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A MODEL FOR INVENTIVE IDEATION IN PHYSICO-MECHANICAL SYSTEMS

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ABSTRACT

Motivation

Significant progress has been made over the past six decades in the development and use of techniques and tools to assist in problem solving and invention. However, obstacles still exist as far as their understanding and application are concerned. Selecting a suitable creative thinking technique(s) from the plethora of options that are available creates a dilemma to especially inexperienced users, and methods to assess the completeness of thinking also are lacking. Invention heuristics, on the other hand, offer problem solvers and inventors more guidance in dealing with particular types of problems. However, being based on past experience, they are perceived to only represent best practices and therefore less likely to lead to novel ideas. Also, they are not always efficient and can be cumbersome to use.

The purpose of the research documented in this thesis was therefore to develop a model to improve the understanding and thereby enhance the use of inventive ideation techniques. This model would incorporate the various *mechanisms* that underpin these techniques and thus integrate the areas of creative thinking and invention heuristics. Since many problems in the technology and engineering arenas involve systems and tangible objects, their properties and functions, the model would be tailored to the *attributes* of physico-mechanical systems. Whilst being predominantly theory building in nature, the work was also targeted at demonstrating the practical value of the model in a variety of areas.

Model development

The *mechanisms* of inventive ideation were identified by analysing a diverse range of creative thinking techniques, invention heuristics, as well as a number of historical examples in science

and technology. As shown by way of example in **Figure 1**, the analysis of creative thinking techniques involved a study of their structure as well as the way in which the various mechanisms are applied. Each node in the figure represents a concept that was derived by applying, to the previous node, the mechanism depicted.

From the analysis, ten generic mechanisms of inventive ideation have been identified. These mechanisms, which can also be interpreted as 'keywords' that describe the various techniques, can be grouped into five conceptually distinct 'themes', *viz* Change, Copy, Combine, Separate and Convert. They involve thinking at different metaphorical distances from the problem and thus demand different degrees of creative intuition to lead to new ideas. Furthermore, they are used with different frequency and tend to be applied preferentially to certain types of problems. For example, both Osborn's Checklist and the 40 TRIZ inventive principles make use of only five of the ten mechanisms and areas where the creative thinking could be complemented have thus been identified.

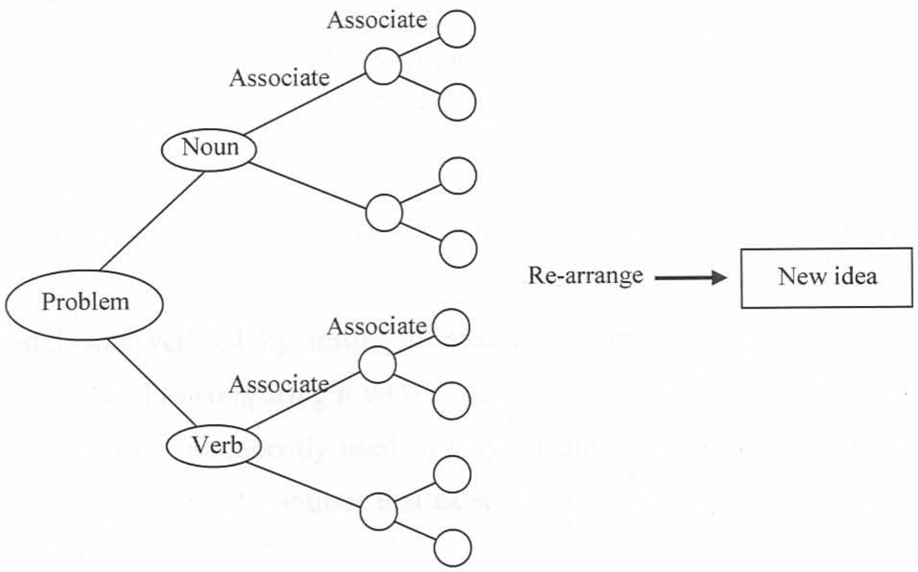

Figure 1 Analysis of the Attribute Splitting technique.

An ideation model for use in physico-mechanical contexts (**Figure 2**) was derived by integrating the generic mechanisms with a system model. The system model comprises 16 attributes that describe the physical, temporal and spatial dimensions of objects and their environments. The mechanisms have been positioned such as to reflect their respective themes (enclosed in broken lines), the metaphorical distance that they remove the thinking from the problem (represented by their distance from the centre), and their frequency of use (decreasing in a clockwise direction).

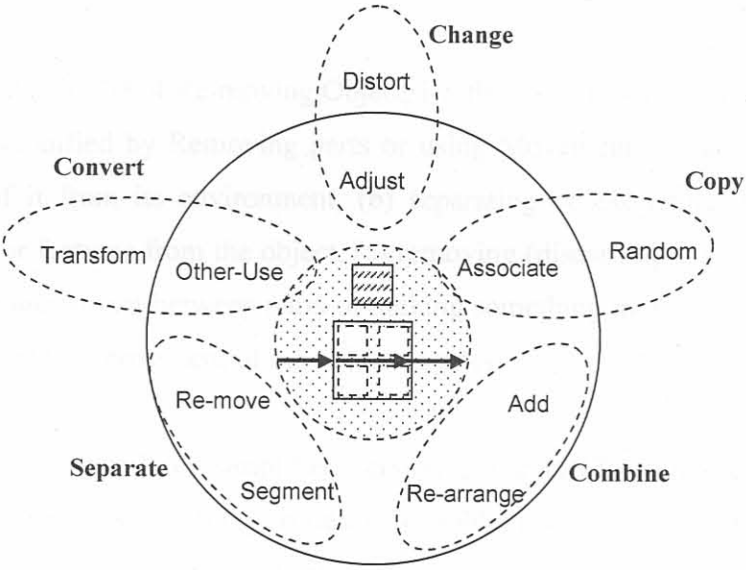

Figure 2 Model for inventive ideation, tailored to a physico-mechanical context.

The model was verified by testing it against examples sourced from the literature and elsewhere, as well as comparing it with a parsimony rule-based model derived from invention heuristics. It was subsequently used in a systematic fashion to establish, in detail, the full range of inventive ideation options that exist within the defined system and thus can be used to solve problems.

Application

In addition to providing a better understanding of the mechanisms underlying inventive ideation techniques, their use and relationships, the model enhances inventive ideation in a number of areas. This includes (1) the development of ideation strategies best suited to the skills and needs of the individual or problem solving group and the type of problem, (2) the definition of Ideation Domains (IDs), describing the full range of inventive possibilities that pertain to each inventive mechanism and system attribute, (3) a methodology to audit the ideas that have been produced during ideation sessions and thus identify areas of the problem that may yield additional ideas, and (4) an ability to create novel ideas systematically, rather than relying on 'off-the-wall' inputs such as for instance advocated by Random stimulation.

By way of example, the ID of Re-moving Object, i.e. the various ways in which an Object and its parts can be modified by Removing parts or using Movement, includes (a) removing an object or part of it from its environment, (b) separating or extracting useful, required or interfering parts or features from the object, (c) removing (discarding) used or spent parts, (d) allowing relative movement between parts or making something movable, and (e) preventing, or limiting the need for, movement of the object or parts.

The IDs were used to develop a simplified version of the TRIZ Contradiction Matrix (CM), which eliminates the need of having to define a problem in terms of system contradictions. This tool was applied to a random selection of 40 mechanical engineering patents, using in each case the four system attributes that are associated most closely with the engineering parameter that needs to be improved. An overall success rate of 79% was achieved, comparing favourably with the 54% of the classic CM under the same conditions. In the cases where the 4-attribute strategy was unsuccessful, the additional use of the Dimension and Function attributes improved the success rate significantly.

