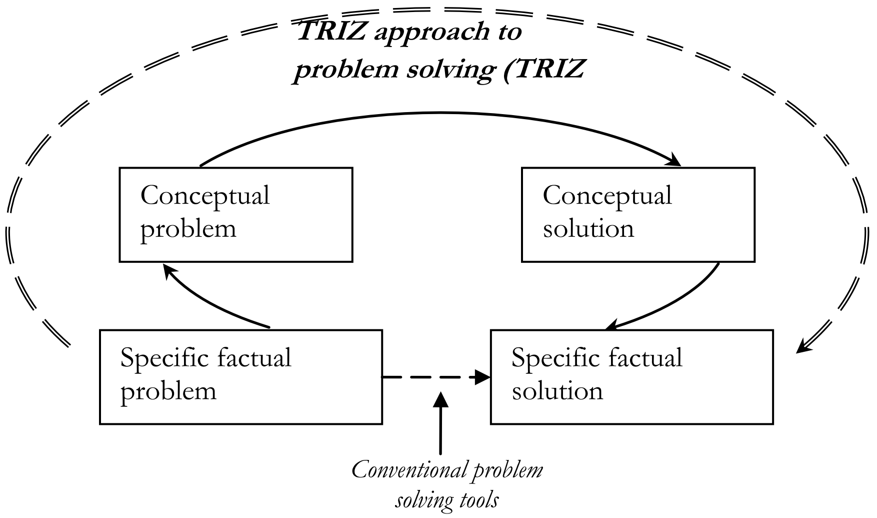


Figure 1.1 - TRIZ systematic approach to problem solving (the TRIZ prism) (adapted from Savransky, 2000 and Gadd, 2011)

The processes of translating factual problems into their conceptual formats and vice-versa (to arrive at factual solutions) are perhaps the more challenging aspects of the TRIZ methodology. However, there are tools and techniques (e.g. function analysis and nine windows) that help through these stages.

1.3 TRIZ and the levels of difficulty of problems

The effectiveness of TRIZ as a problem solving methodology is most evident when the level of difficulty associated with a problem is high, or when the problem is classed as a non-routine or *inventive* problem whose solution requires some creativity. Altshuller classified problems according to five levels of difficulty or creativity. Gadd (2011) has presented these difficulty levels and related them to the source of knowledge (either within our outside the organisation's industry) required to solve them. Levels two to five difficulty problems may be classed as the inventive (or non-routine) problems, for which TRIZ is suited.

- **Level one.** It is about using knowledge easily available and solving a simple problem in an obvious way.

- **Level two.** Here problems require knowledge and solutions outside one's organisation but still easily available within the industry.

- **Level three.** In this level, solutions require a search outside one industry but still within a particular discipline.
  It is about clever analogous thinking – involving looking for proven, tested solutions from other industries.

- **Level four.** Here, new technical systems are created by bringing together solutions from wide boundaries of knowledge (e.g. a mechanical engineering problem solved by applying knowledge from chemistry).

- **Level five.** This level involves discovery - exciting, sometimes unexpected breakthroughs in science to produce new systems which can be used to meet previously unfulfilled needs.

1.4 Main TRIZ concepts

1.4.1 Technique

The development of TRIZ is rooted in technological systems. Savransky (2000) explains that the background and foundations of TRIZ is found in the systematic study of techniques and their functions. 'Technique' is the term used to jointly describe technical systems (TS) and technological processes (TP). A TS is described as "any artificial object within an infinite diversity of articles, regardless of its nature or degree of complexity" and a TP as "any single action or consequences of procedures to perform an activity with assistance of a TS or a natural object", p 33 (Savransky 2000). TP and TS usually act together and supplement each other.

All techniques have inputs (raw object or raw material) and outputs (products) in relation to their environment (which might include other techniques and humans). Savransky (2000) identified three classes of raw objects and products: substances, fields and information. A substance is any matter with a mass and volume, while a field is a carrier of energy. Information is in form of commands, e.g. requests and desires. It is noted that information cannot be classified as a distinct object in TRIZ since it is non-material and does not carry energy that produces a force-effect on matter. Rather, it must be dependent on, or in the nature of a substance or a field for it to be considered as an object in TRIZ. To explain this, an example is the information (lines of code) contained in the computer program which may not be considered as objects until they are in the form of electrical signals (electromagnetic field).

As depicted in figure 1.2, techniques exist in simple hierarchies, so that a technique would consist of subsystems (smaller systems), and is a part of another system, referred to as the super-system. The subsystems of a technique are determined by the nature or make-up of the technique, while the nature of the super-system depends on the context in which the technique is perceived by a problem solver (Savransky, 2000).

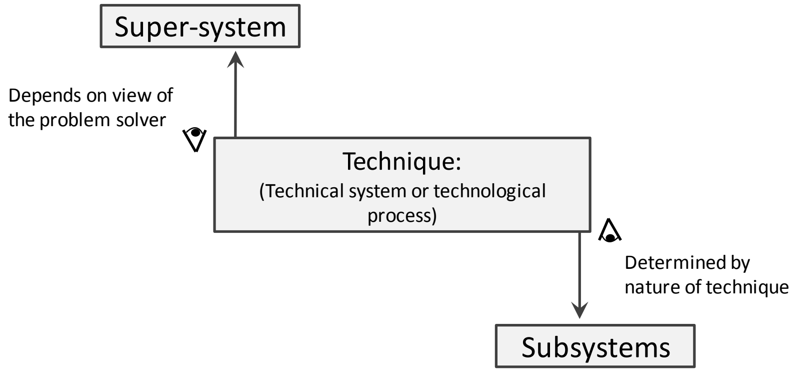


Figure1.2 Hierarchy of a technique (based on Savransky, 2000)

Actions (or sets of actions) performed by techniques are the functions of the technique. These could be useful functions (UF) or harmful functions (HF) depending on whether they are wanted or unwanted actions. The fundamental action which the technique is expected to carry out (for which it was created) is its primary function (PF) (Savransky, 2000). Table 1.1 gives a quick summary of the makeup of a technique and the different types of functions associated with it.

Term	Description
Technique	A system of interrelated subsystems (elements or processes) that possesses the features not present in the features of the separate subsystems.
Subsystem	Parts forming the technique (systems are the focus of TRIZ).
Element/Operation	The smallest part of a technique recognized for a problem.
Super-system	That which the technique is part of.
Environment	All that is outside the technique.
Primary functions (PF)	Functions for which the technique was created.
Support functions	Functions assuring the execution of the PF.
Secondary functions	Functions reflecting subsidiary goals of the technique creators.
Auxiliary functions	Functions assuring the execution of the higher-level functions.
Harmful functions (HF)	Functions not intended for or desired of the technique and that have undesired results.

Table 1.1 Summary of the constituents of a technique and associated functions

1.4.2 Contradiction and Ideality

The philosophy of TRIZ rests majorly on the concepts of ideality and contradiction. At least one of these concepts is embedded in any TRIZ problem solving process (Savransky, 2000; Rantanen & Domb, 2008; Gadd, 2011).

Contradiction

Altshuller distinguished between three types of contradictions (Savransky, 2000).

- Administrative contradiction: This arises in carrying out a process, when an undesirable phenomenon accompanies the desired result.
- Technical contradiction: This occurs when in the bid to improve ability of a system to carry out certain functions, other functions are adversely affected or harmful functions are introduced. For example, in an effort to increase the speed of a car, a bigger engine might be installed give higher power output. However, a bigger engine would naturally lead to increased weight, which would adversely affect the speed at which the car can travel.
- Physical contradiction: This arises when there are inconsistent requirements to certain physical conditions of the same technique. For example, a system might have a function which is both beneficial and adverse or unpleasant, for instance, an umbrella's big size helps with the protection of rain, but is too cumbersome to carry around.

Rantanen & Domb (2008) and Gadd (2011) both point out technical and physical contradictions as the types of contradiction. This might be so since administrative conditions and technical contradictions appear to be fundamentally the same, with their difference being that administrative contradictions focus on processes, while technical contradictions focus on systems. Problems can often be characterised as contradictions, and an objective of TRIZ is to remove these contradictions.

Ideality

Ideality is the measure of how close a system is to its best solution possible for given conditions, i.e. its ideal final result (IFR) (Savransky, 2000; Rantanen & Domb, 2008). Ideality of a system can be expressed in mathematical terms as:

$$Ideality = \frac{\Sigma\ Benefits}{(\Sigma\ Costs + \Sigma\ Harms)} = \frac{\Sigma\ UF}{(\Sigma\ Inputs + \Sigma\ HF)}$$

One of the main objectives of TRIZ is to increase ideality. As the above equation indicates, this can be achieved by increasing the benefits provided by the system or reducing the costs of resource inputs towards providing those benefits, or reducing the harmful functions that come with the benefits.

Defining the IFR of a problem within a system is important for understanding the goals or the solution requirements of the problem. This gives direction to the problem solving process and eliminates unnecessary rework that might arise from lack of proper problem understanding. It also helps to determine the optimum resources (inputs) to use in delivering the functions of the system and recognise the constraints of the problem to be solved (Savransky, 2000).

The importance of explicitly defining the IFR is further brought to bear when a group of stakeholders is involved in problem solving. Since they would often have different views of a problem, by getting each person to define his/her ideal system, it is possible to highlight the differences between the stakeholder needs and reach a consensus on what would constitute an acceptable solution. Also, performing an 'ideality audit' would help in identifying gaps between the ideal solution expressed and the present situation, and as such the objectives of problem solving are made clear (Gadd, 2011).

1.4.3 Evolution of a technique

It has been observed that technical systems and processes generally follow certain regularities in their development. These regularities have been translated into patterns of evolution and are useful for developing good solutions to problems and predicting the future evolution of a technique (Rantanen & Domb, 2008). Savransky (2000) points out that it is possible to express the idea of a technique's evolution through the concept of ideality, using the notion that "any technique's evolution brings the increase of its ideality".

According to Savransky (2000) a technique evolves towards the increase ideality in two ways:

- **Evolution over its lifespan to increase its 'local' ideality**. This is described as the α-evolution by Savransky (2000). In this, the technique's mode of operation (i.e., the manner in which it performs its primary function (PF)) is unchanged but its parameters are improved. This increases its useful function (UF) and/or decreases its harmful functions (HF) and resource costs, thereby increases ideality. When ideality of a technique is plotted against time along the phases of technique's development (birth, childhood, growth, maturity and decline) an S-Curve is usually produced. Towards the end of its lifetime, the technique's ideality approaches its limits as it becomes increasingly difficult to improve it any further.

  The S-Curve can be matched with other curves showing the equivalent of the stages in terms of level of creativity, number of innovations and profitability associated with the development of the technique (See figure 1.3).

