CHAPTER 1

LITERATURE STUDY

1.1 PROBLEM SOLVING

Problem solving is an activity that people perform every day. This ranges from simple tasks such as deciding what to wear or which restaurant to visit, to more complex issues such as solving traffic problems or finding a cure to a certain disease. Problem solving is also a key aspect of innovation, which is widely regarded as the engine of economic growth.

The term 'problem solving' is indeed broad and one which is interpreted and used in a wide sense. There often seems to be a tendency for any type of effort to solve non-trivial problems to be called 'creative thinking' or 'inventive problem solving', even though not all problems are solved creatively, and producing new ideas is only part of the problem solving process. Therefore, in order to clearly specify the scope of this thesis and provide essential background on the topic, the following sections will take the reader through some key definitions, the process and different types of problem solving, and finally, to inventive problem solving tools and techniques.

1.1.1 Definition

A ***problem*** can be defined as a gap or discrepancy that exists between an existing situation, and a desired, or more desirable, situation or outcome. As shown in **Figure 1.1**, in engineering terms, the desired outcome is normally either to:

(1) restore a baseline, i.e. the *initial* or designed working condition, in situations where for instance the functionality or efficiency of a system has deteriorated,
(2) improve upon the initial working condition, remove a drawback or achieving a specific enhancement or improvement, or
(3) find a new solution or create something new.

Problem solving is a single or multi-step transformation of the existing situation to the desired situation, or at least moving closer to it. According to Savransky (2000: 17), three major requirements for a successful problem-solving methodology are that it:

1. Directs the problem solver to the most appropriate and strong solutions.
2. Signals the most promising strategies.
3. Provides access to important, well-organised, and necessary information at any step of the problem-solving process.

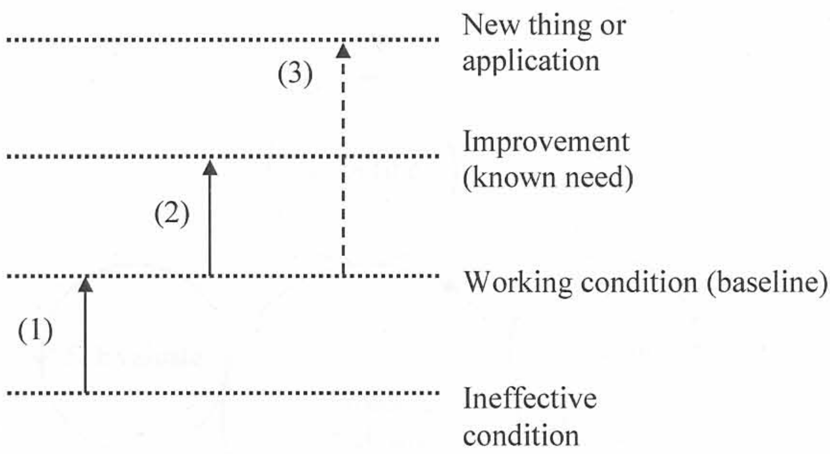

Figure 1.1 Types of problems, as defined by different desired states.

1.1.2 Process

As shown in **Figure 1.2**, problem solving is a ***process*** that can be represented as five generic stages (Koberg & Bagnall 1976; Fogler & LeBlanc 1995), *viz*:

1. Definition – understanding the cause(s) of the problem, information gathering, exploring all dimensions and defining the objectives and criteria that must be met in order to solve it successfully.
2. Ideation – creating a range of ideas, alternatives and options that potentially meet the requirements of the problem.
3. Decision – determining which of the options would be best to implement, considering issues such as available resources, cost and safety.
4. Implementation – putting the best option(s) into action, doing the planning, design and manufacture, mobilising resources.
5. Evaluation – monitoring the action and assessing the extent to which the implemented solution has met the specified criteria sustainably.

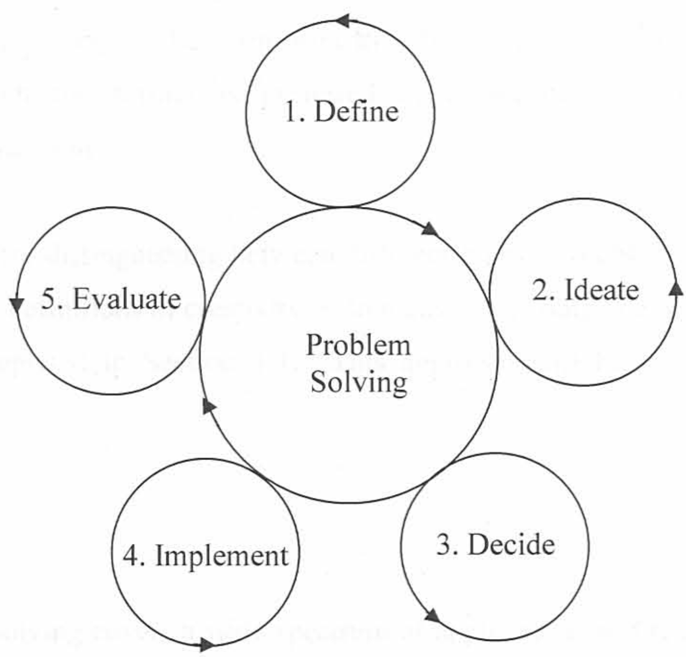

Figure 1.2 The problem solving process.

An important point to note with respect to this generic representation is the fact that different types of problems call for different approaches, and not all of the above elements of the process may be relevant or present in all cases.

1.2 TYPES OF PROBLEM SOLVING

Although often believed otherwise, and despite the sales talk of consultants and some authors, not all problems are solved creatively – problems that call for inventive solutions make out only a part of all engineering, technical and design problems. Having said that, the line between 'creative' or not is not always clear and what to one person is creative might be commonplace to another. The definition of creativity, or what constitutes a creative effort or outcome, is a very broad and complex topic and today still the leading experts in the world struggle to reach consensus.

Interestingly, whilst the 'creativity' in creative problem solving appears to be much hyped, the 'non-creative' efforts are normally referred to simply as 'problem solving' and a commonly accepted terminology in this regard seems to still be lacking. For the purpose of this thesis, the two concepts will forthwith be distinguished by the terms 'analytical' and 'inventive' problem solving respectively. The term 'inventive(ly)' will be used interchangeably with 'creative(ly)', although the former is preferred in engineering environments; they are interpreted to mean the same.

A more robust basis for distinguishing between different types of problem solving, rather than for instance by using definitions of creativity, is to measure the outcome of the process against the desired states depicted in Section 1.1. This approach will be used in the following sections.

1.2.1 Analytical

Analytical problem solving covers a wide spectrum of applications and relates to both desired states (1) and (2), *viz* restoring a working baseline, or achieving an improvement on this condition.

On the lower end of the complexity scale as far as satisfying desired state (1) is concerned, the problem solving is normally referred to as 'routine' or 'fixing'. These types of problems typically encompass a physical or hardware dimension only, and a basic knowledge or experience of the topic is normally sufficient for the solution to be immediately apparent. Often the process occurs according to a set sequence of steps, each of these being well understood and documented in operating or working manuals. Fixing a leaking tap, setting up a VCR and servicing a car are all examples of what would be considered '*fixing*' problems.

In other cases the problems may be more complex, and a number of dimensions and issues need to be analysed either in sequence or simultaneously. In this regard, problem definition techniques such as the Kepner-Tregoe (1981) Problem Analysis (KTPA) and Duncker diagrams (Fogler & LeBlanc 1995: 42) are popular tools.

Analytical problem solving can also satisfy desired state (2), by achieving enhancements or improvements to what is already an effective working condition. This, mostly non-routine, activity typically requires technical expertise in the particular area. Finding the optimum thicknesses of magnets and steel discs in a permanent magnetic roll and the conditions under which certain arrangements would work best is an example of such effort. Whilst the desired outcome (improving the performance of the apparatus) is clear, the exact steps and the best route(s) to follow may not be. Finding the best solution thus calls for sound judgement based on deep knowledge and experience in the particular topic.

1.2.2 Inventive

Inventive problem solving describes the process in, or through, which:

- A critical step is provided to achieve desired state (2), that could not have been achieved by analytical problem solving alone, or
- new things or applications with value are created in situations where no previous norm existed (desired state 3).

The major difference between *analytical* and *inventive* problem solving therefore lays in the type of ideas that are required for successful achievement of desired states (2) and (3). This depends on several factors, including the complexity of the existing or initial situation, an ill-definable desired situation, unknown solution or hidden search directions (Savransky 2000).

1.3 CREATIVITY

The term 'creativity' is integral to creative (inventive) problem solving but, not being a key element of this study, only a brief overview of the defining features will be attempted below.

1.3.1 Novelty and value

Two concepts that seem to have a unanimous place in the definition of creativity are ***novelty*** and ***value***. In the context within which it is created, something has to be new, or represent an approach that has not been followed before. Having value means that it also has an impact or lasting influence, enhancing the quality of life in some way. Margaret Boden (1992: 30) proposes a further qualification and argues that novelty and value alone are not sufficient. *Genuinely creative ideas are surprising in a deeper way.... Our surprise at a creative idea recognises that the world has turned out differently not just from the way we thought it* would, *but even from the way we thought it* could. (emphasis added by author).

1.3.2 Continuity

Another prerequisite for creativity, linked closely to novelty and value, is that of ***continuity***. The saying that a truly creative idea is one which is 'logical only in hindsight' means that it must be assessable in the context of what has preceded it; elements or features of the old need to be traceable to the new, even if in a much modified or altered form. If this continuity is not manifested and the idea or concept is not interpretable or implementable in the one form or the other, the novelty is merely eccentricity (Boden 1992). Tied into continuity is the notion that the idea or end product must be *complete* in order to be assessable in the context of what has preceded it - a poem of four lines or 10 bars of a symphony would not meet these requirements.