Contributions

The main contribution of this work lies in the fact that it has provided a conceptually sound framework for inventive ideation. Being based on the mechanisms that underpin a wide range of creativity techniques and invention heuristics, it has provided a unifying platform for the two areas of practice. Not only has it improved the understanding of the mechanisms of inventive ideation and their relationships, and thus could result in a more systematic approach to problem solving, but it has also been demonstrated that it can enhance inventive ideation in four key respects.

A secondary contribution of the work is the development of a consistent description of the nature of, and the relationships between, the four sources of inventive ideas, *viz* Inspiration, Experimentation, Intervention and Serendipity (**Figure 3**). As far as could be ascertained, this is the first time these have been integrated into such a defining framework. This framework has also provided an essential platform for understanding the role of 'deliberate creativity' – the conscious application of thinking techniques and tools – in inventive ideation.

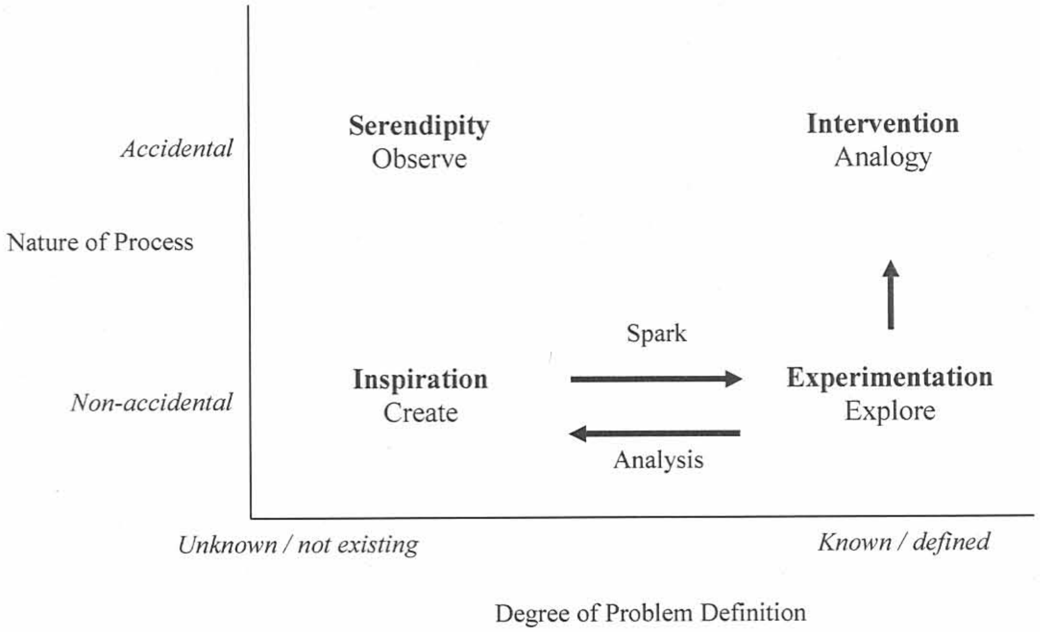

Figure 3 The four sources of inventive ideas.

Further work

The research has also highlighted a number of study areas that could further improve the model as well as the use of ideation tools and techniques. This includes (1) empirical studies focused on the application of the ideation model in a range of areas, (2) developing of system models for a range of disciplines, thus allowing the generic inventive mechanisms to be

applied more widely, (3) deeper investigation into the structures of creative thinking techniques and establishing whether there is a relationship with respect to the novelty of the ideas they produce, and (4) the further development of the simplified (contradictionless) version of the CM. Significant progress has already been made by the author on the latter, including the development of a visual tool to enhance teaching and user-friendliness.

KEYWORDS

inventive ideation, problem solving, mechanism, creative thinking, invention heuristics, TRIZ Contradiction Matrix, systems model, attributes

SYNOPSIS

Significant progress has been made over the past six decades in the development and use of techniques and tools to assist in problem solving and invention. However, several obstacles still exist as far as their understanding and application is concerned. The purpose of the research documented in this thesis was therefore to develop a model that integrates the key aspects of these tools into one unifying framework.

The *mechanisms* of inventive ideation, *viz* the ways in which the parameters of the problem can be manipulated, were identified by analysing a diverse range of creative thinking techniques, invention heuristics, and a number of historical examples in science and technology. From the analysis, ten generic mechanisms have been identified, which can be grouped into five conceptually distinct 'themes'. An ideation model for use in physico-mechanical contexts was derived by integrating the generic mechanisms with a system model. It was subsequently used in a systematic fashion to establish the full range of inventive ideation options that exist within the defined system and thus can be used to solve problems.

The main contribution of this work lies in the fact that it has provided a conceptually sound framework for inventive ideation. Not only has it improved the understanding of the mechanisms of ideation and their relationships, but it has also been demonstrated that it provides an enhanced ideation capability in a number of areas. This included the (1) development of inventive ideation strategies suited to the skills and needs of the thinker or group, (2) the use of Ideation Domains (IDs), detailing the full range of inventive options that pertain to each system attribute and mechanism, (3) a methodology to audit the ideas that have been produced by brainstorming and thus identify parts of the problem that may yield additional ideas, and (4) an ability to create novel ideas in a structured fashion.

A secondary contribution of the work is the development of a consistent description of the nature of, and the relationships between, the four sources of inventive ideas, which has provided an essential platform for better understanding the role of 'deliberate creativity' – the conscious application of thinking techniques and tools – in inventive ideation.

SAMEVATTING

Beduidende vordering is oor die afgelope ses dekades gemaak in die ontwikkeling van tegnieke wat probleemoplossing en innovasie vergemaklik. Daar is egter nog verskeie beperkinge sover dit die insig in die tegnieke en hulle toepassing aanbetref. Die doel van die navorsing in hierdie verhandeling was dus om 'n model te ontwikkel wat die belangrikste aspekte van hierdie tegnieke in 'n bruikbare konteks saamvat.

Die meganismes waardeur innoverende idees ontwikkel word, naamlik die maniere waarop die parameters van die probleem gemanipuleer kan word, is geïdentifiseer deur 'n analise van 'n diverse reeks van kreatiwiteitstegnieke, innovasie heuristieke asook geskiedkundige voorbeelde in die wetenskap en tegnologie. Die analise het aangedui dat daar tien generiese meganismes bestaan, wat in vyf konsepsueel-onderskeibare 'temas' gegroepeer kan word.

'n Model wat in fisies-meganiese kontekste gebruik kan word om innoverende idees te genereer, is ontwikkel deur die generiese meganismes met 'n sistemiese model te integreer. Dit is daaropvolgens gebruik in a sistematiese wyse om 'n gedetaileerde oorsig te ontwikkel van die volle reeks van opsies vir innoverende idees wat binne die gedefinieerde sisteem bestaan en dus gebruik kan word in probleemoplossing.

Die primêre bydrae van die navorsing is gesetel in die feit dat dit 'n konsepsueel-betroubare raamwerk vir innoverende idees daarstel. Dit verdiep nie bloot die insig in die meganismes van idee-ontwikkeling en hulle verwantskappe nie, maar demonstreer ook, in 'n aantal areas, die verhoogde innovasie moontlikhede wat dit teweegbring. Dit sluit in (1) die ontwikkeling van geskikte strategieë vir idee-generasie, (2) die gebruik van Idee Domeins (IDs) wat die innovasie opsies rondom elke eienskap van die sisteem uitlig, (3) 'n metodologie om die idees wat gedurende idee-sessies geproduseer is, te oudit en dus areas te identifiseer waar addisionele idees gevind mag word, en (4) 'n metode om innoverende idees op 'n gestruktureerde wyse te onwikkel.