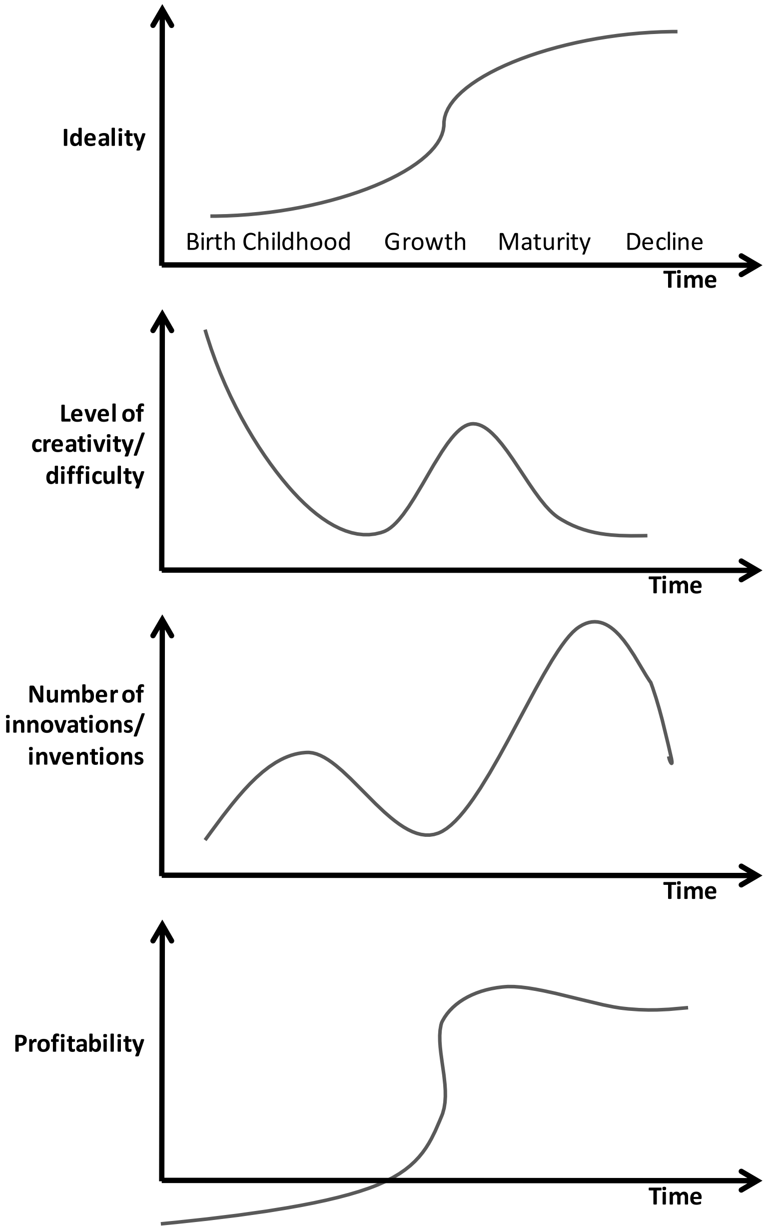


Figure 1.3 The α-evolution of a technique (Savransky, 2000; Gadd, 2011)

- **Evolution by transitioning to another technique.** This is described as the β-evolution by Savransky (2000). This occurs as a technique approaches the end of its lifespan, and the potential for improvement of its ideality reaches its limits. As shown in figure 1.4, through an inventive solution, a transition to a new technique can be accomplished. The PF of the new technique will be the same as in the older one, but the manner in which it is delivered will be different. From its birth, this new technique may either have a better ideality than the previous technique, or have a lower ideality, which has the potential of improving quickly beyond the older system (Gadd, 2011; Savransky 2000).

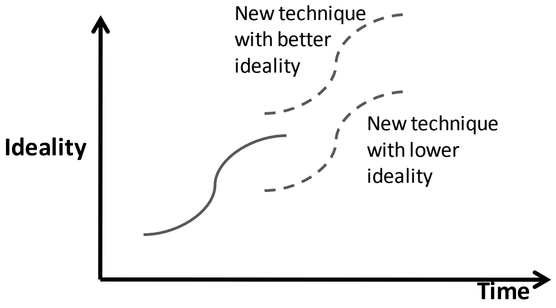


Figure 1.4 The β-evolution of a technique (Gadd, 2011; Savransky, 2000)

According to Gadd (2011), there are eight distinct trends that guide a technique's development, and each trend further divides into lines of evolution.

- Less human involvement: more automation and self systems.
- Non-uniform development of parts: some parts of the system develop faster than others.
- Simplicity – Complexity – Simplicity: a repeating pattern where a system starts by being simple, and then increases in complication and then is simplified again.
- Increasing dynamism, flexibility and controllability: systems become more dynamic and flexible. This increase in dynamism requires more control and therefore controllability also increases.
- Increasing segmentation and use of fields: progressive use of smaller parts until parts are so small that together they have a field effect.
- Matching and mismatching: the system evolves to deliver all the required functions more effectively. It becomes matched to deliver all its benefits, not just its primary benefits. The system can also be deliberately mismatched to improve performance.
- Increased ideality: more benefits are achieved while costs and harms decrease.
- Stages of evolution: systems slowly improve when they are newly invented, and afterwards there is a rapid increase in ideality which tails off until further improvement is no longert possible and new systems are required.

Substantial importance is found in having knowledge of trends of evolution since it helps in:

- Technological forecasting (or foresight). It shows possible paths for technique development.
- Problem solving and creation of technical systems and technological processes. It helps in pointing at the subsystems that need improvement and the likely nature of the improvements.

- Marketing of innovations. It provides objective views of the likely and profitable features of future products, which can be applied for refining and focussing market research. In this regard knowledge of evolution can be applied with tools such as QFD (Savransky 2000).

1.4.4 Resources

Recognising and mobilising appropriate resources is an essential aspect of TRIZ, and these resources can include any aspect of the system and its environments which helps to provide the necessary features. TRIZ lays importance on following a systematic approach in searching for resources. The search for resources is focused by understanding of function requirements of the solution being sought (Gadd, 2011).

Resources can be grouped according to the following according to Savransky (2000):

- Natural or environmental resources
- System resources
- Functional resources
- Substance resources
- Energy/field resources
- Time resources
- Space resources
- Information resources

Savransky further points out that to increase ideality (through the reduction of resource input costs, and reduction of harm), the preferred order of resource search is:

i. 'Harmful' resources – identify harmful functions or objects from which benefits can be extracted.
ii. Readily available resources – identity freely available resources which can be used in their existing state.
iii. Derived resources – identify resources obtainable through the transformation of freely available resources, that are not useful in their existing states.
iv. Differential resources – identity resources derivable from the difference in structure or properties of available substances or fields.

1.5 TRIZ tools

This section is based on the manner in which TRIZ tools were presented by Gadd (2011). The preference of Gadd's view of these tools and techniques is as a result of the familiarity already the authors have with it

1.5.1 Forty (40) Inventive Principles – the Contradiction Matrix and Separation Principles

Both technical and physical contradictions can be solved using the 40 principles (see table 1.2). The set of the forty principles is a major tool for problem solving in TRIZ and its usage is quite easy and effective. These principles were built from knowledge gathered from patent information explored by Altshuller.

There are two ways of using the principles depending on whether the problem involves a technical or a physical contradiction.

- The contradiction matrix is used in the case of technical contradictions and it points to the inventive principles that can be applied for solving specific contradictions. The matrix is made up of 39 technical parameters arranged along the horizontal and vertical axes of the matrix. These 39 parameters which describe the features and functions of technical systems. The cells within the body of the matrix provide the principles that relate two parameters such that when one of them improves, the other does not get worse.
- The separation principles are applied for understanding and solving physical contradictions. The four principles are:
    - Separation in time: the two conflicting requirements are in action at different times
    - Separation in space: one solution at one location, and another at a different location
    - Separation on condition: solutions manifest under different conditions
    - Separation by scale (or by switching to a sub-system or super-system)

  Each separation principle offers a set solution options from the 40 inventive principles. To identify the right separation principle to apply to the problem, it is important to understand the nature of the inconsistency in the demands being placed on the system, which in turn make up the physical contradiction. This may be achieved by asking the question "under what conditions (including where? and when?) are the opposing requirements needed?".

40 Inventive Principles				
1. Segmentation (fragmentation)	2. Separation (or taking out)	3. Local quality	4. Asymmetry	5. Merging
6. Universality	7. Nested doll	8. Weight compensation	9. Prior counteraction	10. Prior action
11. Cushion in advance	12. Equipotentiality	13. The Other Way Around	14. Curvature increase	15. Dynamics
16. Partial or excessive actions	17. Another dimension	18. Mechanical vibration	19. Periodic action	20. Continuity of Useful Action
21. Rushing through	22. Blessing in Disguise	23. Feedback	24. Intermediary	25. Self-service
26. Copying	27. Cheap disposables	28. Replace Mechanical System	29. Pneumatics and hydraulics	30. Flexible membranes
31. Porous materials	32. Colour change	33. Homogeneity	34. Discarding and recovering	35. Parameter change
36. Phase transition	37. Thermal expansion	38. Accelerated oxidation	39. Inert atmosphere	40. Composite materials

Table 1.2 The 40 inventive principles

1.5.2 Function analysis

Before the search for problems and their solutions begins, it is important to understand interactions between all the components of a system. Function analysis helps to draw out difficult-to-recognise issues in the problems. Analysis of function of a system is closely tied with the understanding of the benefits delivered by that system. This helps to clarify how well the benefits are being delivered and what harms are present. This understanding makes it easier to take appropriate steps in problem solving.

To perform a function analysis, a list of all components of a system is generated along with their interactions. This involves breaking down the system into simple units and laying them out in form of Subject-Action-Objects (SaOs). The SaO is the statement describing the action on an object by a subject. The subject is the active tool or initiator of the action or influence, while the object is the receiver of the action. The action is any influence that causes the object to change. The SaO is mapped in the form presented below (figure 1.5) along with other symbols applied in function mapping.