1.3.3 Assessment

An aspect that somewhat complicates the definition of creativity is introduced by the judgement as to whether an idea or effort is creative or not, as this also depends on the perceptions of society at any given point in time. In this regard, Csikszentmihalyi (1996) proposed a model which incorporates the *individual* that produces some new work, and the *field* - people 'guarding' the entrance to the domain in which the work was produced. In science, the field would typically consist of other scientists knowledgeable about the principles involved; in art, it would for instance include other artists, critics, and gallery owners.

Before new work can become a permanent part of the *domain*, i.e. be worth preserving to influence future generations, the field has to value it positively. If, for whatever reason, it rejects a novel piece of work, the model implies that neither the work nor the person that produced it can be called creative. However, as Weisberg (1992: 245) demonstrates with historical examples from the world of art, this creates an akward implication: If a previously ignored work becomes valued by the field, often long after it has been produced, the work, and per definition the person that produced it, all of a sudden is deemed creative. This can for instance arise because of changes in taste, perceptions and preferences in society over time, and one would therefore never be able to tell finally and conclusively whether a person or his product is, or was, or perhaps will be, 'creative'. However, it must be acknowledged that the scientific and engineering worlds are very much less, if at all, exposed to these types of vagaries.

Weisberg (1992) then provides a different angle on the debate, by separating the nature and *outcome* of the work from its *valuation.* The definition is also helpful in clarifying the concept of genius as compared to ordinary creative individuals:

I would, therefore, propose to limit the term creativity to an individual's goal-directed *production of* novel *work; the result of the assessment by members of the field would be the* value *of the product. A work of value can also have* influence *if it is incorporated in the works of others, and I would use the term* genius *to refer to the individual who produces work of exceptional value and/or influence.*

The concept of goal-directedness, however, apart from being interpretable in different ways, introduces its own set of difficulties. In history, there are several examples of serendipitous discoveries – fortuitous discoveries that happened by chance or accident - where it can be argued that 'goal-directedness', i.e. a focused or conscious effort in producing something of value, manifested itself probably not until well after the implication of the idea or observation has been realised by its discoverer. There is bound to be much debate if it was claimed that the non-directed, accidental nature of the discovery of teflon and penicillin, and the development of Velcro and the Instamatic camera, precludes them from being considered highly creative.

Whilst Weisberg alludes to it, it is Boden (1992) who addresses the main limitation of Csikszentmihalyi's model by distinguishing between two senses of the term 'creative' as relevant to ideas, i.e. concepts or styles of thinking. One sense is psychological (P-creative) while the other is historical (H-creative). Whilst the P-creative sense involves ideas that are fundamentally novel with respect to the individual mind that had the idea, the H-creative sense applies to ideas that are fundamentally novel with respect to the whole of human history, i.e. those that in Csikszentmihalyi's model were valued positively by the field.

A more robust definition of creativity can thus be derived by integrating the three perspectives discussed above. As shown in **Figure 1.3**, this model proposes that any idea or outcome (not only as a result of goal-directed effort) that is *novel in the context within which it was created* could be regarded as P-creative. Should this idea or outcome be communicated, such as by way of patenting or publication, and its value acknowledged by the field, it would be regarded as H-creative. The extent to which the value is acknowledged and the resultant magnitude, duration and scope of influence would be key factors in determining the genius of the creator.

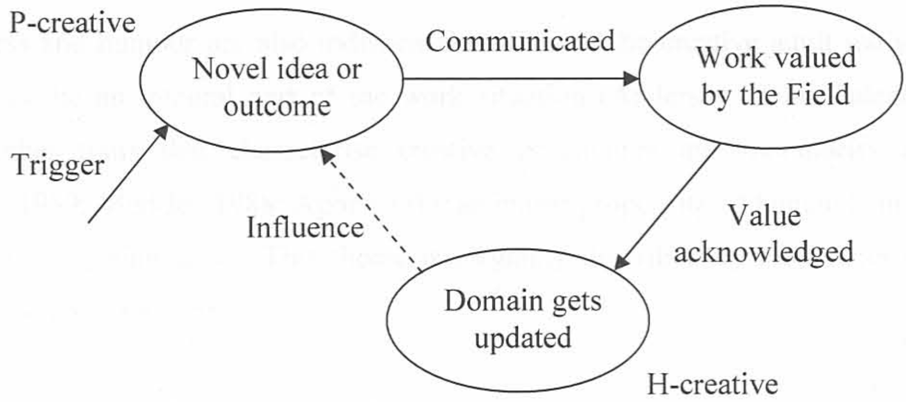

Figure 1.3 A model for creativity.

1.3.4 Enablers

The propensity of an organisation to produce creative ideas and outcomes is determined by more than just the creativity of the people it employs. The model shown in **Figure 1.4**, an expansion by the author of the work of Amabile (1998), represents in three main groups the factors that contribute to creativity, *viz*:

(1) the personal Traits and creative thinking skills of the individual and/or team. These determine how flexibly, imaginatively and purposefully people approach problems.
(2) the three E's - Expertise (technical, procedural and intellectual knowledge) in the relevant field, Exposure to others and the means for Experimentation.
(3) the levels of intrinsic Motivation, i.e. the drive, passion and commitment to get problems solved.

Traits

The earliest sources that creative individuals draw upon are linked to childhood play, stimulation and playful learning (John-Steiner 1997: 37 and 40):

Intensity is then the one universal given in this account of creative thinking; all the (creative) individuals I interviewed recalled some recognition of their engagement with play, with ideas, with the world, and while still very young (p.220).

Playfulness and humour are also indispensable traits of the creative adult individual, and as such should be an integral part of the work situation (Anderson 1994; Tulenko & Kryder 1990). Other traits that characterise creative endeavours are spontaneity and intuition (Roweton 1989; Markley 1988; Agor 1991), an innate propensity of human beings to explore, and to do so continuously. This theme is elegantly described by Hofstadter (1982) in his definition of creativity, *viz*

... *'a non-deliberate yet non-accidental slippage along the hidden fault lines of the mind'.*

Figure 1.4 The enablers of creativity.

Creativity 'enjoys' the fact that concepts have a natural tendency of 'slipping' from one into another, following an unpredictable path. It is not something that can be forced or turned on at will - while the potential is always there, the actual act is something that happens, most of the time, unforeseen. Robinson & Stern (1997) support the notion of spontaneity and self-initiative in fostering creativity in corporate environments, *'when employees do* (produce) *something new and potentially useful ... without being directly shown or taught.'*

Spontaneity and play are enhanced by work situations in which experimentation is promoted, failure is tolerated and people are encouraged to express self-initiative and their own perspectives. The willingness to take risk and tolerate ambiguity, and alertness to new and serendipitous opportunities, are key elements of an entrepreneurial mindset (Gundry *et al.* 1994). This, together with the inquisitiveness that John-Steiner (1997) captures as 'a continuity of concern, an intense awareness of one's active inner life combined with sensitivity to the external world' (p.220) and the tenacity personified in an Edison ('1% inspiration and 99% perspiration'), are major drivers for the realisation and championing of new ideas.

Expertise, Exposure and Experimentation

Creative individuals are thought to embody a tension of knowledge breadth and depth, *viz* lateral and vertical thinking (Fiol 1995) and have been described as 'the embodiment of contradictions' (p.75). As such, they should not only be given opportunities to deepen their knowledge and acquire requisite expertise in the field (Ericsson & Charness 1994), but also to be stimulated by exposure to a diversity of information, thoughts, people and situations. The serving of 'apprenticeships' by gifted young artists and scientists in which they acquire a diversity and depth of skills that form the basis of craftsmanship and major achievements in later life is highlighted by John-Steiner (1997, Chapter 2) and Root-Bernstein (1989: 44).

In organisations in particular, communication and effective structuring of group interactions are key enablers of diversity and knowledge building (Robinson & Stern 1997; King & Anderson 1990; Kurtzberg & Amabile 2001). This can be supplemented by 'positive turbulence' created through initiatives both external and internal to the organisation, for instance travel, conferences, sabbaticals, joint ventures and cross-functional teams (Gryskiewicz 1995). The system should also have sufficient slack to enable 'enlightened experimentation' (Thomke 2001) and unofficial activity (Robinson & Stern 1997), as the fusion of these create opportunities through serendipity.

Motivation

People will be most creative when they feel motivated primarily by the interest, satisfaction and challenge presented by the work itself (Amabile 1998), more so than for instance via extrinsic rewards such as money. Key elements of this intrinsic motivation are recognition and encouragement via organisational, supervisory or work group supports, as well as autonomy, freedom (Kondo 1995), allowing self-initiated activity (Robinson & Stern 1997), personal initiative (Lewis & DeLaney 1991; Perry 1995; Frohman 1999) and provisioning of effective incentives (Collins & Amabile 1999). The importance of providing creative people with challenging work that provides 'stretch', whilst minimising workload pressures and tolerating failure, is emphasised by several sources (e.g. Amabile *et al.* 1983; Robinson & Stern 1997; Gundry *et al.* 1994). This is critical to the incubation of ideas (Olton 1979; Olton & Johnson 1976; Thompson 1991) that eventually leads to new insights and discoveries.

Other strategies that can impact on the generation of inventive ideas in an organisation include outsourcing, decentralisation into narrowly focused business units, and tapping ideas from customers, competitors or different industries (Rubinstein 1994; Von Hippel 1988).

1.4 TYPES OF INVENTIVE IDEATION

Referring back to the generic process of problem solving depicted in Figure 1.2, two issues collectively determine the sources of inventive ideas, *viz* (1) the degree of problem definition and (2) the nature of the ideation process. Regarding the first, there are several examples in history to prove that creative outcomes are not only the result of well-understood, carefully defined problems. Likewise, with regard to the nature of the process, there are equally convincing examples to show that creativity is not necessarily an essential trait for a creative outcome but that chance events, accidents or mistakes can also play a major role (Robinson & Stern 1997).