'n Sekondêre bydrae van die werk was die ontwikkeling van 'n robuuste beskrywing van die eienskappe en die verwantskappe van die vier oorspronge van innoverende idees. Dit verseker 'n belangrike platform waarvolgens die rol van 'doelbewuste kreatiwiteit' - die gefokusde toepassing van tegnieke en metodes in innoverende denke - beter verstaan kan word.

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DECLARATION

I hereby declare that, unless stated otherwise, the work contained in this thesis is my own original work. It has not been, either in its entirety or in part, submitted at any institution for any academic or other qualification.

Ross.

Victor Emul Ross

September 2006

DEDICATION

To P-T and E

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I would like to acknowledge the following people for making this work a reality.

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2. De Beers Technology, for providing the opportunity to develop some of the concepts in this study.

3. Francois Grobler, for introducing me to TRIZ.

4. Indirectly, but significantly, the work of Douglas Hofstadter, Margaret Boden, Vera John-Steiner and others in the field of cognitive science and psychology has shaped my interest and insight into creativity and inventive problem solving. To them, I am much indebted.

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PREFACE

In *Variations on a Theme as the Crux of Creativity*, Douglas Hofstadter writes about the French saying '*Plus ça change, plus c'est la même chose*', which loosely translates to "The more it changes, the samer it gets." He interprets this apparently non-sensical statement to mean that, the more different manifestations one gets to observe of a phenomenon, the more deeply one gets to understand it, and therefore the more clearly one can see the 'vein of sameness' that runs through all its manifestations.

This thesis was sparked by a desire – that later became a bit of an obsession - to understand the 'veins of sameness' that run through 'inventive ideation', namely the process by which novel, potentially useful ideas are produced to solve existing problems and create new things. Having graduated as a chemical engineer, educated in logic and analysis, I soon understood that the technological research environment demanded problem solving skills that were not part of this education. This brought me in contact with creativity, and the use of 'creative thinking techniques' and other tools for invention, problem solving and producing new ideas.

As I started delving into the creativity literature, I found a myriad of techniques, in total probably around one hundred. However, only a relatively small number were encountered on a regular basis in the literature and cited by the leading practitioners in the field. On closer inspection, some techniques appeared to be very similar to others in structure and application; some authors have borrowed freely, either unknowingly or without acknowledgement, from established approaches and principles. What has resulted is a field that in terms of tangledness is beaten only by a sizeable plate of spaghetti and has done the image and application of creative thinking as much good as Mike Tyson's dentals did Evander Holyfield's ear at Madison Square Garden.

The main aim of the work documented in this thesis was therefore to untangle the many different manifestations of creative thinking techniques and other ideation tools to such an extent that they could be represented in the form of an understandable, usable framework. A study as broad as this invariably takes the researcher into other areas of interest; I have tried to incorporate salient aspects of these in the thesis in places where it could serve to provide a deeper and more complete view of this wonderfully exciting topic.

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.

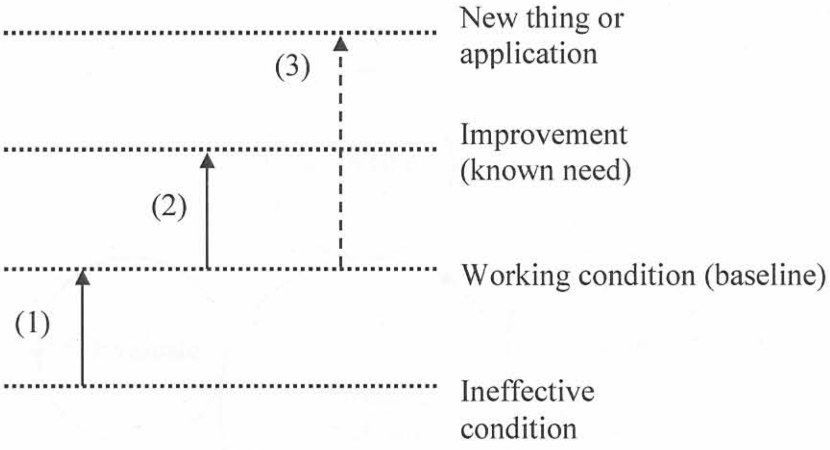

Figure 1.1 Types of problems, as defined by different desired states.

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.

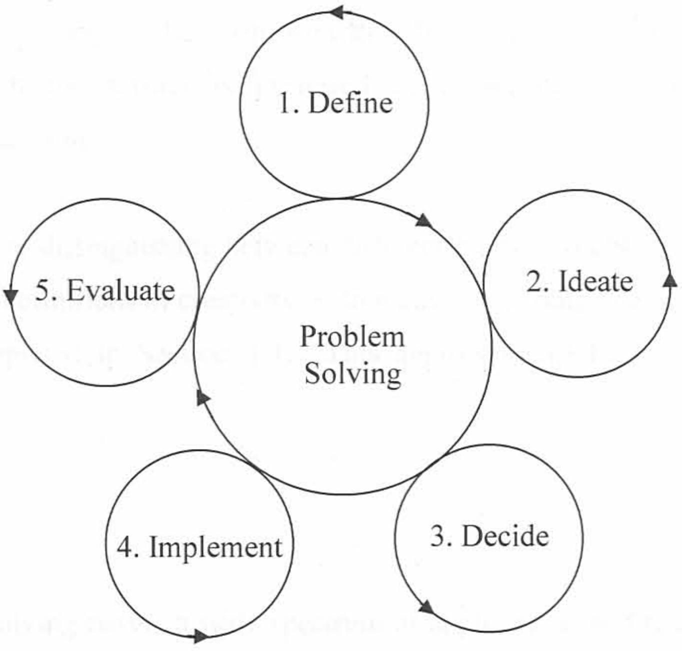

Figure 1.2 The problem solving process.

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.

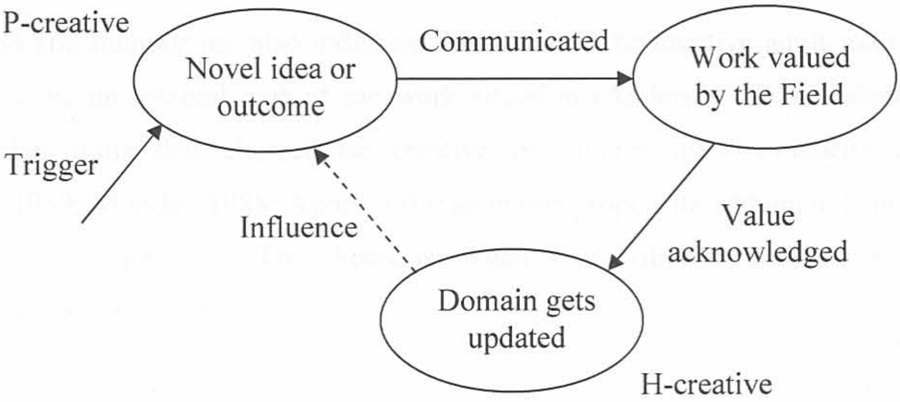

Figure 1.3 A model for creativity.