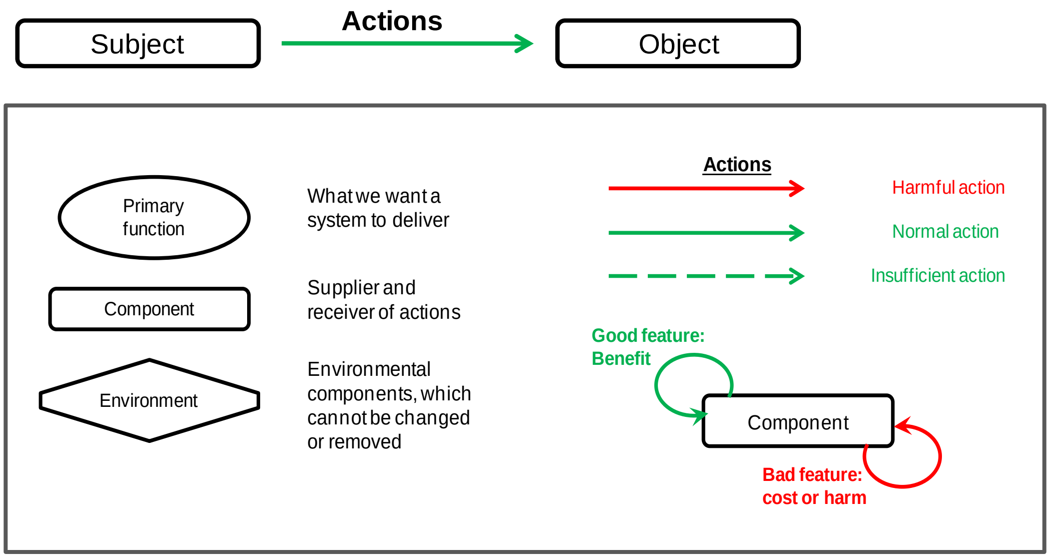


Figure 1.5 Function mapping symbols (Gadd, 2011))

1.5.3 Substance-Field analysis

The substance-field analysis (Su-Field analysis) is another way (apart from function analysis) of pointing exactly to problems that exist within systems without adding unnecessary details. Like function analysis, it involves mapping out the system. In its case however, it uses simple triangles.

Each triangle models the problem (figure 1.6), and consists of one substance S_2 acting on another substance S_1through a field F. While function analysis is often leads to the application of the 40 principles and the contradiction matrix, Su-field analysis provides an understanding of a problem to provide indication of which of the 76 standard solutions will be applicable (76 standard solutions will be discussed next).

Within the Su-Field model, a substance is any object regardless of its complexity. Substance S_1 is the substance acted upon (e.g. changed, processed, converted) by substance S_2, through a force or energy, field F.

Figure 1.6 also shows that there are different generic Su-field models depending on the nature of the problem, and gives indication of how these problems can be solved.

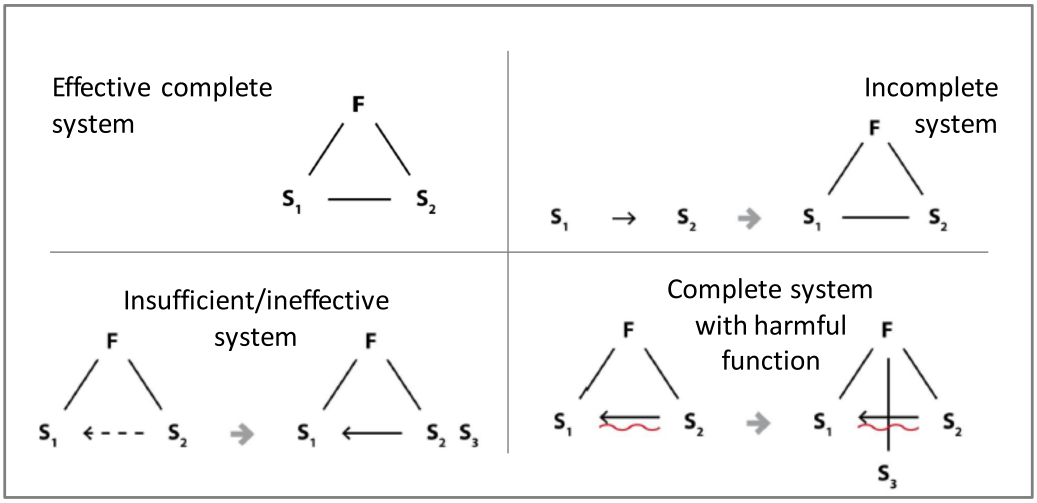


Figure 1.6 Su-Field Models (adapted from Gadd, 2011)

The incomplete system can be transformed into a complete system by adding a field, while an insufficient or ineffective system can be transformed by adding another substance to make the interaction between substances effective. A harmful complete system can be transformed into an effective system by introducing another substance to block the harm.

1.5.4 Standard solutions

There are 76 standard solutions classified into five groups according to the nature of the engineering problems they solve.

These classes are:

- Building and destruction of Su-Field models.

  There are thirteen solutions to help in solve problems by building or destroying the Su-Field model, if they are incomplete or have harmful functions.
- Development of Su-Field models.

  Twenty-three solutions are available for improving the efficiency of engineering systems by introducing minor modification. These solutions offer conceptual solutions of how to improve and evolve systems.
- System Transitions and Evolution.

  Six solutions are applied in solving problems by developing solutions at different levels in the system. In this class of solutions, the improvement of systems is mostly achieved by combining elements or combining with other systems.
- Detection and measuring.

  There are seventeen solutions for measuring or detection problems of engineering systems. Major recommendations of this class are:
  - to try to change the system so there is no need to measure/detect,
  - to measure a copy of the parameter of the system instead of the actual, and

    - to introduce a substance that generates a field.
- Extra helpers

  While the preceding four categories usually lead to solutions which increase complexity (since they introduce new features or objects into the systems to solve the problem), this category contains seventeen solutions that show how to get something extra without introducing anything new.

These solutions can also be grouped into three categories according to how they deal with functions:

- Harms – 24 ways of dealing with harmful functions.
- Insufficiency – 35 ways of dealing with insufficiency.
- Measurement – 17 ways of carrying out measurements or detections.

1.5.5 Nine windows (thinking in time and scale)

This tool is made up of nine cells arranged in a 3X3 matrix. It is an important technique for understanding the context of a problem and finding solutions. As shown in figure 1.7, the horizontal time axis focuses on the problem (or the system which carries the problem) in terms of the problem's history, its present and its future. The vertical scale is used for looking into the details and the wider context of the system, by looking at its subsystems and the relevant super-system respectively. By mapping a system in the nine windows, possibilities for action, especially when the future of the system is understood (in terms of what we would like it to be e.g. by defining the ideal final result) receive greater clarity.

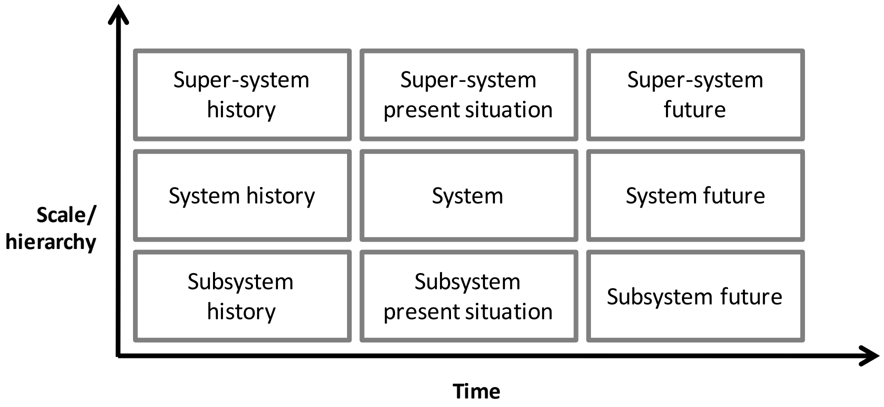


Figure 1.7 Nine windows (adapted from Gadd (2011))

Thinking in time and scale is useful in identifying and mapping the history and context of a problem, its solutions, the needs and requirements of the system, for locating cause and effect relationships across time and system level, as well as resources that will help in solving the problem.

1.5.6 Other TRIZ tools and techniques

i. Bad Solutions Park

The bad solutions park is a technique used to aid problem solving. It is used to temporarily store (or 'park') for 'bad solutions' during a problem solving process. 'Bad solutions' are so called because they are solutions that occur to problem-solvers before the problem is fully understood. These solutions are usually problematic or inadequate in nature. The Bad Solutions Park therefore acts as a temporary storage for these solutions so that they can easily be recorded and temporarily forgotten, to allow problem understanding and analysis to continue unhindered. Ideas captured on a Bad Solutions Park could serve as valuable starting points for finding the best solutions once the problem has been properly understood.

A Bad Solution Park is suitable in a workshop problem solving session as it can take the form of a simple sheet where all ideas written on Post-Its are stuck and analysed later.

ii. Asking Why? And How?

Asking Why? is important for understanding the requirements of a solution, system and its functions (and benefits) and avoiding insufficient solutions to problems.

Asking How? helps to see ways to solve a problem; to decide which functions and systems can deliver the required benefits and what resources need to be sourced.

As shown in figure 1.8, the linkage between the highest systemic level of a problem's solution (i.e. the ideal outcome) and the lowest level (the resources) can be established by asking Why? and How?

Questions to ask in Problem Solving:

- What is the problem with our present solution?
- Why is this a problem? (Ask WHY? as many times as necessary until we reach clearly defined requirements/benefits we want)
- What is the Ideal? What benefits are being sought?
- HOW? do we provide the benefits (which functions would deliver those benefits)?
- HOW? do we provide the functions (what available solutions/resources can deliver the functions and solve the problem)?

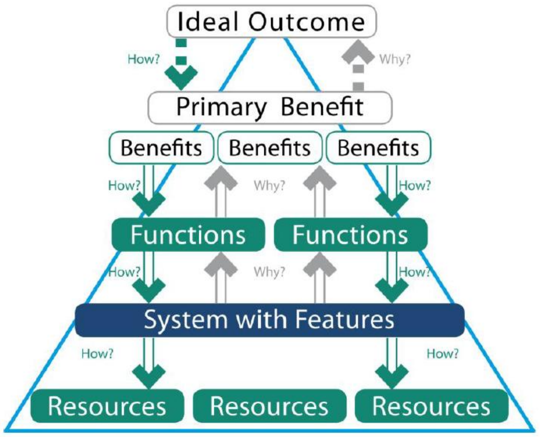


Figure 1.8 Asking How? and Why? in problem solving (adapted from Gadd (2011))

iii. ARIZ

ARIZ is the algorithm for inventive problem solving. It is particularly suitable for difficult and complicated problems, but can be too rigorous for simpler problems. The overall progression of ARIZ is:

- Step 1: Problem definition
- Step 2: Uncovering of system contradictions
- Step 3: Analysis of system contradictions and formulation of mini-problem(s)
- Step 4: Analysis of resources
- Step 5: Development of conceptual solutions

Other techniques that may be applied for problem solving and stimulating ideas and creativity include X-factor, Smart Little People, Size-Time-Cost.

1.6 Logic of TRIZ problem solving

The following steps can be followed to solve a problem based on the TRIZ prism pointed out in section 1.2 (figure 1.9)

- Identify the problem by defining the system we have and the system we want (e.g. using, patterns of evolution, ideality, nine windows to map the problem context, constraints, requirements and resources surrounding the problem). Problem might have been discovered by other applications or methodologies such as QFD and roadmapping.

- Once identified, the specific problem can then be translated or modeled into its conceptual form by applying tools or concepts such as ideal final result, function analysis, and Su-Field analysis, which will further help to understand and pinpoint the problems.