If these two issues are considered together, an area is defined in which four main domains can be observed (**Figure 1.5**). Shown in each domain are some famous examples in the history of the arts, science and technology. Each domain has a unique nature and the four domains have been labeled such as to reflect these as descriptively as possible. It is pertinent to note that, by virtue of their 'non-accidental' nature, Experimentation and, to a lesser extent, Inspiration, can be grouped in the category that Weisberg (1992) defines as 'goal-directed' effort.

1.4.1 Inspiration

Inspiration has as its basis creativity, the 'non-deliberate yet non-accidental slippage along the hidden fault lines of the mind' (Hofstadter 1982) that happens continuously in the sub-conscious mind, an innate trait of the individual to tweak the 'conceptual knobs' of his/her environment and mentally exploring the implications of doing so. It is the essence of great achievements in the arts and sciences, the intuitive sensing of potentially valuable new pathways in the particular concept space (Boden 1992). The nature of this domain is easy to visualise or imagine when thinking of the great composers, painters, writers and scientists.

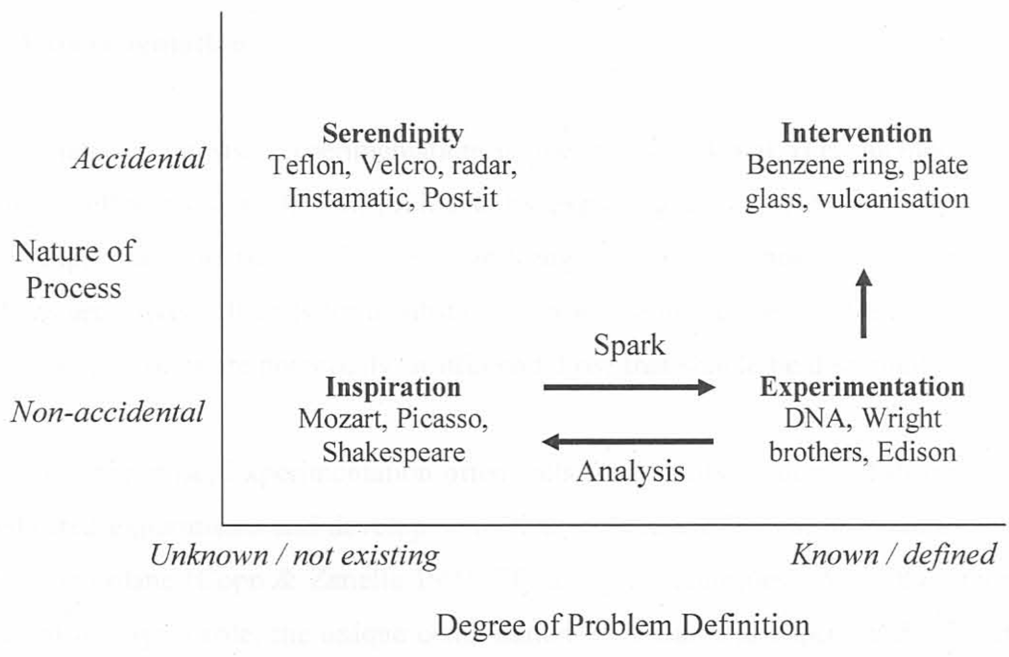

Figure 1.5 The four sources of inventive ideation.

One of the main drivers of Inspiration is an innate propensity to create, and hence it often *sparks* Experimentation by providing the initial insight or hunch that needs to be verified by further study and investigation. This spark is also triggered when artists or scientists for instance question or *analyse* their styles or theories and in the process arrive at some fundamentally new insights as how to solve certain problems.

1.4.2 Serendipity

As alluded to earlier, it may be argued that serendipitous discoveries - accidental in nature and solving problems that did not exist until the idea was conceived - do not really qualify as problem solving. They do not address existing or known needs but are the fortuitous outcome of chance events such as accidents, mistakes, or seemingly silly remarks (Robinson & Stern 1997). However, since they not only conform completely to the definition of creativity (producing something novel and of value), but also in the interest of developing a complete understanding of the conceptual framework involved, they are included here. Serendipity calls for keen observation skills and an alertness to the potential value of what is observed.

1.4.3 Experimentation

As the name suggests, Experimentation is the non-accidental (i.e. methodic) and often systematic effort to solve known problems by exploring various pathways. It represents by far, in especially the fields of science and engineering, the most frequent way in which problems are solved. It calls for a substantial expertise in the specific field in order to assess which manipulations are potentially fruitful and those that should be discarded.

Apart from expertise, Experimentation often calls for tenacity - Thomas Edison and the years of dedicated experiments and developments that enabled the Wright brothers to build and fly the first aeroplane (Copp & Zanella 1993: 78) are good examples. As in the other domains, chance also plays a role; the unique combination of talents and expertise that resulted in the discovery of the structure of the DNA molecule had a lot to owe to a series of fortuitous events (Robinson & Stern 1997).

1.4.4 Intervention

Interventionist, or 'pseudo-serendipitous', problem solving occurs when Experimentation (sometimes many years of intensive effort) fails to produce a solution, which is eventually found by chance, in an unexpected way or place. According to legend, Charles Goodyear, after having worked for more than 20 years on a process to make rubber flexible, accidentally spilled molten rubber and sulphur onto his brother's hot stove, and in the gooey mess that was left saw the birth of the vulcanisation process.

Interventionist solutions are often triggered by strong visual analogies, which makes diversity a key element of this domain. "*Among chosen combinations the most fertile will often be those formed of elements drawn from domains which are far apart... Most combinations so formed would be entirely sterile, but certain among them, very rare, are the most fruitful of all.*" (Henri Poincare, quoted in Boden 1992: 21). Unlike the gradual and normally step-wise progress of Experimentation, the solution normally occurs in a brilliant flash of insight. This is the so-called moment of *illumination* (Boden 1992), the discovery of the plate glass process by Pilkington and the structure of the benzene ring by Kekule being famous cases in point.

The main difference between Intervention and Serendipity therefore lies in the fact that in the case of the former, the solution is preceded by focused, goal-directed experimentation to solve a known problem. This involves the so-called periods of *preparation* (getting intimately involved with the problem, investigating various options) and *incubation* (removing the problem from conscious and focused effort, allowing the subconscious mind to work at it.) [1]

1.5 ' DELIBERATE CREATIVITY '

Over the past number of decades, significant progress has been made in the development of thinking techniques and tools to enhance the skills of people in creative problem-solving and invention. These techniques, commonly referred to as 'deliberate', 'serious' or 'forced' creativity, seek to simulate or reproduce the elements that underpin the four sources of inventive ideas, *viz* those that:

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[1] This type of problem solving was defined by the mathematician Jacques Hadamard in the 1920's, viz Preparation, Incubation, Illumination and Verification. Over the years there have been several modifications and extensions of this basic algorithm. For example, the problem solving methodology described by Koberg & Bagnall (1976) consists of six stages, but follow the same functional process: Define the problem, Analyse the different parts, find new ideas through Ideation, and Rate the outcome (Decisioning). The best idea is then Developed and Implemented, and finally Evaluated.

1) simulate the conditions that are perceived to be conducive to creativity (conditioning techniques),

2) organise and arrange ideas and concepts in useful and manageable formats (organising techniques),

3) produce new ways or combinations of thinking (creative thinking techniques), or

4) learn from, and use, the principles of successful inventions and problem solving (invention heuristics).

Of the above, only creative thinking and invention heuristics are what will forthwith be collectively referred to as inventive ideation (**Figure 1.6**), i.e. systematic approaches to manipulate the attributes of problems in such ways that novel, non-trivial perspectives or new applications are established. Whilst these will be the focus of the thesis, in the interest of completeness and clarity a brief overview of the other techniques will be provided.

1.5.1 Conditioning techniques

Conditioning techniques are aimed at creating the optimum psychological conditions for creativity, stimulating the alpha brainwaves and putting the mind in a relaxed but alert state. They try to simulate the nature of the Inspiration domain and range from activities such as removing conceptual blocks (Koberg & Bagnall 1976; Adams 1986), relaxation, intuition, (day)dreaming, drawing, doodling and collage, psychosynthesis, hypnogogic imagery, listening to music, visualising, meditating etc. (Nolan 1987; Michalko 1991) to the more structured approach of neuro-linguistic programming, or NLP (Dilts *et al.* 1991).

NLP is a suite of methodologies and models that examine and capture the thought processes involved in creativity, in order to identify the essential elements of thinking and behaviour that is used to produce a particular response or outcome. Once these elements are understood, they are used to 'reconstruct' conditions most suitable for peak performance and creativity.

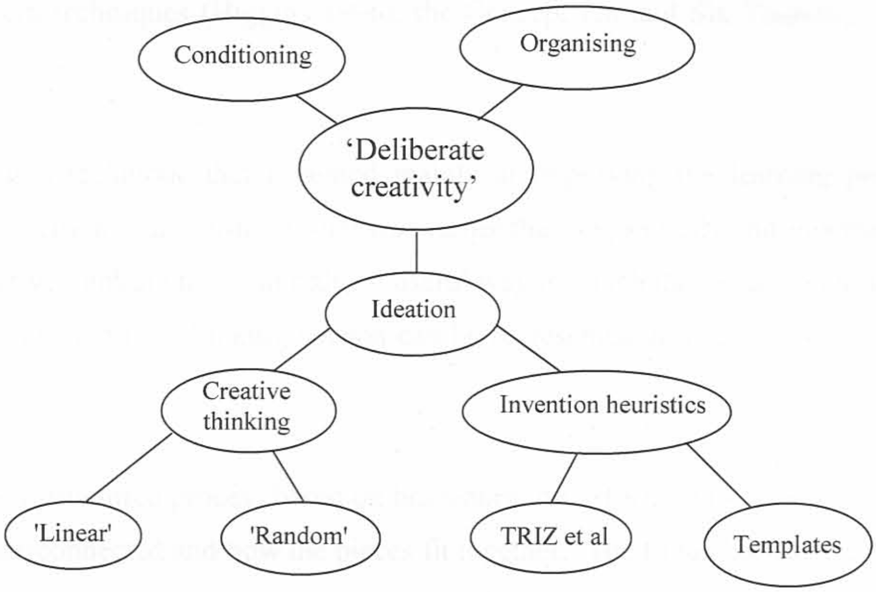

Figure 1.6 Elements of 'deliberate' creativity.