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'.*

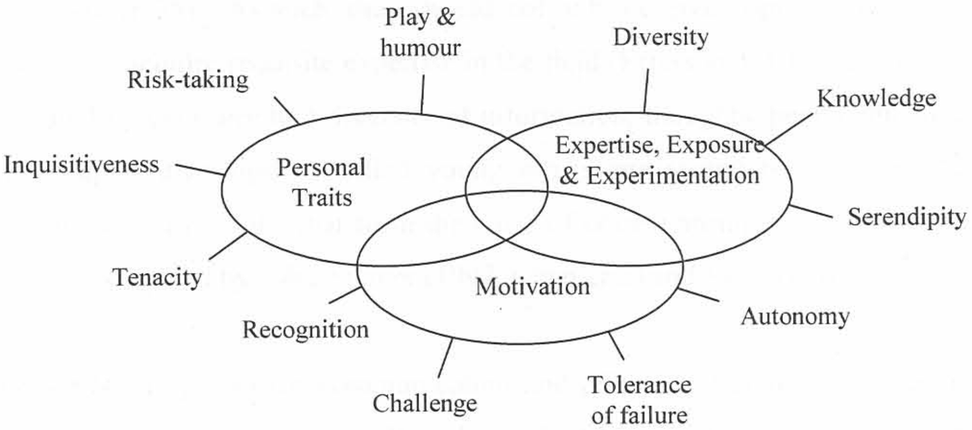

Figure 1.4 The enablers of creativity.

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.

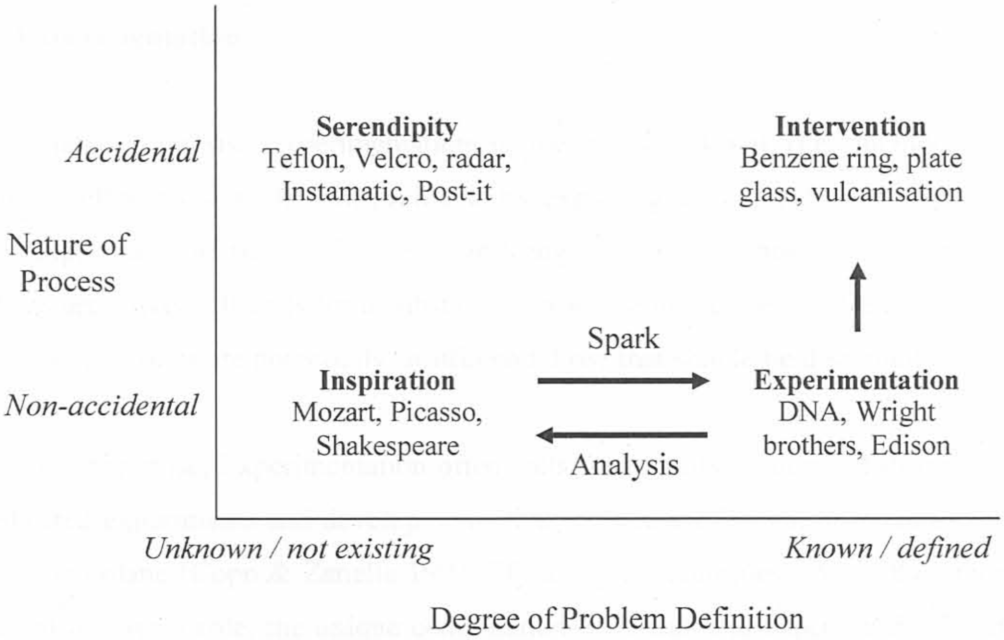

Figure 1.5 The four sources of inventive ideation.

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:

---

[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.

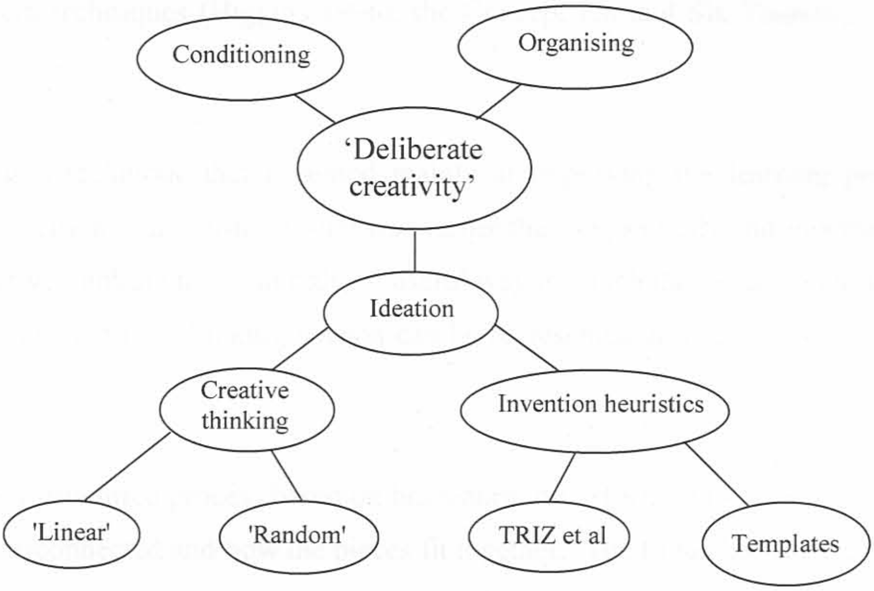

Figure 1.6 Elements of 'deliberate' creativity.

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	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
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		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				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	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	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		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		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			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	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		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		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				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	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		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		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				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	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		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	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	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. 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		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	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		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	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	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	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	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. 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		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		6. 27. 19. 16		1. 40. 35				35. 34. 38					39. 3. 35. 23				19. 18. 36. 40				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	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		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	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	. 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	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			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		19. 9. 6. 27								36. 37			27. 4. 29. 18	35				19. 2. 35. 32					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	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			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	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			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	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	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. 24. 35	10. 35. 5	1. 26	26	30. 26	30. 16		2. 22	26. 32						10	10		19			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	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	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. 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	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	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	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	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		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	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		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	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	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	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	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	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	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	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		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	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		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	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		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	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		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	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	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. 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		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. 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	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.

CHAPTER 2

PROBLEM STATEMENT AND OBJECTIVES

2.1 INTRODUCTION

Creative thinking and invention heuristics are today practised by companies and individuals across the world. Despite their apparent popularity and the proliferation of creativity consultants, there continues to be a number of obstacles as far as their understanding and application are concerned. The following sections will highlight some of these deficiencies and on the basis of these, define the objectives and the benefits to be derived from this work.

2.2 PROBLEM AREAS

2.2.1 Novelty vs Guidance

Creative thinking and invention heuristics have developed as essentially independent fields of practice and research in different parts of the world. Whilst most of the leaders in creative thinking have been working in the United States and Europe, invention heuristics such as TRIZ have been developed in the ex-Soviet Union and only until fairly recently was not really known or applied in the west. In addition, the two fields have also developed in different directions: whilst creative thinking has been targeted to a significant extent towards the pro-active exploring of new ideas in open-ended problem situations, invention heuristics, by their very nature, focused on solving defined problems in which specific outcomes are sought.

Today still, little reference is made in each as to the existence of, and advantages offered by, the other. In the case of invention heuristics, one of these advantages is for instance the fact that it is based on years of experience in solving particular types of problems, for example, as defined by contradictions. It thus offers the inventor or problem solver a fair amount of guidance in solving similar problems. However, this strength is at the same time also one of its weaknesses. It essentially describes in engineering terms only 'what has been done before, and done so most frequently'.