- Tools and techniques such as contradiction matrix, inventive principles and separation principles would be required for the necessary step of finding conceptual solutions to the conceptual problems.

- The final step of translating the conceptual solution into a set of factual solution options is a necessary one to complete the problem solving process. This can be achieved by applying the nine windows or using other creativity tools such as *smart little people*. “Bad solutions” which might have been identified during the course of solving the problem might also be applicable here for identifying the required solution. A choice can then be made from the set of solutions prescribed.

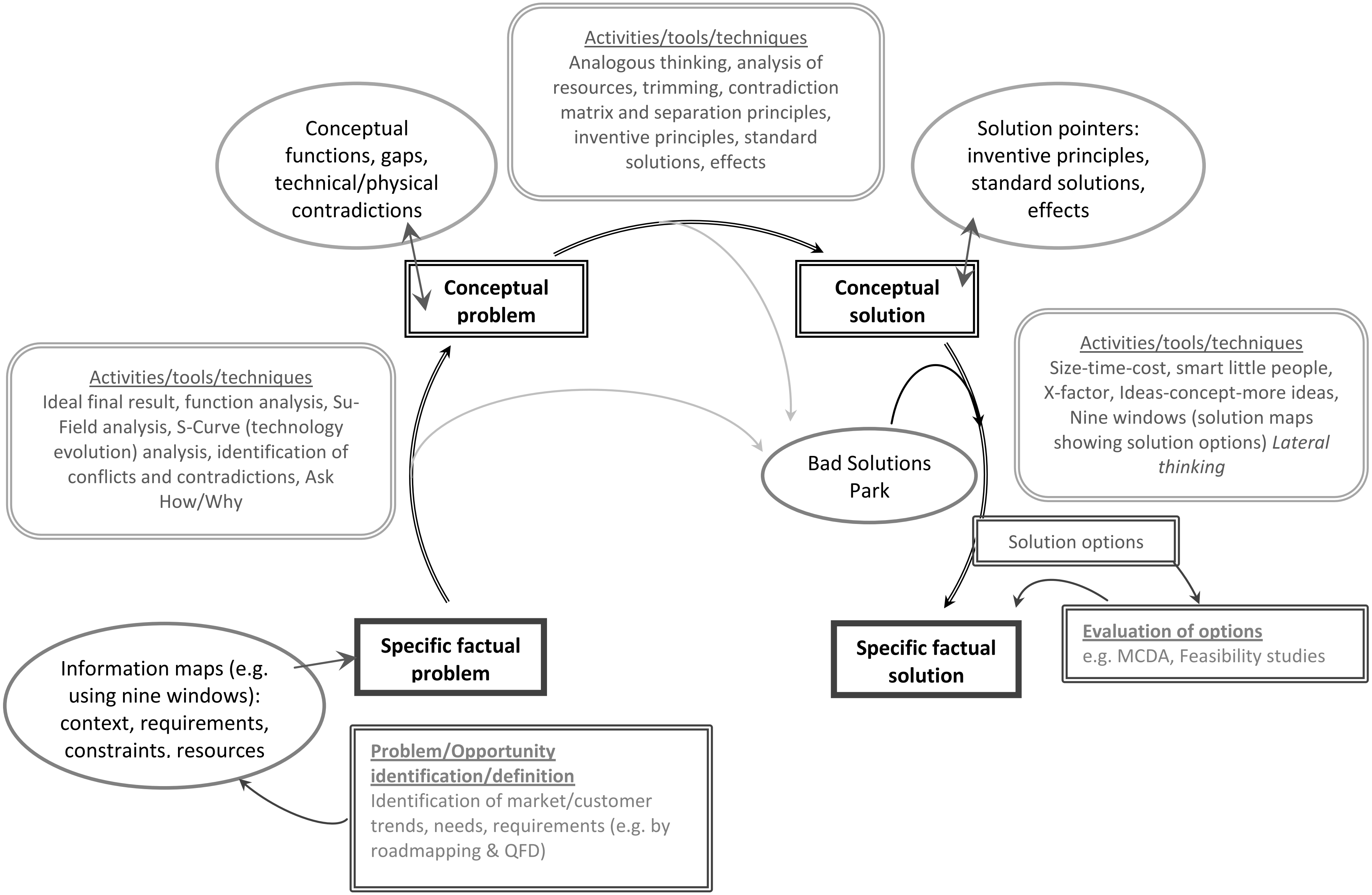


Figure 1.9 The logic of TRIZ problem solving showing applicable tools and techniques

PART 2 – TECHNOLOGY ROADMAPPING (TRM)

2.1 Introduction

Roadmapping could be described as a planning process that guides decision making in identifying and evaluating strategic investment alternatives for achieving specified objectives (Industry Canada, 2006). It may also be described simply as the process of creating roadmaps (Garcia & Bray, 1997; Kappel, 2001). The development of roadmapping as an approach to planning is generally attributed to Motorola's application of the process in the 1970s for supporting its product development strategy (Wilyard & McClees, 1987). Since then, roadmapping has been applied for supporting strategy across companies, industries and governments (Phaal, 2004; UNIDO, 2005).

The application of roadmaps took root in science and technology, and the roadmapping process was conventionally applied in identifying technological solutions in response to market demands (de Laat & McKibbin, 2001; Garcia & Bray, 1997). As a result, the term *technology roadmapping* has been found more dominant in literature. However, Phaal et al (2003) pointed out that technology is only an aspect of the roadmapping process, and that the terms 'business', 'strategic', or 'innovation' roadmapping may be more appropriate. Nevertheless, the terms "roadmapping" and "technology roadmapping" are used interchangeably in this report.

2.2 The roadmapping framework

The flexibility of the roadmapping process and roadmap structure promotes its application in various contexts (Probert, Farrukh, & Phaal, 2003). It can be applied in various forms as a tool incorporating foresight, for linking business strategy with the evolution of markets and technologies, and providing focus and coordination for technology developments within an organization (Lee & Park, 2005). Across various applications, roadmaps share the distinctive and useful characteristic of giving a visual summary of strategy (for complex issues) in a logical and easily comprehensible manner (Phaal, Farrukh, Mills, & Probert, 2003).

The most common format of roadmaps is the multi-layered time-based format, which has two dimensions (Phaal, et al., 2003; Phaal & Muller, 2009) (Figure 2.1).

- The timeframe which gives a chonological outline to the aspects of the roadmap along the horizontal axis, and
- The layers in terms of broad layers and sub-layers, which reflect important aspects of the business or focus of planning.

Roadmaps help organizations that create them answer three main questions:

- Where are we now?
- Where are we going?
- How do we get there?

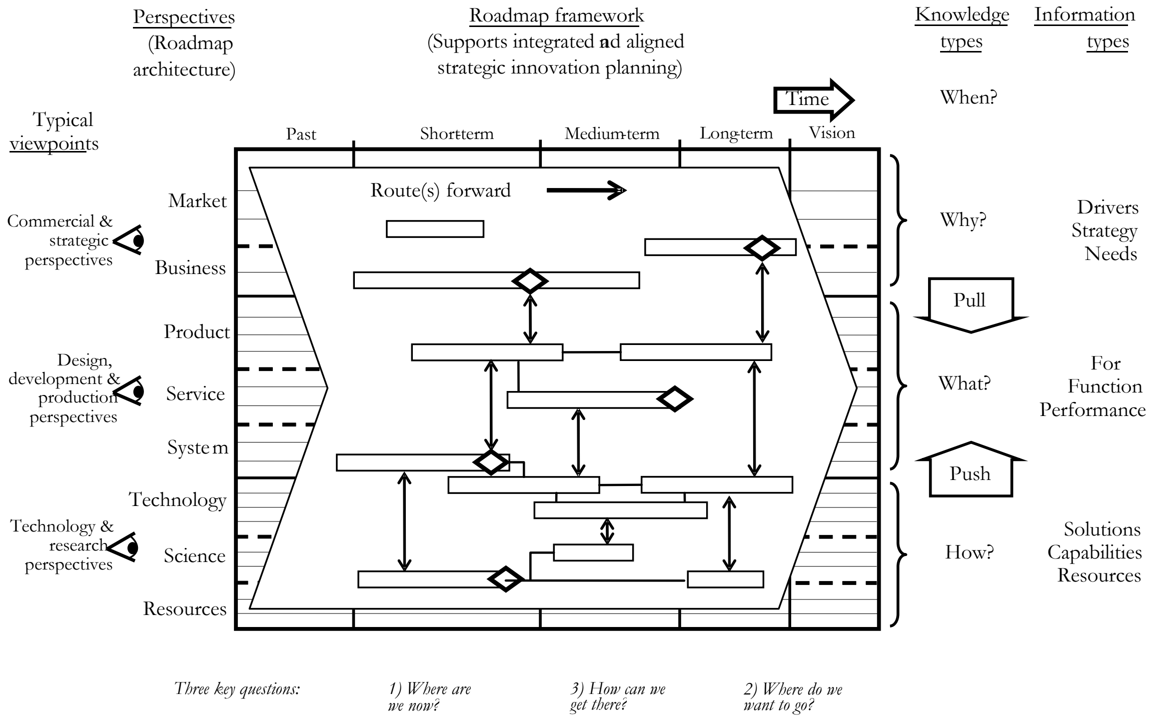


Figure 2.1 Schematic of multi-layered roadmap (Phaal & Muller, 2009)

Also, three broad layers can be identified within the roadmap.

- The 'know-why'- The top layers relate to the overall goal or purpose for which the organization draws out the roadmap, along with the factors that influence the purpose (e.g. internal business trends, drivers, milestones, objectives, and external market and industry trends and drivers: social, technological, economic, environmental, political and infrastructural).
- The 'know-how' - The bottom layers are concerned with the technology and other resources that will be used in meeting the demands of the top layer. These include the physical and knowledge-based resources that need to be used in developing the required products.
- The 'know what' - The middle layers bridge the purpose and the resources, (i.e. the top and bottom layers) focussing on the technology applications such as products and services, infrastructure, and other mechanisms for integrating technology, capability and resources necessary to link the top and bottom layer.

The time dimension could as well be referred to as the 'know-when'. Embedded within the content of the roadmap are the 'know-who' and 'know-where', which point out key stakeholders and geographical locations (Phaal, et al., 2003).

2.3 Types of roadmaps

According to Phaal, Farrukh & Probert (2001), roadmaps can be grouped into eight broad areas based on their purpose. These are outlined in Table 2.1 below.