For example, one of the tools is the so-called ROLE model, which identifies the critical steps of the mental strategy and the role that each step plays in the overall neurological 'program' (Dilts *et al.* 1991). On the micro level of the thinking process, the Representational systems (i.e. the R of the acronym) deal with which of the five senses are most dominant for the particular mental step, while the Orientation has to do with whether the sensory representation is focused externally or internally. On the macro structure of the creative process, the Links element determines whether representations are linked sequentially (digital) or simultaneously (analog), whilst Effect has to do with the result, effect or purpose of each step in the thought process.

1.5.2 Organising methods

Organising methods are tools that present information or ideas in a structured fashion, thus assisting in the cross-fertilisation of diverse ideas and the expanding of groups of concepts. They are also useful in structuring the running of meetings or ideation sessions. These include Mind Maps (Buzan 1991), Fishbone diagrams (Fogler & LeBlanc 1995), the Storyboarding and Lotus blossom techniques (Higgins 1996), the Concept fan and Six Thinking Hats (De Bono 1993).

Mind mapping is a technique that is aimed mainly at improving the learning process by representing information in a holistic, visual way rather than sequentially and in writing. It is not a formal creative thinking tool, but rather a useful way in which the expansion of ideas and concepts that are created in a thinking session can be represented and act as source of cross-fertilisation.

Storyboarding is a structured process based on brainstorming, which allows participants to see how ideas are interconnected and how the pieces fit together. The Lotus blossom technique is especially useful in generating strategic scenarios and is so named because it begins with a central core idea, surrounded by an ever-expanding set of related ideas. Brainstorming is used to produce ideas that are written into eight boxes; each of these becomes the core of another set of eight. The process continues until a satisfactory solution or a sufficient number of ideas have emerged (Higgins 1996).

The Concept fan is a way of structuring the route between the problem objective ('what needs to be done') and the range of ideas ('how it can be done practically'). Three levels of concepts are used to structure the thinking, ranging from 'directions' (broad concepts or approaches) to 'concepts' (general methods or ways to do something) to ideas (specific ways in which a concept can be put into practice).

The Six Thinking Hats is used to formalise and order the thinking process, of which ideation or 'creativity' (represented by the green hat) is but one aspect. It covers the same attributes as for instance the Whole Brain Model (Herrmann 1996), namely the factual (white), organisational (blue), emotional (red) and holistic (green) aspects of problems. In addition, it includes a statement of the positive (yellow) as well as the negative aspects (black) of the ideas that have been generated.

1.5.3 Creative thinking

In the context of this work, creative thinking is defined as 'the deliberate, i.e. conscious, application of one or more mental manipulations (forthwith referred to as '***mechanisms***') to one or more attributes of a problem, in order to produce ideas that are both novel and useful'. As mentioned earlier, the suite of creative thinking techniques is very large, but, as suggested by some exploratory studies in this area and will be expanded upon in this thesis, draw from only a relatively small number of mechanisms.

Table 1.1 gives for example a list of 'creative processes' categorised according to the four quadrants of the Whole Brain Model (Herrmann 1996). The use of the term 'creative process' is somewhat misleading as not all of these are focused on creative ideas, especially those in the Analytical quadrant. Different such categorisations can be made - Zusman & Zlotin (1999) for instance categorised techniques into seven classes based on the methods and means utilised. However, the mainstream creativity literature distinguishes normally only between two groups, namely:

(a) 'linear' or 'focusing' techniques. Examples are Osborn's checklist (Osborn 1979), attribute listing and attribute splitting (Koberg & Bagnall 1976; Souder & Ziegler 1977; Michalko 1991; Higgins 1996; Zusman & Zlotin 1999).
(b) 'random' or 'intuitive' techniques. These include brainstorming (Souder & Ziegler 1977; Schwab & D'Zamko 1988; Nolan 1989; Higgins 1996), random stimulation, excursion techniques (Nolan 1989; Higgins 1996), provocation and Synectics (Gordon 1961; Nolan 1989, De Bono 1993).

Whilst the 'linear' techniques aim to explore the problem space incrementally, all the time staying on familiar territory, the purpose of the 'random' techniques is to snap the mind out of old or routine ways of thinking and provide fresh starting points or new directions. Some people argue that brainstorming is more about the process of setting the right environment for thinking, i.e. a conditioning technique rather than a creative thinking technique, but for the purposes of this work it will be considered as part of the latter group.

Table 1.1 Categorising 77 'creative processes' in terms of the Whole Brain Model.

Analytical (A quadrant)	**Conceptual (D quadrant)**
Attribute listing	Brain writing
Electronic brainstorming	Creative dramatics
Bionics	Creative materials (ACT1)
Factual analysis	De-doodling
Forced field analysis	Dreaming
Idea Fisher software	Free association
Kepner-Tregoe process	Guided imagery
Mathematica	Incubation
Method 6-3-5	Intuition (solutions)
Operation Research	Journeys into creative problem solving
Pert program	Lateral thinking
Problem definitions	Meditation
Pure 'logic'	Mess worksheet
Rational thinking	Metaphoric thinking
Re-engineering	Modeling
Value analysis	Play
	Sketching
	Solution after next
	Synectics
	Theta state / free flow
	Visual brainstorming
	Visualisation
	Visual thinking
Organisational (B quadrant)	**Emotional (C quadrant)**
Delphi method	Expressive
Detailed	Human factors
Force fitting	Interactive brainstorming
Idea evaluation	Intuition (feeling)
Implementation aspects	Kinesthetic modelling
Instinctual	Passion point process
Morphological	People design principle
Operation analysis	Sensory processing
Orderly	Symbolic
SCAMPER	Task team
Step-by-step	Team process
Strictly procedural time line principle	
Trigger concept	
Work simplification	
Zero defects	
Multi-dominant	
Applied creative thinking process	Six thinking hats
CPSI process	Storyboard
ACT creative process	TLC (tempting, lacking, change)
Mind mapping	Whole brain creativity
Pugh method	Whole-brain problem solving walk-around

Source: Herrmann (1996)

Computer programs

Computer programs have also been developed to stimulate the creative thinking process by means of associations and word lists (e.g. Bond & Otterson 1998; Watson 1988; Fisher 1996). According to Jalan & Kleiner (1995), it has been empirically established that the use of Fisher association lists not only increased productivity but also encouraged the creative thinkers to work longer at the subject. It was however not clear whether the quality of the creative responses was improved as well. The development of computer programs that simulate artistic creativity by composing and drawing (e.g. Boden 1992; Holmes 1997) falls outside the scope of this thesis.

Other tools

Tools for problem analysis and decision-making (such as Kepner & Tregoe 1981) fall outside the scope of this study as they are classified as analytical problem-solving or problem definition techniques. It is of course possible that creative ideas may be triggered during their application. Initiatives such as suggestion schemes, creativity workshops or tapping ideas from customers, competitors or other industries, also fall outside the scope of the thesis.

1.5.4 Invention heuristics

Invention heuristics are a group of methods based on the experience, best practices and rules of thumb that have been acquired, normally in the technological and engineering disciplines, over several years. Heuristics can be defined as:

"*... criteria, methods or principles for deciding which, among several alternative courses of action, promises to be the most effective in order to achieve some goal. They represent compromises between two requirements: the need to make such criteria simple and, at the same time, the desire to see them discriminate correctly between good and bad choices.*"
(Pearl, J. quoted in Savransky 2000: 25).

One of the most prominent in this regard is the TRIZ (pronounced 'trees') methodology in which inventive principles embedded in a large body of patents have been generalised to guide inventors and problem solvers in potentially useful directions. The methodology was developed by Genrich Altshuller (1986) and others between the late 1940's and 1980's and is the Russian acronym for what can be translated as 'the theory of inventive problem solving'. It consists of a range of tools and heuristics based on the notion that most problems that engineers and technologists face contain key elements that have already been solved in other applications (Altshuller 1986; Tate & Domb 1997; Mann 2002). By generalising these solutions, the same methods of problem solving can be applied in a range of areas.

Altshuller, a mechanical engineer, when working in the patent department of the then Soviet navy, searched for a systematic procedure for guiding inventors to promising areas. From an analysis of the inventive principles used in more than 40 000 patents, he identified five levels of solution (Savransky 2000). These range from established solutions in the personal context, and thus no inventive component present (level 1), to the rare discovery (level 5), which for instance requires a new understanding of some natural phenomena. TRIZ sought to improve the engineers' ability to invent at levels 2 to 4. Today, the methodology is based on more than two million patents filed worldwide over many years, industries and locations (one estimate puts the effort that has gone into this amazing feat at 35 000 man-years !) By the end of the 1980's, TRIZ has come to be applied to a range of non-technical problems as well, including architecture, management, education, journalism, public relations and investment.