For a new principle to become a TRIZ heuristic and thus to be reflected in a particular cell in the contradiction matrix, it must recur in many high-level patents in a number of engineering fields. Whilst there is currently not consensus on the number of such inventions required, the lowest appears to be 10 and the highest 500, and TRIZniks (expert practitioners of the methodology) generally tend to use their own interpretation of what is sufficient and what is not (Savransky 2000: 221). Often, these 'best practices' are already implemented by leading technological companies and therefore would tend to generate solutions that they already have. These companies are thus unlikely to benefit from the potentially novel, or additional, solutions that could be created by utilising a wider range of creative options. As mentioned in Chapter 1, recent research (Mann 2002) has for instance put the overall *effectiveness* of the classic CM to be around 48%, a figure which appears to be representative of the average success rate of the matrix.

Whilst more experienced users would probably have developed, over time, a better intuition for which principles to test first (regardless of the order, i.e. frequency of use, in which they are recommended), inexperienced users could find the effort quite laborious and frustrating.

On the other side of the coin, whilst there are many creative thinking techniques in existence (also see the following Section), there appears to be no consistent structure that can point problem solvers or inventors in potentially useful directions. The lateral thinking techniques for instance request problem solvers to make off-the-wall statements 'boldly and without thinking' in order to try and deliberately provoke new ways of thinking. As shown in the following Figure, integrating the potential novelty offered by a wide range of creative thinking mechanisms with the more tangible pointers provided by invention heuristics could therefore yield significant benefits as far as inventive ideation is concerned.

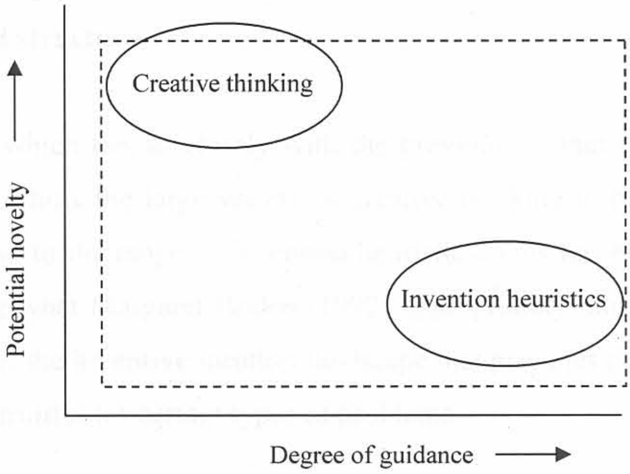

Figure 2.1 Benefits to be derived from integrating creative thinking with invention heuristics (suggested by broken line).

2.2.2 Number and diversity

Anyone researching creative thinking is left with a lasting impression of the plethora of techniques that exist. For example, in the *Whole Brain Business Book*, Herrmann (1996) categorises 77 'creative processes' on the basis of how they relate to four styles of thinking preferences. Michael Michalko (1991), in *Thinkertoys*, describes 34 'linear' (structured) and intuitive techniques, Souder & Ziegler (1977) cover 20 operational techniques, and several more may be found in *101 Creative Problem Solving Techniques : The Handbook of New Ideas for Business* (Higgins 1994).

However, this oversupply creates a dilemma for the creative problem solver as to which technique to use, and how to go about making the choice. Each technique offers a specific way of approaching the problem, a particular route to a potential solution. Therefore, unless the problem solver has an in-depth knowledge of creative thinking, he/she is most likely to be confused or overwhelmed by the sheer number and diversity of techniques. This is probably one of the key reasons for brainstorming being the preferred option for inventive ideation - people opt for the simpler and more 'general' approach to problem solving.

2.2.3 Mechanisms and structure

The third observation, which ties in closely with the previous, is that there appears to be a limited understanding of how the large variety of creative thinking techniques relate to each other, and secondly, also to the range of invention heuristics. This has been one of the major obstacles in developing what Margaret Boden (1992) appropriately alludes to as a 'signpost' model, namely, a map of the inventive ideation landscape that provides pointers to the creative paths most likely to be fruitful for certain types of problems.

This gap in a fundamental understanding of the basic principles also seems to have resulted in, amongst others, a duplication of techniques. Whilst they have the same structure and use the same mechanisms, they are often known by different names. The Filament technique (DeBono 1993), for example, extracts a number of key features of the problem and then uses association to create a number of concepts that conform to the particular criteria of each feature. The resulting concepts are then re-arranged in different combinations to create new ideas. The same approach also forms the basis of the Morphological Synthesis technique and Attribute Analogy Chains (Koberg & Bagnall 1976).

Another example of the seemingly unchecked proliferation of techniques is the fact that Word association, Random input, Synectics and Excursion, are all versions of the same creative thinking mechanism, namely creating a remote or unrelated analogy that are then explored for possible links or commonalities with the problem. In this regard, it therefore appears that there is considerable scope for simplifying and improving the usefulness of creative thinking by appropriate grouping of similar, or the same, techniques.

2.2.4 Completeness of thinking

A key aspect of creative thinking, and brainstorming in particular, is the notion of deferring judgement and building on the ideas of others, i.e. 'putting quantity before quality'. Alex Osborn's 'quantity breeds quality' is quoted as often as Linus Pauling's 'in order to have a good idea, you need many ideas' and Emile Chartier's 'nothing is as dangerous as a good idea, if it's the only one you have.'

But, just how much is many ? It is normally relatively easy to measure the ideas that have been created in a brainstorming session against the objectives, if these have been defined properly. However, very scant, if any, regard is normally given to assessing aspects of the problem space that may not yet have been explored. As such, areas in which further thinking could potentially reap rewards are seldom, if ever, identified.

2.2.5 'Logical design' vs 'Off-the-wall'

A claim of lateral thinking, in particular the random input technique, is that is 'very good for producing ideas that would never have been reached by any sort of logical design or analytical process' (De Bono 1993: 180). These ideas are claimed to be 'logical in hindsight only'. For example, in *Serious Creativity*, the technique is illustrated in developing new ideas for cigarettes. For this purpose, the word 'traffic light' was chosen as random analogy. The idea that originated from this was to print a red band close to the butt of the cigarette, indicating where it becomes (even more) dangerous to smoke further. Like the red light stops traffic, the red band would stop the smoker.

Whilst this approach appears to be novel, there is a lingering doubt as to how representative such examples are of reality. There is still a perception that, although popular and intriguing, little practical value has ever come out of deliberate idea-generating efforts. The value of 'serious creativity' is questioned in view of the 'absence of documented evidence of either spectacular successes, or spectacular failures, having been achieved this way':

One of the problems with ever-popular self-help books on how to be creative is that they all encourage 'off-the-wall' thinking (under such slogans as lateral thinking, conceptual blockbusting, getting whacked on the head) while glossing over the fact that most off-the-wall connections are of very little worth and that one could waste lifetimes just toying with ideas in that way..... Frantic striving to be original will usually get you nowhere.... The most reliable kinds of genuine insight comes from strong analogies in which one experience can be mapped onto another in a pleasing way. The tighter the fit, the deeper the insight, generally speaking.' (Hofstadter 1982).