#	Category	Description
1	Product planning	The insertion of technology into manufactured products
2	Service/ capability planning	Focussed on how technology supports organizational capabilities; more suited to service-based organizations/purposes
3	Strategic planning	Includes a strategic dimension in terms of supporting the evaluation of different opportunities and threats, typically at the business level
4	Long-range planning	Extends the planning time horizon, and is often performed at the sector or national level as a foresight process
5	Knowledge asset planning	Aligns knowledge assets and knowledge management initiatives with business objectives
6	Programme planning	Implementation of strategy more directly related to project planning
7	Process planning	Supports the management of knowledge, focussing on a particular process area
8	Integration planning	Integration and evolution of technology in terms of how different technologies combine within products and systems or to form new technologies

Table 2.1 Classification of roadmaps based on purpose (Phaal, Farrukh, & Probert, 2001b)

2.4 Tools applied in roadmapping

Various tools are applied during the roadmapping process. Vatananan & Gerdsri (2010) identified tools that have been used by roadmapping professionals to support the roadmapping process and put them into three categories.

Market analysis tools (e.g. Experience curve, Porter's five forces, SWOT, STEEP, Concept visioning and scenario building), which are used predominantly at the top layer of the roadmap for investigating the market, and deciding on requirements and needs.

Technology analysis tools (e.g. bibliometrics, soft systems methodology, patent analysis, morphology analysis, analytic hierarchy process), which are used for the bottom layer of the roadmap, for identifying, measuring and mapping technology, knowledge and skills capabilities.

Supporting tools (e.g. Quality function deployment, innovation matrix, matrix scoring methods) are applied to support the development of the roadmap by processing the data collected during the roadmapping process.

Other important methods applied in roadmapping, as identified by Phaal et al (2010) are technology and system readiness levels, technology foresight and intelligence, linked analysis grids, portfolio management, valuation tools, balanced scorecard, Porter's value chain and TRIZ.

2.5 **Fast start approaches to roadmapping**

Fast start (workshop) approaches to roadmapping, called the *S-Plan* (Phaal, Farrukh, & Probert, 2007) and the *T-Plan*, (Phaal, Farrukh, & Probert, 2001a) have been developed for the rapid and economical initiation of roadmapping, and as the first step towards a longer term roadmapping process. The S-Plan is more general, and is useful for strategic appraisal as well as the identification of new business opportunities. The T-Plan can be applied to develop a more detailed product or technology plan for a promising opportunity.

Although not explicitly stated, it could be put forward that the scope of analysis (or level of granularity) of the S-Plan and T-Plan provide a basis for a broad classification of roadmaps into *high-level* roadmaps and *low-level* roadmaps. High level roadmaps, drawn up at the corporate or industrial sector level, will point out necessary products, projects, systems, knowledge and infrastructure necessary to drive the overall vision. Roadmaps within the strategic planning and long-range planning categories are expected to fall under this group. Lower level roadmaps will outline the details necessary for the development of capabilities, processes, products or projects identified within the higher level roadmaps.

2.6 **Steps in the roadmapping process**

There is no single universal method for roadmapping (Phaal, Farrukh, & Probert, 2010). However, the roadmapping process may be said to consist of 4 major stages (planning, input and analysis, roadmapping output and interpretation/implementation/integration). These phases indicate the underlying concept and progression of the roadmapping process and the various approaches put forward by practitioners may be said to fit within them (Table 2.2).

- In planning, the need for the roadmap is defined (Garcia & Bray, 1997) and thought is given to the structural elements of the roadmap (Kostoff & Schaller, 2001).
- It is usual for input and analysis (of knowledge and data) stages to be carried out in workshop forums, and relevant knowledge is captured, structured and shared at these meetings (Phaal, et al., 2003).
- It is necessary that roadmaps developed be interpreted or implemented correctly to fulfil their purposes (Beeton, 2007; Vatananan & Gerdsri 2010).

Generic phase	**Groenveld (1997)**	**Garcia & Bray (1997)**	**Phaal et al (2001) (T-Plan)**	**Phaal et al (2007) (S-Plan)**
Planning	1. Problem recognition by management.	1. Satisfy initial conditions of need and availability of relevant stakeholders for roadmapping activity as well as roadmap leadership/ sponsorship.	1. Planning: Identify the business needs and objectives, scope people and schedule of roadmap. Customize the roadmapping process and carryout any preparatory work.	1. Plan: define objectives, focus and boundaries: i. Design the roadmap architecture and process. ii. Identify stakeholders that will participate. iii. Plan the logistics of the workshop event.
	2. Development of provisional roadmap.	2. Define the scope and boundaries of technology roadmap.		
Input and analysis	3. Roadmap discussion and information gathering by a small team.	3. Identify the product that will be the focus of roadmap.	2. Workshop I: Market Consider dimensions of product performance. Identify, group and prioritise market and business drivers for different market segments considered.	2. Roadmapping workshop process a. Strategic landscape activity to outline market trends and drivers, products and services, and identify a list of priority topics to focus upon.
		4. Identify the critical system requirements and targets.		
		5. Specify major technology areas which will help in achieving the system requirements.		
	4. Workshop(s) with multi-disciplinary participation to draft roadmaps.	6. Specify the technology drivers and their targets.	3. Workshop II: Product Identify and group product features and assess their impact on market and business drivers.	b. Explore key topics identified in the landscape activity in more depth: i. Summarize key drivers, constraints and assumptions ii. Clarify vision and objectives iii. Summarize current situation iv. Map a route forward v. Highlight key risks,
		7. Identify the technology alternatives and their timelines.		

				enablers, barriers, decision points and knowledge gaps.
		8. Recommend technology alternatives that should be pursued.	4. Workshop III: Technology Identify alternative technology options. Assess their impact on product features	c. Present topics for discussion and review in order to agree on which to further pursue.
Roadmap output	5. Upgrading of roadmaps and their format.	8. Create, critique and validate the technology roadmap.	5. Workshop IV Bring the market, product and technology aspects of the business together on a roadmap. Identify milestones in product evolution and technology responses.	3. Create a report (or presentation or both) containing a summary of outputs.
Interpretation/ implementation/ integration	6. Improvement of supporting tools.	9. Develop an implementation plan.	6. Roll out and integrate the process	
	7. Stimulation of learning.	10. Review and update the roadmap.		

Table 2.2 Steps in a roadmapping process (adapted from (Beeton, 2007))

The familiarity that has been developed with the T-Plan and S-Plan at the University of Cambridge, coupled with their wide applicability to various technology and strategic planning concerns makes them the approaches favoured for the combination of roadmapping and TRIZ in this project.

2.7 Benefits of roadmapping

The development and implementation of a roadmap by an organisation is very often carried out with the objective of anticipating market and technological changes, to prompt a strategy that will ensure the survival of that organisation or the achievement of a laid-out vision (Vatananan & Gerdsri 2010). However, roadmaps can also be applied on a regular basis to ensure that the organisation is on track to fulfil its vision. It is strongly suggested that roadmaps be updated frequently.

The value created in roadmapping arises from both the finished form of the roadmap created and the process of its creation. Through the roadmapping process, learning, communication and consensus among stakeholders is achieved, thereby increasing the prospect for better decision-making. In addition, a created roadmap serves as a powerful tool for subsequent communication of key strategic information to internal and external stakeholders (Probert, et al., 2003). The roadmapping approach also helps to identify needs, strengths and weaknesses of the organization as well as future opportunities (Beeton, 2007).

PART 3 – A TENTATIVE PROPOSAL ON HOW TECHNOLOGY ROADMAPPING (TRM) AND TRIZ CAN BE APPLIED IN COMBINATION

3.1 Features of TRM and TRIZ

Technology roadmapping is primarily an approach to technology planning for science and technology and applied to products and services. It can be applied to other planning concerns such as strategy and business planning and identifying market opportunities for new products and technologies. TRIZ is a problem solving tool for technical systems, applied for the creation and renewal of products and services. Also, its concepts are now being applied in other fields such as human resources for problem solving. TRIZ and TRM share a similarity in their underlying logic of systems thinking to the processes.

3.2 Strengths and weakness of TRM and TRIZ

Roadmapping is flexible in its approach and can be applied as a framework integrating several tools. Major strengths of the method include the communication and consensus it generates between stakeholders and those involved in the process, as well as the visual summary of a technology or innovation plan it provides. Zhang et al (2010) argue that roadmapping has a defect of subjectivity and unreliability of personal knowledge and judgements, which often serve as a key source of data for the process.

TRIZ has its major strength in its ability to solve difficult innovation problems in a systematic and logical manner. However, it appears to pay little attention to linking the inventive problems and their solutions to market needs and drivers. Therefore there exists the unpleasant possibility of TRIZ providing a solution to a problem which has little or no profitability or commercial benefit to an organisation.

3.3 Existing research on the combination of TRM and TRIZ

It is evident from literature that there has been some effort to combine TRIZ and TRM. These combinations appear conceptual in nature with little or no evidence of their applications in practice. However, they will be presented as a background for further analysis on ways in which TRIZ and TRM can be combined for practical purposes.

Shuch & Grawatsch (2003) present a process for technology intelligence based on TRIZ. The technology intelligence method incorporates different tools within TRIZ such as the evolution trends and other TRIZ-related methods including systems theory and morphology. The goal of the process is to evaluate the potential of different technologies that perform the same primary function from the perspective of the technology owner. The process culminates in the development of a roadmap of these technologies.

The process is in four stages:

- Define relevant system and its surroundings (super- and subsystems), along with competing (or alternative) systems.
- Identify the main parameters and functions that are relevant for the success of the systems.
- Anticipate the future of the different systems and estimate their potential
- Documents the results in a roadmap

The first two steps are carried out using system and function analysis. The search for alternative systems can be carried using morphology analysis and the anticipation of the future of the systems is accomplished using the S-curve analysis, evolution trends, and ideality.

Moerhle (2004) gives an outline of an approach to the roadmapping process based on TRIZ (quite similar to Shuch & Grawatsch's (2003) process), with the goal of applying trends of technical systems evolution to forecasting future technologies and gain product and service ideas. This could be focussed on a single technology, several technologies that make up an application system, or a profile of products and services incorporating these technologies.

The process suggested contains five steps:

- Definition of the investigation field to document the present state of the selected system.
- Functional abstraction of the considered system to identify the current functions and the functions considered desirable for the future (from the view of the future customer).
- Application of the evolution trends to forecast the future of the relevant functions within the system, to generate a list and an understanding of the technical problems to be solved.
- Creation of technology roadmaps. The time frame of the roadmap will be based on the information generated from preceding steps along with other market information. Functional dependencies between the technologies should also be highlighted.
- Products ideas can be generated from the combination of technologies according to their timelines highlighted on the roadmaps.

Norrie (2007) points out how the roadmapping process can benefit from TRIZ, focussing primarily on the steps: "define major technology areas" and "explore alternatives and timelines" of the roadmapping process outlined by Garcia and Bray (1997).

Major technology areas are those technologies that help achieve the critical system requirements for the product which is the focus of the roadmap. It is pointed out that in defining the major technology areas it will be useful to carry out *function analysis*, identifying the functional elements of the system (i.e. the focus of the roadmap) and see if their relationship is effective, ineffective or harmful.