One of the major TRIZ instruments is a technical Contradiction Matrix (CM), a tool to point inventors to principles that may assist in solving particular types of problem. The CM was the first original TRIZ instrument proposed by Altshuller for general technical systems that can be in conflict (i.e. have technical or physical contradictions). A contradiction arises when the desired improvement of one parameter (e.g. strength) is countered by the simultaneous deterioration of another (e.g. size or thickness, and therefore weight). In the analysis of patents, Altshuller's group identified 40 inventive *principles* (**Table 1.2**) that may be used in different ways to address a range of 39 engineering *parameters* (**Table 1.3**). By the mid-60's, 400 000 patents have been analysed, of which 82 000 (i.e. 21 percent) passed their criteria for creative/inventive solutions to problems. The original contradiction matrix had 32 principles; the list contracted and expanded as more patents were examined, and stabilised at 40 in 1985. Some of the principles are dual or can be inverted, or are complementary in space and time. Continuous research into new principles has added six additional principles to Altshuller's original list (Savransky 2000: 220).

Table 1.2 Altshuller's list of 40 Inventive Principles.

1. Segmentation
A) Divide an object into independent parts.
B) Make an object modular or easy to disassemble.
C) Increase the degree of fragmentation or segmentation.

2. Taking out
A) Separate an interfering part or property from an object, or single out the necessary part.

3. Local quality
A) Change an object's structure or external environment from uniform to non-uniform.
B) Make each part of an object function in conditions most suitable for its operation.
C) Make each part of an object fulfill a different and useful function.

4. Asymmetry
A) Change the shape from symmetrical to asymmetrical.
B) If already asymmetrical, increase its degree of asymmetry.

5. Merging
A) Bring closer together identical or similar objects, assemble similar parts to perform parallel operations.
B) Make operations parallel, bring them together in time.

6. Universality
A) Make part or object perform multiple functions, eliminate the need for other parts.

7. Nested doll
A) Place one object inside the other.
B) Make one pass through a cavity in the other (telescopic effect)

8. Anti-weight
A) To counter the weight of an object, merge it with others that provide lift.
B) To compensate for the weight of an object, make it interact with the environment to provide buoyancy etc.

9. Preliminary anti-action

A) If an action has both harmful and useful effects, replace it with anti-actions to control harmful effects.

B) Create actions or stresses beforehand in an object that will oppose known undesirable actions or stresses later on.

10. Preliminary action

A) Perform, before it is needed, the required change of an object, partially or fully.

B) Pre-arrange objects that that they come into action from the most convenient place and not losing time for their delivery.

11. Beforehand cushioning

A) Prepare emergency means beforehand to compensate for the relatively low reliability of an object.

12. Equipotentiality

A) In a potential field, limit position changes.

13. 'The other way round'

A) Invert the action used to solve the problem.

B) Instead of the action dictated by requirements, implement the opposite action.

C) Make movable parts (or the external environment) fixed, and fixed parts or objects movable.

D) Turn the process or object 'upside down'.

14. Spheriodality

A) Instead of rectilinear parts, surfaces or forms, use curvilinear ones.

B) Use rollers, balls, spirals and domes.

C) Go from linear to rotary motion, use centrifugal forces.

15. Dynamics

A) Allow or design characteristics of object, or environment, or process to change to be optimal or find optimal operating condition.

B) Divide an object into parts capable of movement relative to each other.

C) If object or process is rigid, make it movable or adaptive.

16. Partial, satiated or excessive action

A) If 100% of object is hard to achieve using a given solution method, use slightly less or slightly more of the same method.

17. Another dimension

A) Move an object in two or three-dimensional space.

B) Use a multi-storey arrangement rather than single-storey.

C) Tilt or re-orientate the object, lay it on its side.

D) Use another side of a given area.

18. Mechanical vibration
A) Cause an object to oscillate or vibrate.
B) If oscillation exists, increase its frequency or use its resonant frequency.
C) Use piezoeletric vibrators instead of mechanical ones.

19. Periodic action
A) Instead of continuous action, use pulses or periodic actions.
B) If the action is already periodic, change the magnitude or frequency of periodic actions.

20. Continuity of useful action
A) Carry on work continuously, make all parts work at full load, all the time.
B) Eliminate idle or intermittent actions or work.

21. Skipping
A) Conduct a process, or certain stages (e.g. harmful or hazardous operations) at high speed.

22. 'Blessing in disguise'
A) Use harmful factors (harmful effects of the environment or surroundings) to achieve a positive effect.
B) Eliminate primary harmful action by adding to another harmful action to resolve the problem.
C) Amplify a harmful factor to such an extent that it is no longer harmful.

23. Feedback
A) Introduce feedback to improve a process or action.
B) If feedback is already used, change its magnitude or influence in accordance with operating conditions.

24. Intermediary
A) Use an intermediary carrier article or process.
B) Merge one object temporarily with another (which can easily be removed).

25. Self-service
A) Make an object serve or organize itself by performing auxiliary helpful functions.
B) Make object perform supplementary or repair operations.
C) Use waste resources, energy or substances.

26. Copying
A) Instead of an unavailable, expensive, fragile object, use simpler and inexpensive copies.
B) Replace an object or process with optical copies.
C) If visible copies are used, move to IR or UV copies.

27. Cheap short-living objects
A) Replace an expensive object with a multiple of inexpensive objects, compromising certain qualities (e.g. service life).

28. Mechanical substitution
A) Replace a mechanical means with a sensory (optical, acoustic, taste or smell) means.
B) Use electric, magnetic and electromagnetic fields to interact with the object.
C) Change from static to movable fields.
D) Use fields in conjunction with field-activated (e.g. ferromagnetic) particles.

29. Pneumatics and hydraulics
A) Use gas and liquid parts of an object instead of solid parts.
B) Use Archimedes forces to reduce the weight of an object.
C) Use negative or atmospheric pressure.
D) A spume or foam can be used as a combination of liquid and gas properties.

30. Flexible shells and thin films
A) Use flexible shells and thin films instead of 3-D structures.
B) Isolate the object from the external environment using flexible shells and thin films.

31. Porous materials
A) Make an object porous or add porous elements (inserts etc).
B) If object is already porous, use the pores to introduce a useful substance or function.

32. Colour changes
A) Change the colour of an object or its external environment.
B) Change the transparency of an object or its environment.
C) In order to observe things that are difficult to see, use coloured additives, or luminescent tracers.

33. Homogeneity
A) Make objects interact with a given object of the same material (or identical properties).

34. Discarding and recovering
A) Make portions of an object that have fulfilled their functions go away (discard, dissolve, evaporate etc.)
B) Conversely, restore consumable parts of an object directly in operation.

35. Parameter changes
A) Change an object's physical state (e.g. to a gas, liquid or solid).
B) Change the concentration or consistency.
C) Change the degree of flexibility.
D) Change the temperature, pressure etc.

36. Phase transitions
A) Use phenomena that occur during phase transitions (e.g. volume changes).

37. Thermal expansion
A) Use thermal expansion (or contraction) of materials.
B) If thermal expansion is used, use multiple materials with different coefficients of thermal expansion.

38. Enriched atmosphere
A) Replace common air with oxygen-enriched air.
B) Replace enriched air with pure oxygen.

39. Inert atmosphere
A) Replace a normal environment with an inert one.
B) Add neutral parts, or inert additives, to an object.

40. Composite materials
A) Change from uniform to composite (multiple) materials.

Source: Savransky (2000)

Table 1.3 The 39 Engineering Parameters of TRIZ.

1. Weight of moving object	21. Power
2. Weight of binding object	22. Waste of energy
3. Length of moving object	23. Waste of substance
4. Length of binding object	24. Loss of information
5. Area of moving object	25. Waste of time
6. Area of binding object	26. Amount of substance
7. Volume of moving object	27. Reliability
8. Volume of binding object	28. Accuracy of measurement
9. Speed	29. Accuracy of manufacturing
10. Force	30. Harmful factors acting on object
11. Tension, pressure	31. Harmful side effects
12. Shape	32. Manufacturability
13. Stability of object	33. Convenience of use
14. Strength	34. Repairability
15. Durability of moving object	35. Adaptability
16. Durability of binding object	36. Complexity of system
17. Temperature	37. Complexity of control
18. Brightness	38. Level of automation
19. Energy spent by moving object	39. Productivity
20. Energy spent by binding object	-

Source: Savransky (2000)

Definitions of the 39 engineering parameters are presented in **Appendix 1-3**.

The rows of the CM (refer to **Figure 1.7**) represent the parameters to be improved, whilst the columns contain the parameters that can be affected adversely and/or degraded as a result of improving the particular parameter. The numbers within the cell at the intersection of the row and column are the inventive principles (IPs) that might resolve the technical contradiction. The principles are represented in the cell in the order of the frequency with which they have been identified in high-level patents. The original (classic) version of the CM contained up to four IPs in each cell; later versions contain up to six. Extensive research into the use of the CM for present day innovative practices has resulted in the expansion of the classic CM from 39 to 48 parameters, and an updating of the priority sequencing of IPs for each contradiction (Mann *et al.* 2003).

1.5.5 TRIZ derivatives

Whilst being a simple and useable tool that in recent years has also attracted a fair amount of academic interest, the CM still carries some disadvantages. Three of the most prominent are discussed below.

Technical Contradiction pairs

Perhaps the most significant drawback of the CM lies in the fact that a system contradiction has to be defined. This can not only be difficult and time consuming but conceivably also lead to some frustration when a solution is not attained. For some contradictions, the CM also does not suggest any principles, and in a worst case the inventor therefore would have to try out all 40 principles.

To overcome this obstacle, Liu & Chen (2001) for instance developed a 'contradictionless matrix' (CLM) which describes, for each of the 39 engineering parameters, the frequency with which an inventive principle appears in the CM. Instead of the deteriorating parameter, the inventor now focuses on the frequency with which a principle is used.

Figure 1.7 The TRIZ Contradiction Matrix (CM).