This theme is echoed by Robinson & Stern (1997: 52):

'Although there are many creative problem-solving methods, and the lure of the perfect recipe will no doubt lead to others, the evidence is overwhelming that none of them really works. In companies, creativity does not happen magically when people are taken out of their workplace and a procedure is invoked to set up a special environment where creativity might flourish. The workplace itself is alive with the unexpected; when employees interact with it, it yields provocations no one can possibly expect..... Despite popularity, they [creativity techniques] *are not effective in taking companies where they were not already expecting to go.'*

The question here is therefore to what extent a 'logical design' – applying a systematic procedure - could produce the ideas produced by these 'off-the-wall' techniques more directly. This would make the process more attractive to engineers and technologists, who normally prefer a more structured way of considering options. A better understanding of the types of problems to which some process of logical design may be applicable will also put in perspective the value that is really to be derived from these 'off-the-wall' techniques.

2.3 OBJECTIVES AND CONTRIBUTIONS

It is the contention of this thesis that a better understanding of the mechanisms that are used for inventive ideation, as well as the way in which they are used and interact, will contribute significantly to addressing the above problem areas as well as build the theory of the field.

Such understanding could be embodied in a generic model which, when integrated with one that is specific to the type of problem being targeted, would provide a detailed map of the problem space and thus highlight the potential inventive options. In the context of this work, the model would be tailored specifically for application to physico-mechanical systems, *viz* situations in which a group of interacting, interrelated, or interdependent elements form a complex whole.

The main objective of the work was therefore stated as follows:

"To develop a generic model that improves the understanding of the mechanisms that underpin inventive ideation techniques, as well as their use and relationships. The model should be tailored for application to physico-mechanical problems and demonstrate its worth as a tool that enhances inventive ideation in such a context."

Specific benefits that stand to be realised from such a model are as follows:

2.3.1 Theory building

The major contribution of the work would be in expanding the theory of inventive ideation techniques, by elucidating the mechanisms involved in creative thinking and invention heuristics, as well as their use and relationships. Such a model would also form a basis of understanding that future studies in this area could draw from.

As far as the ability of the model to enhance inventive ideation is concerned, the following benefits are foreseen:

2.3.2 Ideation Strategies

By highlighting the application of different mechanisms, the model would enable the problem solver or group to select a suitable range of mechanisms to suit particular types of problem. For example, engineers may opt for the more 'incremental' or most frequently used mechanisms, interspersed with one 'intuitive' mechanism where relevant. Furthermore, on the basis of successful strategies, a portfolio of preferred approaches could feasibly be developed.

2.3.3 Ideation Domains

The model would provide a detailed view of Ideation Domains (IDs), i.e. the various ways in which the attributes of a physico-mechanical system could be manipulated by the inventive mechanisms. Re-classifying the 40 IPs in terms of these IDs would therefore establish groups of IPs that could effect similar inventive outcomes, and thus alert an inventor using a particular IP to others that could be useful in the same context. By highlighting the ways in which a particular mechanism can be applied to different system attributes, the inventor focusing on a certain attribute would also be provided with potentially useful analogies derived from the others to which the same mechanism may be applicable. Most importantly, the IDs could lead to a simplified and more efficient use of the CM, as well as increasing the quantity and novelty of ideas.

2.3.4 Auditing

Since it would provide a detailed map of the various ways in which a physico-mechanical problem space could be traversed, the model could be used to audit the ideas generated during inventive ideation (brainstorming) sessions. On the basis of such an audit, areas of the problem space that have not been explored and where additional thinking could reap rewards, can be identified. The model could then be used in a systematic fashion to generate ideas in these areas.

2.3.5 Value of Random stimulation

Finally, the work would provide a better idea of the types of problem in which Random stimulation could offer real advantages over a structured, more systematic approach. This could make creative thinking more accessible to people that prefer to 'extend the known' in a systematic fashion rather than clutching at random, 'off –the-wall' type of inputs.

2.4 RESEARCH PROCESS

In order to achieve these objectives, the following research process was followed:

1. Identify the mechanisms used in inventive ideation (Chapter 3).

This was accomplished by analysing a wide and diverse range of the more popular and well-known creative thinking techniques, TRIZ invention heuristics, as well as historical examples of inventions and discoveries, shown in Figure 1.5. The range of creative thinking techniques included simple ones in which the problem space is explored incrementally via single-step manipulations, to more complex situations in which the thinking is removed from the problem space and/or various features of the problem are manipulated in parallel.

2. Construct a generic model of the mechanisms, highlighting their use and relationships (Chapter 4).

An analysis was made of the frequency with which the various mechanisms are applied to different types of problems, as well as their impact on the thinking process, e.g. how far they removed the thinking from the problem. This allowed the various mechanisms to be grouped into conceptually distinct entities or 'themes' that were represented graphically as a holistic 'map' of the inventive ideation landscape.

3. Tailor the generic model to a physico-mechanical context by integrating it with a systems model (Chapter 4).

In order to make the generic model applicable to physico-mechanical problems, i.e. that are typically encountered in engineering environments, it was integrated with a simple systems model that describes the physical, temporal and spatial aspects of objects and their environment. It was subsequently used in a systematic fashion to establish, in detail, the full range of inventive ideation options that exist within the defined system and thus can be used to solve problems.

4. Practically demonstrate the ability of the integrated model to enhance inventive ideation (Chapter 5).

The practical benefit of the integrated model to enhance the inventive ideation capability in physico-mechanical environments was demonstrated by examples sourced from the inventive problem solving literature. This included: (1) the development of a simplified (contradictionless) version of the TRIZ CM, (2) the auditing of ideas generated during brainstorming, and (3) the generation of novel ideas in a systematic fashion.

CHAPTER 3

ANALYSIS

The focus of this chapter is to establish the inventive mechanisms, i.e. the different ways in which attributes or features of a problem can be manipulated, that are used during the Ideation stage of the inventive problem solving process. This was accomplished by an analysis of (1) a diverse and broad range of creative thinking techniques, (2) the inventive principles that are captured in the TRIZ invention heuristics and (3) a number of historical examples from three sources of inventive ideation, *viz* Experimentation, Serendipity and Intervention.

3.1 CREATIVE THINKING TECHNIQUES

Table 3.1 shows, in alphabetical order, the range of techniques that were included in the analysis. The term 'technique' is used here in its broadest sense, as in several cases it consists of only one step at a time (e.g. Osborn's checklist). In other cases, techniques involve a number of steps, used for instance in parallel, e.g. Morphological Synthesis and Synectics.

A number of considerations dictated the selection of the techniques:

1) In order to make the model of inventive ideation widely applicable, the techniques have been chosen to be as representative as possible of the wide spectrum of applications and thinking strategies encountered in the literature. They ranged from the relatively simple techniques in which the thinking is constrained to the problem space and in which single-step, incremental manipulations are made sequentially, to the more complex cases in which the thinking is deliberately removed as far as possible from the problem space or where a number of attributes are manipulated in parallel. In the techniques that constrain the thinking to the

problem space, the merit or value of a manipulation is mostly immediately evident (*Would round tables be better than square ones ?*). However, in the cases where the thinking is removed from the immediate problem space by deliberate provocation (*What if cars did not have steering wheels ?*) and random or remote analogies (Random Stimulation and Synectics being good examples), creative intuition and flexibility of thinking are required to create ideas.

Table 3.1 List of techniques that were analysed.