In addition to a function analysis, a system analysis can be carried out to map the system (the technology areas within the system), its subsystems (e.g. parts of the product (and their respective technologies) and the super-system (the system in which the product is used).

Exploring alternatives and timelines involves seeking out the alternative ways by which set out targets can be achieved. In this step, solutions will be sought to resolve problems or contradictions, and/or point out the evolutionary potential of the system and what the next logical steps for innovation are. For this, S-curve analysis (i.e. technology maturity mapping), usually carried out by patents research and the trends of evolution is also useful. Systems theory and morphology will also be useful in developing an explorative view of what alternatives are available.

Lee (2008) recommends the application of TRIZ to a roadmapping process which follows the outline of the T-Plan by Phaal et al (2001).
In analysing the technology (see step 4 of T Plan in Table 2.2.), Lee (2008) suggests that TRIZ, using S-Curve analysis, can be applied to understand the maturity of technology alternatives. It is also pointed out that in determining R&D activities, TRIZ can help in identifying inventive solutions. However, there is details are given of how this can be done.

Similar to Lee (2008), Zhang et al (2010) suggest that technology maturity mapping (S-curve analysis) and trends of evolution can give structure to decision making in roadmapping.
Focussing primarily on the aspect of making RD&D decisions (see figure 3.1), Zhang et al explain that if the technology is found to be in its infancy stage, and is deemed worthwhile to pursue, then it should be placed within the long-term range of the roadmap. More mature stages of technologies should be placed within mid- and near-terms on the roadmap. For old technologies, substitution should be the focus. This allows the determination of approximate time frames of technology developments and whether those developments should be focussed on optimization (incremental innovation) or replacement (radical innovation).

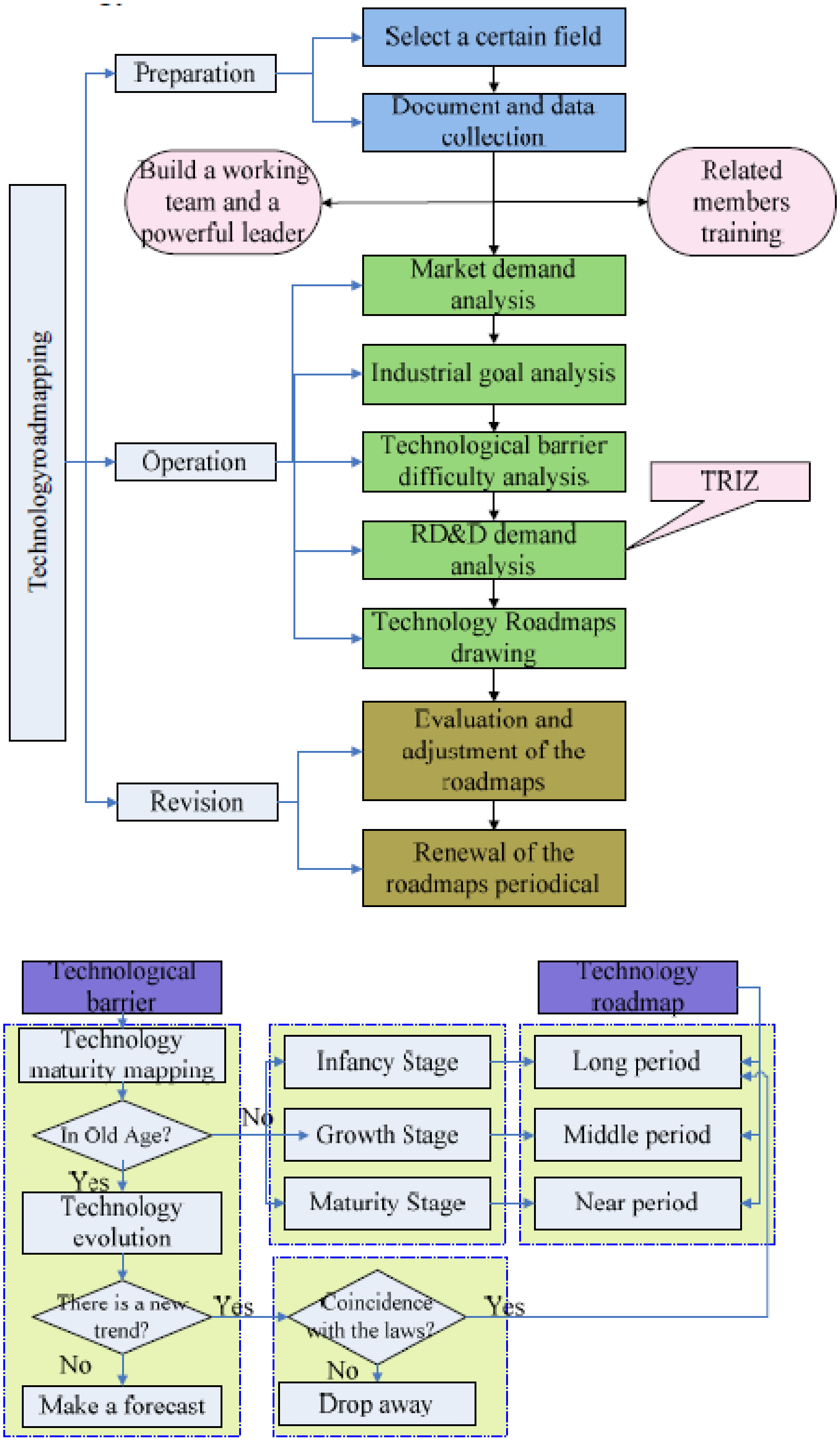


Figure 3.1 Process of technology roadmapping showing how TRIZ is applied (Zhang et al., 2010)

The above strings of literature on TRIZ and TRM combinations are focussed on the enhancement of TRM with TRIZ techniques. Looking across the papers highlighted, the following techniques stand out:

- Function and system analysis
- S-Curve analysis - maturity curve fitting to determine whether to optimise present technologies or search for a new solution
- Analysis of evolution trends- to determine the next logical phase of innovation.

Other tools or concepts mentioned but not deliberated upon as extensively as the foregoing are the inventive principles (Lee, 2008) and ideality (Shuch & Grawatsch, 2003). It is considered that it is possible to apply additional TRIZ tools (those not mentioned in these combinations) to further enhance the TRM process and quality of roadmaps generated. Also, other combinations of TRM and TRIZ can be developed (e.g. enhancing the TRIZ process using roadmapping techniques). These will be discussed in the next section.

3.4 Proposed combinations of TRM and TRIZ

There are at least three modes in which TRIZ and TRM can be combined.

- Mode 1: Applying TRIZ concepts and tools to enhance the TRM process
- Mode 2: Applying TRM concepts to enhance the TRIZ innovation process
- Mode 3: Applying TRIZ methodology to link successive roadmapping processes

These combinations will be based majorly on TRIZ concepts and ideas presented by Gadd (2011) and roadmapping methodologies (the S-Plan and T-Plan) developed at the University of Cambridge. Nevertheless, ideas from other surrounding TRIZ and TRM research will be applied wherever they are seen to present a different but useful approach.

3.4.1 Mode 1: Enhancing TRM with TRIZ

This is similar to the use of TRIZ concepts tools and techniques in the roadmapping process, similar to the efforts of the various authors outlined in the previous section. However, an attempt will be made by suggesting how other TRIZ tools, in addition to those already highlighted, might be applied within TRM. To accomplish this effectively, it will be useful to have a categorisation of TRIZ tools, and understand where and how they can be applied.

Moehrle (2005) explains that there are five main fields of application of TRIZ tools:

- Current state: to understand the current situation of the system.
- Resources: to identify the resources available.
- Goals: to have an understanding of the goals that need to be fulfilled and their requirements.
- Intended state: to understand what the future situation should look like.
- Transformation: to find a means of transforming the current state into the intended state.

Table 3.1 points out the tools belonging to these fields and gives a brief explanation of how they are applied.

Application field	**Concept/ tool/technique**	**Mode of application**
Current state	Function (and object) analysis	Modelling the positive and negative functions, and the components of a system
	Contradiction	Confronting desired functions with harmful factors
	Substance field analysis	Modelling of substances and fields of the problem
	Evolution analysis	Analysing the previous evolution of the system
Resource analysis	Resource analysis (system analysis, substance field analysis and performing a systematic search for resources)	Being aware of all available resources in and around the system
Goals	Ideal final result (IFR)	Identifying the most ideal solution
	Fitting	Consideration of restricting conditions to the ideal
Intended state	Strong solution (or the most ideal outcome achievable)	Balancing between the IFR and fitting
Transformation	Inventive principles	Direct application of inventive principles
	Contradiction matrix (and inventive principles)	Using the contradiction matrix to resolve conflicting benefits and harms
	Separation principles	Separating conflicting system requirements
	Substance field analysis	Application of standard solutions
	Evolution analysis	Anticipation of further development of system
	Resource analysis	Applying available resources
	Effects	Making use of scientific and engineering knowledge from different disciplines

Table 3.1 Classification of TRIZ tools according to application field (adapted from Pannenbacker (2001) through Moehrle (2005))

The application fields highlighted here can be used to suggest a generic approach to TRIZ problem solving. The following can be pointed out as the major stages:

1. Understanding the current state of the system.
2. Highlighting an intended state i.e. understanding what constitutes a strong solution (by identifying the ideal final result and fitting it to the problem context).
3. Transforming between the current state and the intended state.

The transformation stage can be carried out in such a way that it involves a more detailed process such as that shown in figure 1.9.

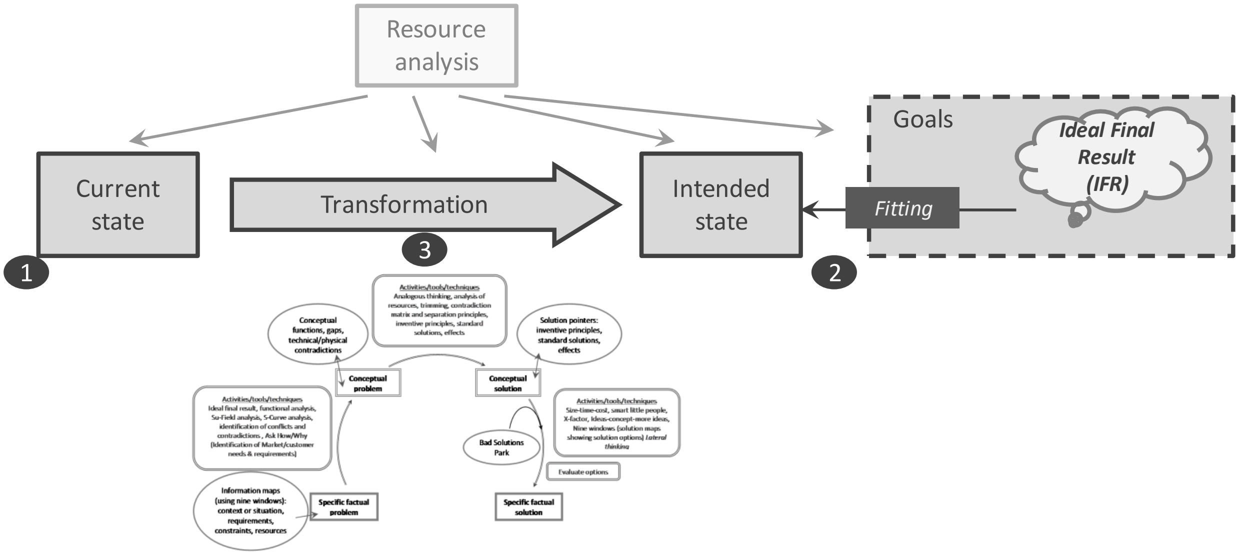


Figure 3.2 A generic approach to problem solving using TRIZ

These three stages are in accordance with the three main questions in TRM as pointed out in section 2.1:

- Where are we now?
- Where do we want to go?
- How do we get there?