GSA-1969	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1			15.8. 29.34		29.17. 38.34		29.2. 40.28		2.8. 15.38	8.10. 18.37	10.36. 37.40	10.14. 35.40	1.35. 19.39	28.27. 18.40	5.34. 31.35		6.29. 4.38	19.1. 32	35.12. 34.31	
2				10.1. 29.35		35.30. 13.2		5.35. 14.2		8.10. 19.35	13.29. 10.18	13.10. 29.14	26.39. 1.40	28.2. 10.27		2.27. 19.6	28.19. 32.22	35.19. 32		18.19. 28.1
3	15.8. 29.34				15.17. 4		7.17. 4.35		13.4. 8	17.10. 4	1.8. 35	1.8. 10.29	1.8. 15.34	8.35. 29.34	19		10.15. 19	32	8.35. 24	
4		35.28. 40.29				17.7. 10.40		35.8. 2.14		28.1	1.14. 35	13.14. 15.7	39.37. 35	15.14. 28.26		1.40. 35	3.35. 38.18	3.25		
5	2.17. 29.4		14.15. 18.4				7.14. 17.4		29.30. 4.34	19.30. 35.2	10.15. 36.28	5.34. 29.4	11.2. 13.39	3.15. 40.14	6.3		2.15. 16	15.32. 19.13	19.32	
6		30.2. 14.18		26.7. 9.39						1.18. 35.36	10.15. 36.37		2.38	40		2.10. 19.30	35.39. 38			
7	2.26. 29.40		1.7. 35.4		1.7. 4.17				29.4. 38.34	15.35. 36.37	6.35. 36.37	1.15. 29.4	28.10. 1.39	9.14. 15.7	6.35. 4		34.39. 10.18	10.13. 2	35	
8		35.10. 19.14	19.14	35.8. 2.14						2.18. 37	24.35	7.2. 35	34.28. 35.40	9.14. 17.15		35.34. 38	35.6. 4			
9	2.28. 13.38		13.14. 8		29.30. 34		7.29. 34			13.28. 15.19	6.18. 38.40	35.15. 18.34	28.33. 1.18	8.3. 26.14	3.19. 35.5		28.30. 36.2	10.13. 19	8.15. 35.38	
10	8.1. 37.18	18.13. 1.28	17.19. 9.36	28.1	19.10. 15	1.18. 36.37	15.9. 12.37	2.36. 18.37	13.28. 15.12		18.21. 11	10.35. 40.34	35.10. 21	35.10. 14.27	19.2		35.10. 21		19.17. 10	1.16. 36.37
11	10.36. 37.40	13.29. 10.18	35.10. 36	35.1. 14.16	10.15. 36.28	10.15. 36.37	6.35. 10	35.34	6.35. 36	36.35. 21		35.4. 15.10	35.33. 2.40	9.18. 3.40	19.3. 27		35.39. 19.2		14.24. 10.37	
12	8.10. 29.40	15.10. 26.3	29.34. 5.4	13.14. 10.7	5.34. 4.10		14.4. 15.22	7.2. 35	35.15. 34.18	35.10. 37.40	34.15. 10.14		33.1. 18.4	30.14. 10.40	14.26. 9.25		22.14. 19.32	13.15. 32	2.6. 34.14	
13	21.35. 2.39	26.39. 1.40	13.15. 1.28	37	2.11. 13	39	28.10. 19.39	34.28. 35.40	33.15. 28.18	10.35. 21.16	2.35. 40	22.1. 18.4		17.9. 15	13.27. 10.35	39.3. 35.23	35.1. 32	32.3. 27.15	13.19	27.4. 29.18
14	1.8. 40.15	40.26. 27.1	1.15. 8.35	15.14. 28.26	3.34. 40.29	9.40. 28	10.15. 14.7	9.14. 17.15	8.13. 26.14	10.18. 3.14	10.3. 18.40	10.30. 35.40	13.17. 35		27.3. 26		30.10. 40	35.19	19.35. 10	35
15	19.5. 34.31		2.19. 9		3.17. 19		10.2. 19.30		3.35. 5	19.2. 16	19.3. 27	14.26. 28.25	13.3. 35	27.3. 10			19.35. 39	2.19. 4.35	28.6. 35.18	
16		6.27. 19.16		1.40. 35				35.34. 38					39.3. 35.23				19.18. 36.40			
17	36.22. 6.38	22.35. 32	15.19. 9	15.19. 9	3.35. 39.18	35.38	34.39. 40.18	35.6. 4	2.28. 36.30	35.10. 3.21	35.39. 19.2	14.22. 19.32	1.35. 32	10.30. 22.40	19.13. 39	19.18. 36.40		32.30. 21.16	19.15. 3.17	
18	19.1. 32	2.35. 32	19.32. 16		19.32. 26		2.13. 10		10.13. 19	26.19. 6		32.30	32.3. 27	35.19	2.19. 6		32.35. 19		32.1. 19	32.35. 1.15
19	12.18. 28.31		12.28		15.19. 25		35.13. 18		8.15. 35	16.26. 21.2	23.14. 25	12.2. 29	19.13. 17.24	5.19. 9.35	28.35. 6.18		19.24. 3.14	2.15. 19		
20		19.9. 6.27								36.37			27.4. 29.18	35				19.2. 35.32		
21	8.36. 38.31	19.26. 17.27	1.10. 35.37		19.38	17.32. 13.38	35.6. 38	30.6. 25	15.35. 2	26.2. 36.35	22.10. 35	29.14. 2.40	35.32. 15.31	26.10. 28	19.35. 10.38	16	2.14. 17.25	16.6. 19	16.6. 19.37	
22	15.6. 19.28	19.6. 18.9	7.2. 6.13	6.38. 7	15.26. 17.30	17.7. 30.18	7.18. 23	7	16.35. 38	36.38			14.2. 39.6	26			19.38. 7	1.13. 32.15		
23	35.6. 23.40	35.6. 22.32	14.29. 10.39	10.28. 24	35.2. 10.31	10.18. 39.31	1.29. 30.36	3.39. 18.31	10.13. 28.38	14.15. 18.40	3.36. 37.10	29.35. 3.5	2.14. 30.40	35.28. 31.40	28.27. 3.18	27.16. 18.38	21.36. 39.31	1.6. 13	35.18. 24.5	28.27. 12.31
24	10.24. 35	10.35. 5	1.26	26	30.26	30.16		2.22	26.32						10	10		19		
25	10.20. 37.35	10.20. 26.5	15.2. 29	30.24. 14.5	26.4. 5.16	10.35. 17.4	2.5. 34.10	35.16. 32.18		10.37. 36.5	37.36. 4	4.10. 34.17	35.3. 22.5	29.3. 28.18	20.10. 28.18	28.20. 10.16	35.29. 21.18	1.19. 21.17	35.38. 19.18	1
26	35.6. 18.31	27.26. 18.35	29.14. 35.18		15.14. 29	2.18. 40.4	15.20. 29		35.29. 34.28	35.14. 3	10.36. 14.3	35.14	15.2. 17.40	14.35. 34.10	3.35. 10.40	3.35. 31	3.17. 39		34.29. 16.18	3.35. 31
27	3.8. 10.40	3.10. 8.28	15.9. 14.4	15.29. 28.11	17.10. 14.16	32.35. 40.4	3.10. 14.24	2.35. 24	21.35. 11.28	8.28. 10.3	10.24. 35.19	35.1. 16.11		11.28	2.35. 3.25	34.27. 6.40	3.35. 10	11.32. 13	21.11. 27.19	36.23
28	32.35. 26.28	28.35. 25.26	28.26. 5.16	32.28. 3.16	26.28. 32.3	26.28. 32.3	32.13. 6		28.13. 32.24	32.2	6.28. 32	6.28. 32	32.35. 13	28.6. 32	28.6. 32	10.26. 24	6.19. 28.24	6.1. 32	3.6. 32	
29	28.32. 13.18	28.35. 27.9	10.28. 29.37	2.32. 10	28.33. 29.32	2.29. 18.36	32.28. 2	25.10. 35	10.28. 32	28.19. 34.36	3.35	32.30. 40	30.18	3.27	3.27. 40		19.26	3.32	32.2	
30	22.21. 27.39	2.22. 13.24	17.1. 39.4	1.18	22.1. 33.28	27.2. 39.35	22.23. 37.35	34.39. 19.27	21.22. 35.28	13.35. 39.18	22.2. 37	22.1. 3.35	35.24. 30.18	18.35. 37.1	22.15. 33.28	17.1. 40.33	22.33. 35.2	1.19. 32.13	1.24. 6.27	10.2. 22.37
31	19.22. 15.39	35.22. 1.39	17.15. 16.22		17.2. 18.39	22.1. 40	17.2. 40	30.18. 35.4	35.28. 3.23	35.28. 1.40	2.33. 27.18	35.1	35.40. 27.39	15.35. 22.2	15.22. 33.31	21.39. 16.22	22.35. 2.24	19.24. 39.32	2.35. 6	19.22. 18
32	28.29. 15.16	1.27. 36.13	1.29. 13.17	15.17. 27	13.1. 26.12	16.4	13.29. 1.40	35	35.13. 8.1	35.12	35.19. 1.37	1.28. 13.27	11.13. 1	1.3. 10.32	27.1. 4	35.16	27.26. 18	28.24. 27.1	28.26. 27.1	1.4
33	25.2. 13.15	6.13. 1.25	1.17. 13.12		1.17. 13.16	18.16. 15.39	1.16. 35.15	4.18. 31.39	18.13. 34	28.13. 35	2.32. 12	15.34. 29.28	32.35. 30	32.40. 3.28	29.3. 8.25	1.16. 25	26327. 13	13.17. 1.24	1.13. 24	
34	2.27. 35.11	2.27. 35.11	1.28. 10.25	3.18. 31	15.32. 13	16.25	25.2. 35.11	1	34.9	1.11. 10	13	1.13. 2.4	2.35	1.11. 2.9	11.29. 28.27	1	4.10	15.1. 13	15.1. 28.16	
35	1.6. 15.8	19.15. 29.16	35.1. 29.2	1.35. 16	35.30. 29.7	15.16	15.35. 29		35.10. 14	15.17. 20	35.16	15.37. 1.8	35.30. 14	35.3. 32.6	13.1. 35	2.16	27.2. 3.35	6.22. 26.1	19.35. 29.13	
36	26.30. 34.36	2.26. 35.39	1.19. 26.24	26	14.1. 13.16	6.36	34.26. 6	1.16	34.10. 28	26.16	19.1. 35	29.13. 28.15	2.22. 17.19	2.13. 28	10.4. 28.15		2.17. 13	24.17. 13	27.2. 29.28	
37	27.26. 28.13	6.13. 28.1	16.17. 26.24	26	2.13. 18.17	2.39. 30.16	29.1. 4.16	2.18. 26.31	3.4. 16.35	36.28. 40.19	35.36. 37.32	27.13. 1.39	11.22. 39.30	27.3. 15.28	19.29. 25.39	25.34. 6.35	3.27. 35.16	2.24. 26	35.38	19.35. 16
38	28.26. 18.35	28.26. 35.10	14.13. 28.17	23	17.14. 13		35.13. 16		28.10	2.35	13.35	15.32. 1.13	18.1	25.13	6.9		26.2. 19	8.32. 19	2.32. 13	
39	35.26. 24.37	28.27. 15.3	18.4. 28.38	30.7. 14.26	10.26. 34.31	10.35. 17.7	2.6. 34.10	35.37. 10.2		28.15. 10.36	10.37. 14	14.10. 34.40	35.3. 22.39	29.28. 10.18	35.10. 2.18	20.10. 16.38	35.21. 28.10	26.17. 19.1	35.10. 38.19	1