No.	Technique	References 1)
	Analogies	
1	Personal	Michalko, 1991; Nolan, 1987
2	Direct	
3	Symbolic	
4	Attribute analogy chains	Koberg & Bagnall, 1976
5	Attribute listing	Koberg & Bagnall, 1976; Souder & Ziegler, 1977
6	Attribute splitting (Fractionation)	Michalko, 1991
7	Brainstorming	Nolan, 1987; Michalko, 1991
8	Excursion technique	Higgins, 1996; Nolan, 1987
9	Forced connections / relationships	Michalko, 1991; Souder & Ziegler, 1977
10	Free (word) association	Nolan, 1987; Souder & Ziegler, 1977
	Lateral thinking:	
11	Reversal	De Bono, 1993
12	Elimination	
13	Exaggerate	
14	Filament technique	
15	Stratals	
16	Matrix method	Michalko, 1991
17	Morphological synthesis / analysis	Souder & Ziegler, 1977; Higgins, 1996; Cox, 1995
	Osborn's checklist / SCAMPER:	
18	Substitute	Osborn, 1979; Michalko, 1991; Higgins, 1994
19	Combine	
20	Adapt	
21	Modify / magnify	
22	Put to Other Use	
23	Eliminate / minify	
24	Reverse / re-arrange	
25	Random stimulation	Michalko, 1991; DeBono, 1993
26	Synectics	Nolan, 1987; Twiss, 1986
27	TRIZ 40 Inventive Principles	Altshuller, 1986; Tate & Domb, 1997; Savransky, 2000

1) The references listed here were chosen on the basis that they provide informative descriptions and examples of the particular technique(s). It does not imply that the author(s) necessarily endorses it or supports its use.

2) A second consideration was that the techniques capture an as wide as possible range of inventive mechanisms, i.e. systematic ways in which the problem attributes can be

manipulated. Of secondary importance was the structure of the technique or the process that is being followed. For instance, techniques such as Storyboarding, the Lotus Blossom (Higgins 1994: 373 and 378) and the Nominal Group Technique (NGT) all use *brainstorming* as the method to generate new ideas, and were thus excluded from the analysis since the same inventive mechanisms are used (brainstorming already being one of the selected techniques).

3) Also playing a role was the consideration that the techniques could be used easily by creative thinking groups and individuals alike, and in a 'manual' format, i.e. not necessarily computerised or for instance requiring extensive facilitation by a professional. Whilst the focus was on techniques that could be applied to 'hardware' type of problems, it was found that the same mechanisms also underpin the 'aesthetic' creativity associated with the arts and the novelty normally associated with advertising.

4) As stated in Chapter 1, the conditioning and organising methods were excluded from the scope of this work as they do not involve the systematic use of inventive mechanisms (as defined within the context of this work).

3.1.1 Classification

In order to ensure a sample of techniques that were as representative as possible of the spectrum of applications and thinking strategies encountered in the literature, they have been categorised on the basis of the following related parameters, *viz*:

1. The **metaphorical distance** that they take the thinker away from the problem, and hence the degree of creative intuition that is required to create an idea.

A technique such as Attribute Listing for instance tweaks the parameters of the problem within the problem space and the realms of reality. Thus, their potential value or relevance to the problem is immediately obvious and directly assessable. On the other hand, Random stimulation creates analogies that fall outside the problem space and are metaphorically as far removed as possible from the problem. In such a case, a more 'winding' route that opens up more options is followed to a solution. It is often assumed that a greater metaphorical distance could result in ideas with greater novelty, although no evidence could be found where this has been proven conclusively.

2. The **number of steps** involved in creating the idea, and whether they occur **in parallel** or **in sequence**. This excludes the final step of judgement or assessment, qualitatively or quantitatively, of the idea.

In the context of this work, a technique using deliberate provocation is for instance regarded as a multi-step process. Even though the provocation is made in one step, subsequent mental 'movement' is required to move from this mental 'stepping stone' to a new idea. Different possibilities have to be tried out, some parameters have to be adjusted, others have to be challenged, etc.

On the basis of these parameters, the creative thinking techniques have been categorised into three groups:

Group A

These 'play-it-safe' techniques typically involve the incremental tweaking of one parameter of the problem at a time. This is done mostly within a range that promises value and/or where the value can be assessed more or less directly, e.g. changing the shape of a table from square to round to triangular.

Group B

The major feature that distinguishes these techniques from those in Group A lies in the type of manipulation made. This is mostly in the form of analogies or associations, thus taking the thinker further away from the immediate details of the problem. Some techniques also involve the manipulation of more than one attribute at a time, and the resulting concepts therefore also need to be re-arranged in order to converge to an idea. Thus, it requires more intuitive skills and experience from the problem solver.

Group C

The Group C techniques re-organise information in ways that help the problem solver break away from normally accepted or reasonable perspectives on the problem. This is often done by generating remote or random analogies that serve as stepping stones, also known as 'intermediate impossibles' or 'random juxtapositions' (e.g. in Synectics (Nolan 1987) or the deliberate use of provocation to provide new angles, e.g. lateral thinking). The latter is normally followed by some form of 'movement' (De Bono 1993), such as for instance:

(a) extracting the key principle suggested by the provocation,
(b) focusing on the differences between the normal and distorted situations,
(c) looking for ideas by visualising the distortion being implemented in a 'moment-to-moment' fashion,
(d) establishing the circumstances under which the provocation could be made to work, and
(e) identifying any direct value offered by the provocation.

The degree of provocation also depends on the way or the context in which a technique is applied. Most notable in this regard is the technique of Reversal, which for instance is included in Table 3.1 in Group A (Osborn's checklist) as well as Group C (Lateral thinking). The reason for this distinction is that, in the former case, the technique is mainly used to explore possibilities in solving a problem (re-actively), whilst in the latter it is a means of deliberate provocation to create new ideas (pro-actively).

As shown in **Table 3.2**, the sample of techniques were evenly spread between the three groups, *viz* Group A (10), Group B (11) and Group C (11). The suite of Analogies and Brainstorming have been included in more than one group, since they typically involve thinking at different distances from the problem area. Whilst the Personal and Symbolic analogies involve mostly Group C thinking because of the forced remoteness of the analogy, in Direct analogy the link between the problem and the analogy is clearer (as a result of the particular problem attribute being targeted) and therefore the thinking happens mainly in Group B. Although a free flow of radical ideas is encouraged during brainstorming, peer pressure and the absence of a structured development of remote analogies (such as for instance in Synectics) cause the thinking to happen predominantly in Groups A and B. However, brainstorming sessions also often contain elements of radical provocation - typically reversal, elimination and exaggeration - and for this reason it also includes Group C thinking.

Table 3.2 Classification of techniques.

No.	Technique	Group	No.	Technique	Group
	Analogies				
1	Personal	B / C	15	Stratals	B
2	Direct	B / C	16	Matrix method	B
3	Symbolic	B / C	17	Morphological synthesis	B
4	Attribute analogy chains	B		Osborn's checklist (SCAMPER):	
5	Attribute listing	A	18	Substitute	A
6	Attribute splitting (Fractionation)	B	19	Combine	A
7	Brainstorming	A / B / C	20	Adapt	A
8	Excursion technique	C	21	Modify / magnify	A
9	Forced connections / relationships	B	22	Put to Other Use	A
10	Free (word) association	C	23	Eliminate / minify	A
	Lateral thinking:		24	Reverse / re-arrange	A
11	Reversal	C	25	Random stimulation	C
12	Elimination	C	26	Synectics	C
13	Exaggerate	C	27	TRIZ 40 Inventive Principles	A
14	Filament technique	B			

3.1.2 Mechanisms

Having provided a framework for classifying the various techniques, the next step in the analysis was to identify the mechanisms that are used by each, and the ways in which they are applied to create 'stepping stones' and new ideas. The way in which the various mechanisms are applied imparts to each technique a unique structure, or 'fingerprint', and understanding this was important in identifying them.