This will suggest that the aspects of roadmapping which focus on these questions can be addressed using the corresponding TRIZ tools, analysis and concepts. This provides an idea of how TRIZ ideas and concepts might be integrated into TRM. Figure 3.3 presents the generic roadmapping framework overlaid with the generic TRIZ process, concepts and tools.

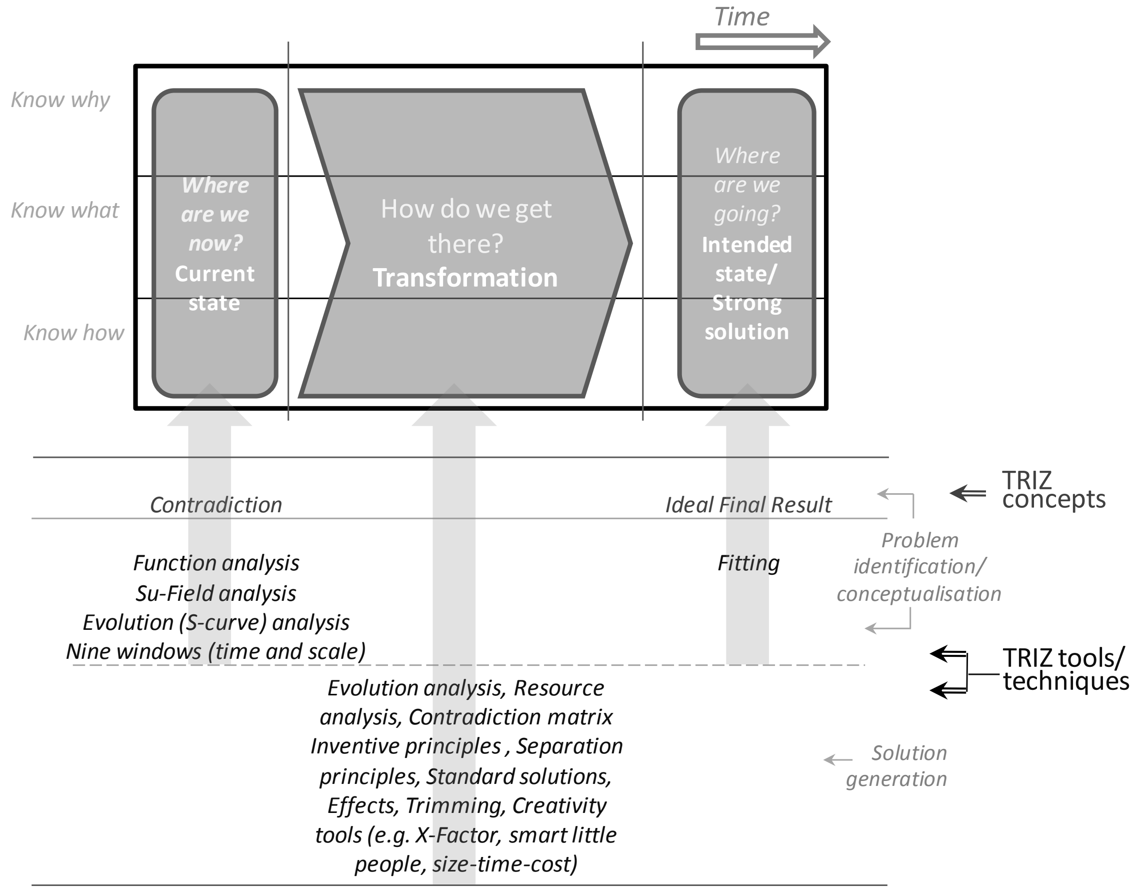


Figure 3.3 The generic roadmapping framework overlaid with the generic TRIZ process, and the application of its concepts and tools.

As identified in section 3.3, an example of TRIZ tools is evolution (or S-curve) analysis, and it can be used in understanding and conceptualising an identified problem, i.e to identify the nature of technology developments that need to be carried out (whether incremental or disruptive), and also gives an indication of the sequence of developmental phases (or able to give logical ideas on the future versions of product and technology), i.e. as a step in generating solutions.

The following describes in greater detail a TRM process which conceptually incorporates TRIZ ideas and tools. It is based on the T-Plan roadmapping process. The TRIZ concepts and tools which will be applicable in the roadmapping process are highlighted in italics along with the process description. Figure 3.4 is provided as an illustration for this.

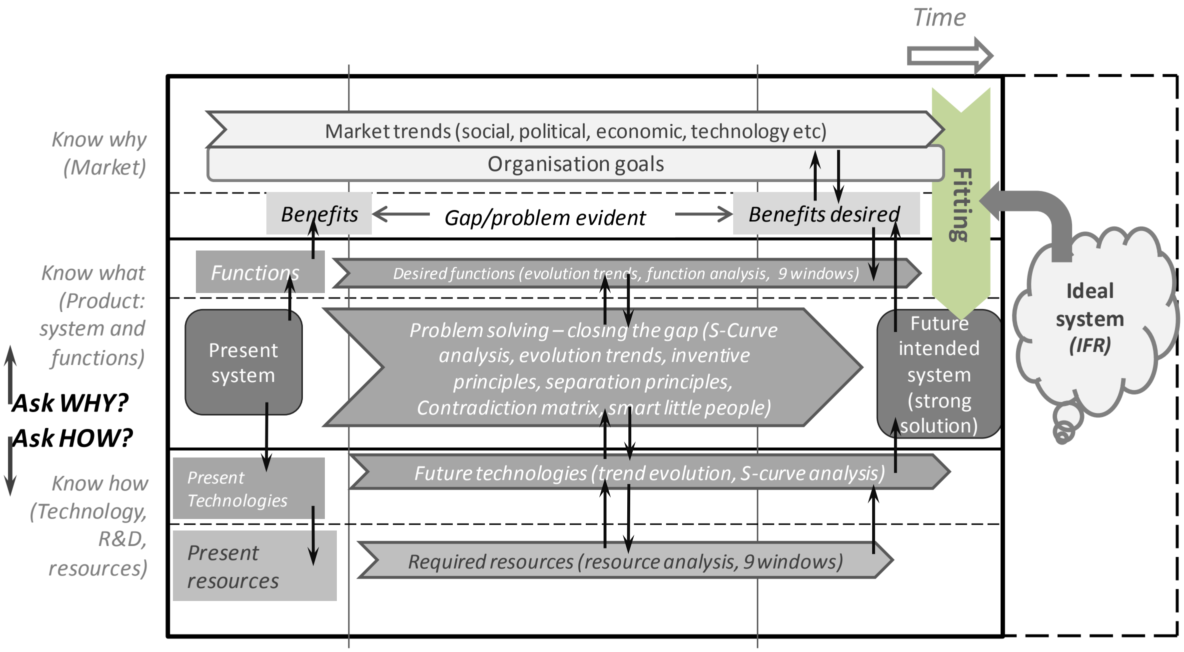


Figure 3.4 Illustration of the application of TRIZ concepts in TRM (Mode 1)

TRM-TRIZ process (based on the T-Plan)
1. Planning: Identify the business needs and objectives, scope of the roadmap, the people that would be involved and the schedule for creating it. Customize the roadmapping process and carryout any preparatory work.
2. Market Consider dimensions of product performance. Identify, group and prioritise market and business drivers for different market segments considered.
3. Product Identify and group product features and assess their impact on market and business drivers. Identify and understand features and functions of the present product. Highlight its benefits and harms *(function/system analysis*). Identify the ideal product for the market or customer. Identify the future/intended product based on the recognition of desired benefits and functions of the products for the future *(nine windows, function analysis).*

This can be accomplished by identifying the ideal product *(IFR)* and then modifying (fitting) it to the prevailing context based on market trends and drivers, and organisation goals *(fitting/strong solution)*.

Identify the gap/problems between the present product and a strong solution for the desired future product by highlighting the differences between the benefits the present system delivers and the expected benefits in the future product (i.e. the identified strong solution)*(ideality audit)*.

Transform the problem(s) into conceptual problem(s) *(function analysis, Su-Field analysis, Asking How? and Why?, etc)* and find conceptual solution(s) to them (*contradiction, inventive principles, contradiction matrix, effects, etc)*, and proceed to solve the problem conceptually. Keep records of bad solutions that might come to mind as the process continues *(Bad solutions park)*.

Problem solving would involve stripping down the products or services into their respective functions and finding out where the problems lie within the functions. Solutions may then be found to these problems (at functional level) individually, and a carefully laid out sequence of actualizing the solutions (by deploying the required resources in a timely manner) can lead to a process of incremental innovation towards the ideal final result of the future.

4. Technology

Identify alternative technology options. Assess their impact on product features.

The appropriate future technologies can be identified by understanding the present technologies (by carrying out function analysis on present system) and their logical route of future evolution (trend evolution analysis or S-curve analysis). Alternative interpretations of the trends or the S-curve analysis will point at alternative technologies from which choice(s) can be made based on the maturity of the technologies and the availability of resources *(resource analysis and S-Curve analysis)*.

Continually asking WHY? And HOW? throughout the process will also help in arriving at the best possible solution options.

The chosen technologies and resources can then be taken back to the previous step to translate the conceptual solution(s) into factual solution(s) *(smart little people, resource analysis, bad solutions park, etc)*

5. Integration and Charting

Bring the market, product and technology aspects of the business together on a roadmap. Ensure there is a fit between all the aspects *(Asking How? and Why?, nine windows)*. Identify milestones in product evolution and technology responses by matching relevant or related technology evolutions and resources.