GSA-1969	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
1	12.36. 18.31	6.2. 34.19	5.35. 3.31	10.24. 35	10.35. 20.28	3.26. 18.31	3.11. 1.27	28.27. 35.26	28.35. 26.18	22.21. 18.27	22.35. 31.39	27.28. 1.36	35.3. 2.24	2.27. 28.11	29.5. 15.8	26.30. 36.34	28.29. 26.32	26.35. 18.19	35.3. 24.37
2	15.19. 18.22	18.19. 28.15	5.8. 13.30	10.15. 35	10.20. 35.26	19.6. 18.26	10.28. 8.3	18.26. 28	10.1. 35.17	2.19. 22.37	35.22. 1.39	28.1. 9	6.13. 1.32	2.27. 28.11	19.15. 29	1.10. 26.39	25.28. 17.15	2.26. 35	1.28. 15.35
3	1.35	7.2. 35.39	4.29. 23.10	1.24	15.2. 29	29.35	10.14. 29.40	28.32. 4	10.28. 29.37	1.15. 17.24	17.15	1.29. 17	15.29. 35.4	1.28. 10	14.15. 1.16	1.19. 26.24	35.1. 26.24	17.24. 26.16	14.4. 28.29
4	12.8	6.28	10.28. 24.35	24.26	30.29. 14		15.29. 28	32.28. 3	2.32. 10	1.18		15.17. 27	2.25	3	1.35	1.26	26		30.14. 7.26
5	19.10. 32.18	15.17. 30.26	10.35. 2.39	30.26	26.4	29.30. 6.13	29.9	26.28. 32.3	2.32	22.33. 28.1	17.2. 18.39	13.1. 26.24	15.17. 1316	15.13. 10.1	15.30	14.1. 13	2.36. 26.18	14.30. 28.23	10.26. 34.2
6	17.32	17.7. 30	10.14. 18.39	30.16	10.35. 4.18	2.18. 40.4	32.35. 40.4	26.28. 32.3	2.29. 18.36	27.2. 39.35	22.1. 40	40.16	16.4	16	15.16	1.18. 36	2.35. 30.18	23	10.156. 17.7
7	35.6. 13.18	7.15. 13.16	36.39. 34.10	2.22	2.6. 34.10	29.30. 7	14.1. 40.11	25.26. 28	25.28. 2.16	22.21. 27.35	17.2. 40.1	29.1. 40	15.13. 30.12	10	15.29	26.1	29.26. 4	35.34. 16.24	10.6.2. 34
8	30.6		10.39. 35.34		35.16. 32.18	35.3	2.35. 16		35.10. 25	34.39. 19.27	30.18. 35.4	35		1		1.31	2.17. 26		35.37. 10.2
9	19.35. 38.2	14.20. 19.35	10.13. 28.38	13.26		10.19. 29.38	11.35. 27.28	28.32. 1.24	10.28. 32.25	1.28. 35.23	2.24. 32.21	35.13. 8.1	32.28. 13.12	34.2. 28.27	15.10. 26	10.28. 4.34	3.34. 27.16	10.18	
10	19.35. 18.37	14.15	8.35. 40.5		10.37. 36	14.29. 18.36	3.35. 13.21	35.10. 23.24	28.29. 37.36	1.35. 40.18	13.3. 36.24	15.37. 18.1	1.28. 3.25	15.1. 11	15.17. 18.20	26.35. 10.18	36.37. 10.19	2.35	3.28. 35.37
11	10.35. 14	2.36. 25	10.36. 37		37.36. 4	10.14. 36	10.13. 19.35	6.28. 25	3.35	22.2. 37	2.33. 27.18	1.35. 16	11	2	35	19.1. 35	2.36. 37	35.24	10.14. 35.37
12	4.6.2	14	35.29. 3.5		14.10. 34.17	36.22	10.40. 16	28.32. 1	32.30. 40	22.1. 2.35	35.1	1.32. 17.28	32.15. 26	2.13. 1	1.15. 29	16.29. 1.28	15.13. 39	15.1. 32	17.26. 34.10
13	32.35. 27.31	14.2. 39.6	2.14. 30.40		35.27	15.32. 35		13	18	35.23. 18.30	35.40. 27.39	35.19	32.35. 30	2.35. 10.16	35.30. 34.2	2.35. 22.26	35.22. 39.23	1.8. 35	23.35. 40.3
14	10.26. 35.28	35	35.28. 31.40		29.3. 28.10	29.10. 27	11.3	3.27. 16	3.27	18.35. 37.1	15.35. 22.2	11.3. 10.32	32.40. 28.2	27.11. 3	15.3. 32	2.13. 28	27.3. 15.40	15	29.35. 10.14
15	19.10. 35.38		28.27. 3.18	10	20.10. 28.18	3.35. 10.40	11.2. 13	3	3.27. 16.40	22.15. 33.28	21.39. 16.22	27.1. 4	12.27	29.10. 27	1.35. 13	10.4. 29.15	19.29. 39.35	6.10	35.17. 14.19
16	16		27.16. 18.38	10	28.20. 10.16	3.35. 31	34.27. 6.40	10.26. 24		17.1. 40.33	22	35.10	1	1	2		25.34. 6.35	1	20.10. 16.38
17	2.14. 17.25	21.17. 35.38	21.36. 29.31		35.28. 21.18	3.17. 30.39	19.35. 3.10	32.19. 24	24	22.33. 35.2	22.35. 2.24	26.27	26.27	4.10. 16	2.18. 27	2.17. 16	3.27. 35.31	23.2. 19.16	15.28. 35
18	32	19.16. 1.6	13.1	1.6	19.1. 26.17	1.19		11.15. 32	3.32	15.19	35.19. 32.39	19.35. 28.26	28.26. 19	15.17. 13.16	15.1. 19	6.32. 13	32.15	2.26. 10	2.25. 16
19	6.19. 37.18	12.22. 15.24	35.24. 18.5		35.38. 19.18	34.23. 16.18	19.21. 11.27	3.1. 32		1.35. 6.27	2.35. 6	28.26. 30	19.35	1.15. 17.28	15.17. 13.16	2.29. 27.28	35.38	32.2	12.28. 35
20			28.27. 18.31			3.35. 31	10.36. 23			10.2. 22.37	19.22. 18	1.4					19.35. 16.25		1.6
21		10.35. 38	28.27. 18.38	10.19	35.20. 10.6	4.34. 19	19.24. 26.31	32.15. 2	32.2	19.22. 31.2	2.35. 18	26.10. 34	26.35. 10	35.2. 10.34	19.17. 34	20.19. 30.34	19.35. 16	28.2. 17	28.35. 34
22	3.38		35.27. 2.37	19.10	10.18. 32.7	7.18. 25	11.10. 35	32		21.22. 35.2	21.35. 2.22		35.32. 1	2.19		7.23	35.3. 15.23	2	28.10. 29.35
23	28.27. 18.38	35.27. 2.31			15.18. 35.10	6.3. 10.24	10.29. 39.35	16.34. 31.28	35.10. 24.31	33.22. 30.10	10.1. 34.29	15.34. 33	32.28. 2.24	2.35. 34.27	15.10. 2	35.10. 28.24	35.18. 10.13	35.10. 18	28.35. 10.23
24	10.19	19.10			24.26. 28.32	24.28. 35	10.28. 23			22.10. 1	10.21. 22	32	27.22				35.33	35	13.23. 15
25	35.20. 10.6	10.5. 18.32	35.18. 10.39	24.26. 28.32		35.38. 18.16	10.30. 4	24.34. 28.32	24.26. 28.18	35.18. 34	35.22. 18.39	35.28. 34.4	4.28. 10.34	32.1. 10	35.28	6.29	18.28. 32.10	24.28. 35.30	
26	35	7.18. 25	6.3. 10.24	24.28. 35	35.38. 18316		18.3. 28.40	3.2. 28	33.30	35.33. 29.31	3.35. 40.39	29.1. 35.27	35.29. 10.25	2.32. 10.25	15.3. 29	3.13. 27.10	3.27. 29.18	8.35	13.29. 3.27
27	21.11. 26.31	10.11. 35	10.35. 29.39	10.28	10.30. 4	21.28. 40.3		32.3. 11.23	11.32. 1	27.35. 2.40	35.2. 40.26		27.17. 40	1.11	13.35. 8.24	13.35. 1	27.40. 28	11.13. 27	1.35. 29.38
28	3.6. 32	26.32. 27	10.16. 31.28		24.34. 28.32	2.6. 32	5.11. 1.23			28.24. 22.26	3.33. 39.10	6.35. 25.18	1.13. 17.34	1.32. 13.11	13.35. 2	27.35. 10.34	26.24. 32.28	28.2. 10.34	10.34. 28.32
29	32.2	13.32. 2	35.31. 10.24		32.26. 28.18	32.30	11.32. 1			26.28. 10.36	4.17. 34.26		1.32. 35.23	25.10		26.2. 18		26.28. 18.23	10.18. 32.39
30	19.22. 31.2	21.22. 35.2	33.22. 19.40	22.10. 2	35.18. 34	35.33. 29.31	27.24. 2.40	28.33. 23.26	26.28. 10.18			24.35. 2	2.25. 28.39	35.10. 2	35.11. 22.31	22.19. 29.40	22.19. 29.40	33.3. 34	22.35. 13.24
31	2.35. 18	21.35. 22.2	10.1. 34	10.21. 29	1.22	3.24. 39.1	24.2. 40.39	3.33. 26	4.17. 34.26							19.1. 31	2.21. 27.1	2	22.35. 18.39
32	27.1. 12.24	19.35	15.34. 33	32.24. 18.16	35.28. 34.4	35.23. 1.24		1.35. 12.18		24.2			2.5. 13.16	35.1. 11.9	2.13. 15	27.26. 1	6.28. 11.1	8.28. 1	35.1. 10.28
33	35.34. 2.10	2.19. 13	28.32. 2.24	4.10. 27.22	4.28. 10.34	12.35	17.27. 8.40	25.13. 2.34	1.32. 35.23	2.25. 28.39		2.5. 12		12.26. 1.32	15.34. 1.16	32.25. 12.17		1.34. 12.3	15.1. 28
34	15.10. 32.2	15.1. 32.19	2.35. 34.27		32.1. 10.25	2.28. 10.25	11.10. 1.16	10.2. 13	25.10	35. 102.16		1.35. 11.10	1.12. 26.15		7.1.4. 16	35.1. 13.11		34.35. 7.13	1.32. 10
35	19.1. 29	18.15. 1	15.10. 2.13		35.28	3.35. 15	35.13. 8.24	35.5. 1.10		35.11. 32.31		1.13. 31	15.34. 1.16	1.16. 7.4		15.29. 37.28	1	27.34. 35	35.28. 6.37
36	20.19. 30.34	10.35. 13.2	35.10. 28.29		6.29	13.3. 27.10	13.35. 1	2.26. 10.34	26.24. 32	22.19. 29.40	19.1	27.26. 1.13	27.9. 26.24	1.13	29.15. 28.37		15.10. 37.28	15.1. 24	12.17. 28
37	19.1. 16.10	35.3. 15.19	1.18. 10.24	35.33. 27.22	18.28. 32.9	3.27. 29.18	27.40. 28.8	26.24. 32.28		22.19. 29.28	2.21	5.28. 11.29	2.5	12.26	1.15	15.10. 37.28		34.21	35.18
38	28.2. 27	23.28	35.10. 18.5	35.33	24.28. 35.30	35.13	11.27. 32	28.26. 10.34	28.26. 18.23	2.33	2	1.26. 13	1.12. 34.3	1.35. 13	27.4. 1.35	15.24. 10	34.27. 25		5.12. 35.26
39	35.20. 10	28.10. 29.35	28.10. 35.23	13.15. 23		35.38	1.35. 10.38	1.10. 34.28	32.1. 18.10	22.35. 13.24	35.22. 18.39	35.28. 2.24	1.28. 7.19	1.32. 10.25	1.35. 28.37	12.17. 28.24	35.18. 27.2	5.12. 35.26	

Although simplifying the contradiction aspect, each parameter now presents a large number (up to 37) of possible principles. Trying out such a large number of possibilities can not only be cumbersome but also ineffective. A preliminary analysis by the author of contradictions in 40 mechanical engineering patents, obtained from the list of Mann (2002), has shown that only 13 of the inventive principles actually used by the inventors were to be found amongst the 5 most frequently applied for the particular parameter. This represents a 'success rate' of 13/(40x5), or only 6.5%.

Effectiveness

The CM does not always lead to a solution; recent research by Mann (2002), using a random selection of 130 mechanical engineering patents worldwide to estimate its effectiveness, has for instance put this figure for the classic matrix at 48%. This appears to be a representative average and was calculated as the number of principles suggested by the CM for the particular problem, and actually used by the inventor, expressed as a percentage of the total number of principles used by the inventor (as derived from an analysis of the patent). In other words, if for instance the CM suggested principles 4, 10, 22, 27, 33 and 35 as possible solutions for a particular problem, and the inventor used principle 10 only to reach a solution, the effectiveness would be calculated as 100%. If the inventor used, say, principle 5 as well, the effectiveness would drop to 50%.

Another factor that needs to be taken into account is how many principles the problem-solver would have needed to try out before potentially hitting on useful ones, i.e. a measure of the 'strike rate'. Whilst the more experienced users would probably have developed a feel for which principles to target first (regardless of the order recommended in the CM), inexperienced users could find the exercise quite laborious.

Number and nature of principles

A third drawback of the CM is that 40 IPs do not only constitute a fairly large number, but they do not operate on a uniform abstract level and are applied with different frequency (Horowitz & Maimon 1997). Whilst some principles are general, others are problem-specific; whilst some are used frequently, others rarely find application. These factors make training, e.g. by means of repetitive exercises, and application practically difficult.

The ASIT (Advanced Systematic Inventive Thinking) technique (Horowitz & Maimon 1997) is an example of (parsimony rule-based) attempts that have been made to reduce the number of principles, by eliminating those that are too problem-specific or not used very often, and grouping together similar principles. This resulted in the following two rules and five tools:

Rules

1. Closed World. No new type of component is introduced into the problem space.
2. Qualitative Change. Look for solutions in which the influence of the main problem factor is eliminated or even reversed.

Tools

1. Unification. Assign a new use to an existing component.
2. Multiplication. Introduce a slightly modified copy of an existing object/part into the system.
3. Division. Divide an object and reorganise its parts.
4. Break Symmetry. Turn a symmetrical situation into an asymmetrical one.
5. Object Removal. Remove a component from the system. Assign its action to another object in the close environment.

Although, in terms of numbers, these tools simplify the CM, they do not appear to have attracted significant academic interest. Furthermore, a cursory analysis by the author of a number of randomly chosen inventive ideas also did not support the claim of Horowitz (2001) that the Closed World rule was a principle 'almost all the solutions had in common (and most definitely the most elegant ones!)'.

Whilst in essence it may boil down to a matter of semantics as to what constitutes 'the problem space', this is an important aspect of problem solving and needs to be defined carefully. For instance, one of the examples (a famous TRIZ specimen) that Horowitz chooses to demonstrate the Closed World rule involves the application of a magnetic field to a bend in a plastic pipe that conveys metal shots, thus forming a protective layer of shots and reducing the wear on the bend. If the problem space was defined as 'everything inside the pipe', the rule would be supported (i.e. the metal shots themselves 'solving' the problem). However, without the introduction of a magnetic field (in the context of the pipe conveyor, an unrelated and new type of component *outside* the Closed World), the solution would not have been achieved.

The second rule, Qualitative Change, advises the problem solver to look for solutions in which the influence of the main problem factor is eliminated or reversed. This is akin to TRIZ Inventive Principle #22 (Blessing in Disguise), such as using harmful factors to achieve a positive effect, as well as Principle #13 ('The other way round'), such as reversing a process.

In summary, whilst they appear readily applicable to open-ended problems and thus sufficient to analyse ideas in hindsight, the tools are arguably too broad for focused application. Also, since they are not linked to a framework of engineering parameters, it remains to be proven that they can be applied to specific engineering problems in a systematic manner.

1.5.6 Creativity templates

Another branch of heuristics is the use of 'regularities' or 'creativity templates', in advertising but especially also in the ideation of new products (Goldenberg *et al.* 1999a,b). A creativity template is a sequence of formal operations that are applied to the problem, or 'initial structure', thereby obtaining an 'inventive structure' or novel idea. Contrary to the TRIZ approach, which suggests the use of a standard or principle to solve a well-defined problem, the template approach posits that the process should be reversed. In order to support ideation, a template can be used to channel ideation and detect problems or needs which were not yet identified (Goldenberg *et al.* 1999b).

For example, in a survey of adverts, 89% of the award-winning cases contained one of six templates (Goldenberg *et al.* 1999a), and about 25% of these used what is referred to as 'Replacement'. This template replaces a key feature of a product with something that is universally *associated* with the particular trait. For example, in a Nike shoe advert, the heel pad was replaced with an image of a firemen's safety net, the shared trait being 'something soft between you and the pavement'.

As explained more completely in Chapter 2, the focus of the research documented in this thesis was to elucidate the mechanisms underpinning a range of creative thinking techniques and the inventive principles of TRIZ. Once the analysis of these tools has been completed, a cursory analysis of other approaches that could complement the inventive mechanisms thus established, was undertaken. In the case of creativity templates, no additional mechanisms were identified; as highlighted in italics, the example quoted above for instance is based on the inventive mechanism of association. Therefore, further detailed investigation of this approach was not undertaken.