6. Roll out and integrate the process

The upward and downward arrows shown on Figure 3.4 represent *Asking Why? and Asking How?* respectively. These questions help to establish linkage (in the roadmapping and problem solving process) across the market, product, technology and resources layers of the roadmap. They show how one can uncover the best possible solutions and resources that are consistent and well aligned with organisational goals and market trends. For example on the right hand side of the diagram, the arrow pointing upwards from the 'Future intended system' is asking "*Why* do we want this system?", and the answer is "to deliver the 'Benefits desired'".

3.4.2 Mode 2: Applying TRM concepts to enhance TRIZ

Basically, what this would entail would be the application of the visual aspect of TRM to TRIZ. The idea is to use TRIZ and TRM sequentially. A problem is solved using TRIZ, and its solution options are then mapped out on a roadmap (figure 3.5). The benefit would be the visual summary of the solutions inform of the roadmap developed. Here, there will be an opportunity to highlight the links between the problem solved and the reason for seeking out such a solution, and understanding where it fits within the organisation's (or systems) wider business context. This is typically absent in TRIZ problem solving. Also, it will be possible to identify and map out resources and R&D programs that will be required for delivering the solutions across a timeline.

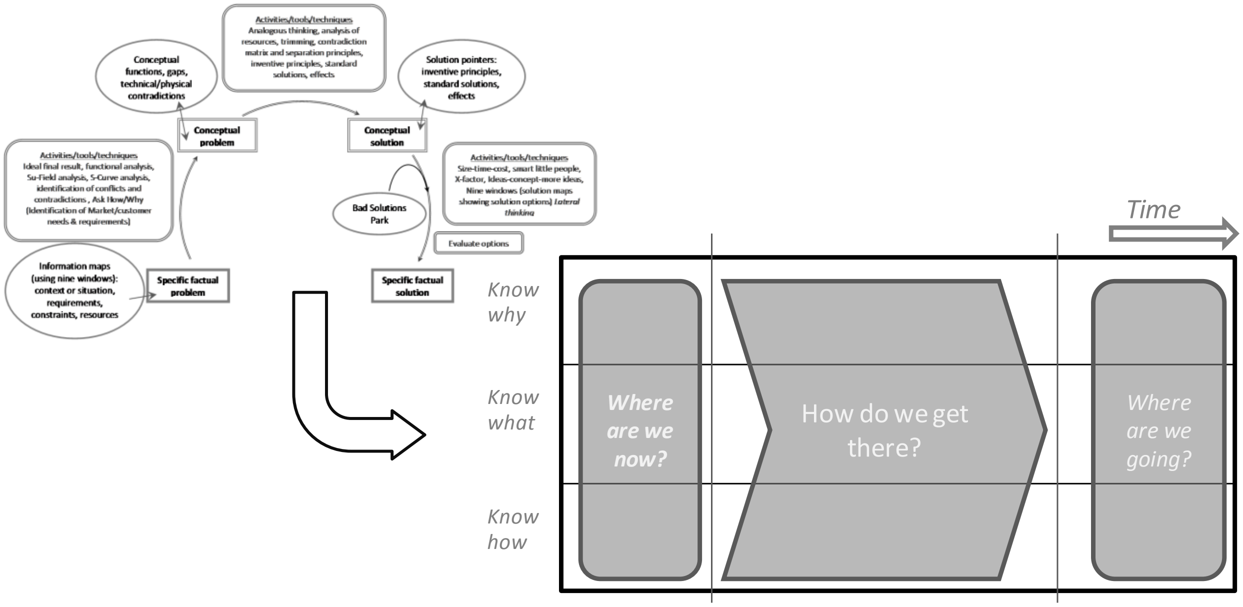
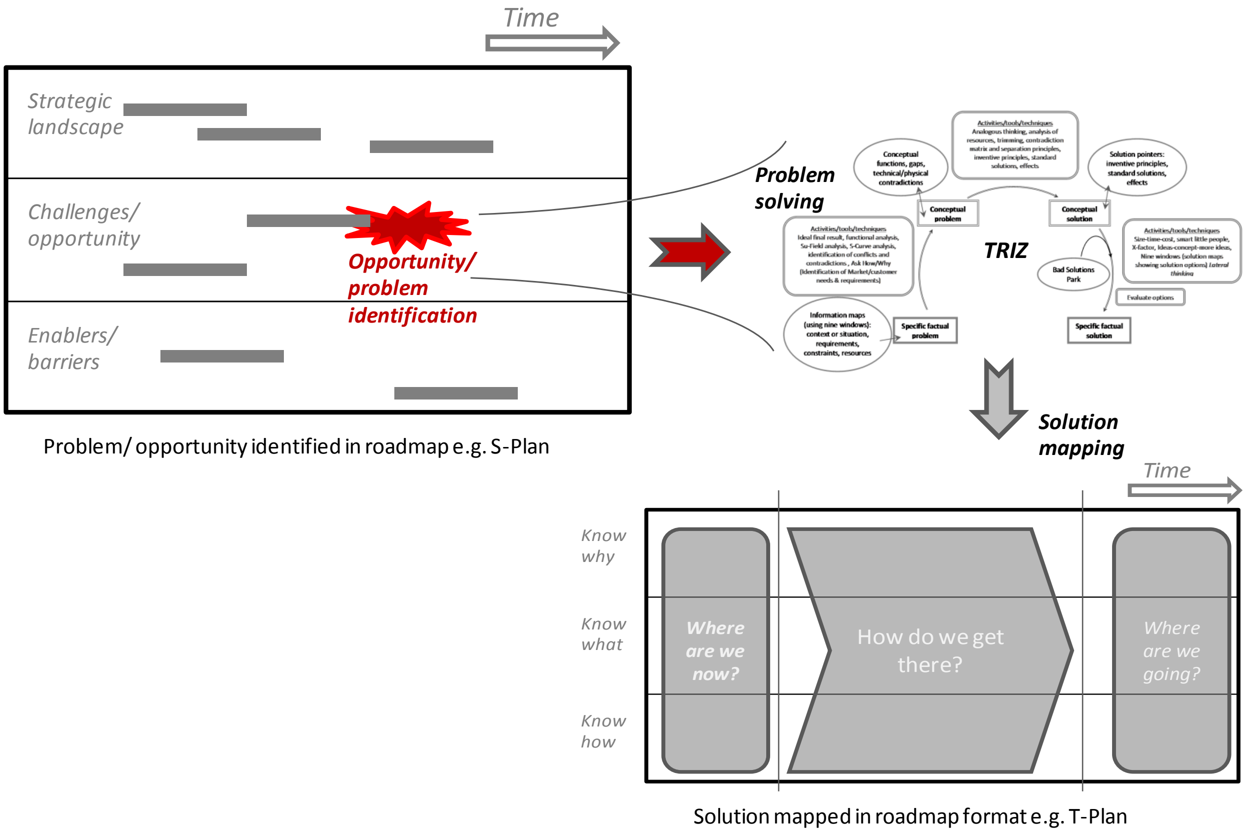


Figure 3.5 Applying roadmapping visualisation to TRIZ (Mode 2)

3.4.3 Mode 3: Applying TRIZ problem solving to link successive roadmapping processes

This is a variant of mode 2 described above. It would involve carrying out a roadmapping process to identify problems, opportunities or technology gaps, and applying TRIZ to identify solution options for problems. The solution options (along with the resources they require) can then be mapped out across a timeline in another roadmap (figure 3.6). For example, opportunities or gaps identified within an S-Plan roadmapping process (which looks at strategy issues and topics), might include innovation problems that require solutions. TRIZ can be applied in solving those problems, and suggesting a range of technology solution options for them. These different solutions can then be mapped out in separate roadmaps to highlight the resource demands and point out a timeline for achieving the finalised result for each of them (as suggested in Mode 2).



Problem/ opportunity identified in roadmap e.g. S-Plan

Solution mapped in roadmap format e.g. T-Plan

Figure 3.6 Linking successive roadmapping processes with TRIZ (Mode 3)

PART 4 – OTHER APPROACHES LINKING TRIZ AND TRM

4.1 TRIZ in combination with QFD

Quality function deployment (QFD) is a method designed to incorporate the Voice of the Customer (i.e. customer needs) into the design of product and services. The joint application of QFD and TRIZ evolution patterns can help to achieve a more objective voice of the customer, which will serve as input for QFD analysis. The product features included in market surveys developed by the marketing department can be tailored to coincide with the trends and paths of evolution indicated by TRIZ, rather than being based entirely on the (subjective) views of the marketing department on the customer needs and priorities (Savransky, 2000).

In addition to this, after the information collected from the customer has been organized in the QFD quality matrix called the "house of quality", identified opportunities or problems (resulting from unfulfilled needs, unnecessary features (*harms* in TRIZ parlance) or conflicting performance measures) can be dealt with using TRIZ (Rantanen & Domb, 2008).

4.2 **TRIZ in combination with Six Sigma**

Six Sigma is a quality improvement methodology used in processes, products and services, based on statistical analysis and a drive for customer satisfaction. High levels of customer satisfaction and technical quality can be achieved even faster when the breakthrough problem solving aspects of TRIZ are added to Six Sigma (Rantanen & Domb 2008). Rantanen & Domb identify organisations that have applied TRIZ (albeit loosely) in Six Sigma. These include Motorola and General Electric. Others reported to have a more structured integration of these methods are Ford Motor Company, Dow Chemical Company and Delphi Automotive Systems.

4.3 **Systems theory: an approach for linking TRM and TRIZ**

TRIZ has strong aspects of systems theory (or systems thinking) instilled in it given its emphasis on technical systems, their super-system and subsystems (See figure 1.2). Also the application in TRIZ of tools such as function analysis and the nine windows bring this to light quite clearly as these tools are included in systems theory (Mann 2002).

Roadmapping also has a systems thinking orientation. It is has been described as a dynamic systems framework, which provides a holistic view of an organisation and how technology and resources are integrated over time into systems which have value for the organisational system and environment. The layers and sub-layers of the roadmap (see figure 2.1) form a hierarchical structure of super-systems, systems, subsystems and resources (Phaal & Muller, 2009). Thus the nature of TRM encourages system thinking since the roadmapping framework forces thought to be given to technology development in the context of larger systems (e.g. the organisation) and aids linkages between the parts of the system (Bruce & Fine, 2004).

Given this shared attribute by TRIZ and TRM, the exploration and combination of both methods through systems theory has potential for a wider variety of combinations of the methods for additional benefits.

FURTHER WORK

The three modes of combining TRM and TRIZ should be further developed and tested.

Further development should be directed at understanding the workings of these methods, especially investigating them in the light of systems thinking which provides a theory or approach in which both methods are rooted.

Applying the combinations in practice would serve as a means of finding out what really works and what does not. It would also help in understanding how to best modify the process into different variants that would suit different planning or problem solving contexts. It will be important to structure the combination into processes that can be carried out quickly in workshop sessions. The development of tested and optimised processes would spur the essential stage of identifying procedures through which organisations can integrating these methods into their operations as part of their innovation and problem solving culture.

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