The following examples, one from each of the three groups, will serve to illustrate the approach that was followed. A more detailed description of the various mechanisms and the motivation for classifying and grouping them in certain ways is given in Section 3.4.

Group A: Attribute Listing

Attribute Listing is one of the most simple creative thinking techniques, in that only one attribute of the problem is picked at a time and explored for ways to change or improve it. These changes should not affect the original function of the object.

In the following example from Souder & Ziegler (1977), Attribute Listing is used to generate new ideas for a picture frame.

Shape	Instead of rectangular, the picture frame could be round, oval, triangular etc.
Material	Instead of being covered with glass, it could be covered with perspex, a plastic film, not covered (i.e. no material), or a drawn (plastic) shade. Instead of being wood, it could be aluminium, plastic, no frame, or built-in.
Action	Instead of hanging by wire, it could be using suction cups, hooks over a ledge, or a magnetic holder.
Dimension	Instead of two-dimensional, it could be three-dimensional.

Graphically, the Attribute Listing technique can therefore be represented as shown in **Figure 3.1**. The shaded node represents the attribute or feature that is chosen as the focus point, or beacon, for the thinking. Subsequent nodes represent the new concepts that arise as a result of applying the stated mechanism.

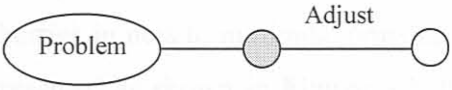

Figure 3.1 Structure of the Attribute Listing technique.

Group B: Attribute Splitting

Attribute Splitting, also known as Fractionation, is a good example of a Group B technique in that it involves the development, in parallel, of a number of problem attributes. It is applied as follows (Michalko 1991: 60):

1. The essence of the problem is stated in two words, normally in the form of a noun and a verb.
2. Each of these is split into two related ones, i.e. that are in some way *associated* with it.
3. This process is continued until there is sufficient material to work with. Normally, this does not extend over more than three or four levels.
4. Each expanded list is examined or the concepts *re-assembled* for new ideas.

The problem chosen as example was posed as follows: A farmer requires new methods to harvest cherries (Michalko 1991: 60). The two keywords for this open-ended problem were chosen as 'cherry' (noun) and 'picking' (verb).

Cherry	Delicate	Damaged
		Blemished
	Separate	Selecting
		Closeness to each other
Picking	Remove	Touch and hold
		Picking
	Transport	Ground
		Boxes

Selecting one attribute, for example 'delicate', gives the idea to create a new type of cherry with stronger skin, to better withstand handling. Re-assembling 'blemished', 'closeness' and 'transport', one might look for a way of satisfying these three attributes. One idea may be to shake the tree and catch the cherries in nets to minimise bruising. The structure of Attribute Splitting therefore can be represented as shown in **Figure 3.2,** the mechanisms used by this technique being identified as Associate and Re-arrange.

Group C: Random Stimulation

The Random Stimulation technique is found in several forms. Although being given different names, they all conform to the basic principle of providing a stepping stone(s) or random juxtaposition(s), i.e. something that, at first, seem to have nothing directly in common with the problem. Links are then sought between this unrelated concept and the problem. Some of the most common forms of Random Stimulation are:

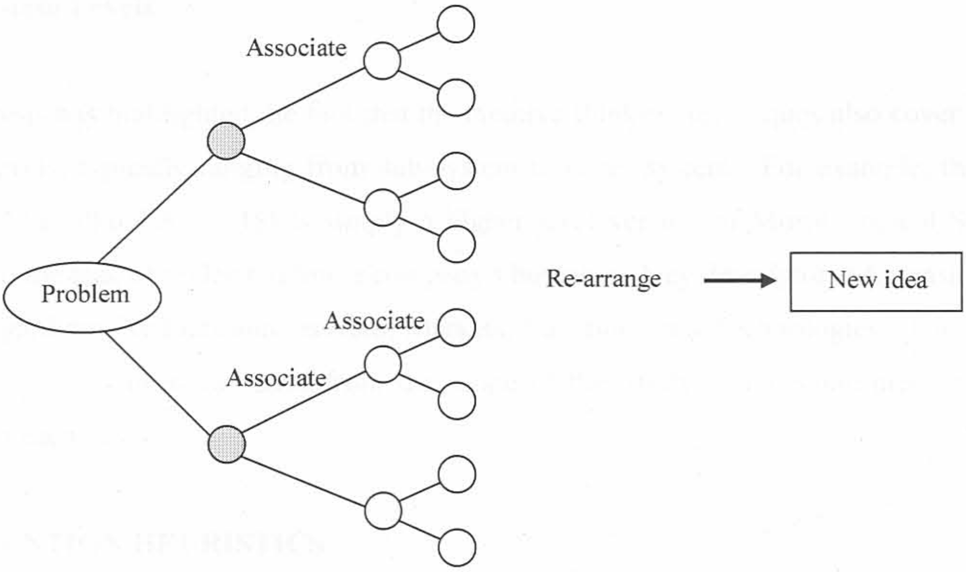

Figure 3.2 Structure of the Attribute Splitting (Fractionation) technique.

1. Words or pictures, obtained from a list or randomly selected from books, dictionaries, newspapers, encyclopaedias etc.
2. Excursion techniques - career , street or example excursion (Nolan 1989).
3. Word association – a number of successive associations are used to move away from the focus of the problem.
4. Drawing or writing sentences with random images or words as starting points.

For this example, the technique of Word Association (Nolan 1989: 46) was used. One feature of the problem is chosen and free association is used to make a number of mental leaps, normally from three to five. Links that are potentially useful are then sought between the final concept (i.e. the random analogy) and the problem.

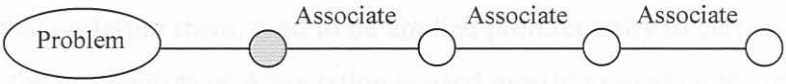

Figure 3.3 Structure of the Word Association technique.

3.1.3 System Levels

The analysis has highlighted the fact that the creative thinking techniques also cover different system levels, typically ranging from sub-system to super-system. For example, the Matrix method (Michalko 1991: 145) is simply a higher-level version of Morphological Synthesis, tailored to the task of understanding a company's business. Key descriptors (dimensions) used in this regard are Products and services, Markets, Functions and Technologies. The aspect of system levels has been excluded from the scope of this study as the same mechanisms are applied in each case.

3.2 INVENTION HEURISTICS

Invention heuristics guide problem solvers and inventors to potential solutions for particular types of problems. As such, in contrast to many of the creative thinking techniques, they always are applied to one feature of the problem at a time and therefore can be classified as Group A techniques. Since it was apparent that different mechanisms are used in each of the 40 IPs, each of the sub-principles was analysed individually. In other words, rather than for instance considering IP10 (Preliminary action) as a whole, sub-principles 10A and 10B were examined individually.

3.3 HISTORICAL EVENTS

Table 3.3 shows the historical examples sourced from the creativity and invention literature that were also analysed. Being technical or scientific in nature, these excluded the Inspiration domain but covered all other three and involved a range of inventive mechanisms.

A key aspect that emerged from the analysis was the fact that the techniques, and therefore the mechanisms that underpin them, tend to be applied preferentially to certain types of problems. For example, the mechanism of Association is used mostly to explore the physical and sensory attributes of objects, such as colour, action, function and size.

Table 3.3 Historical events in science and technology.

Example	Type 1)	Reference
Einstein: Relativity	Experimentation	Robinson & Stern (1992)
Kekule: Benzene ring	Intervention	Boden (1992)
Pilkington: Plate glass process	Intervention	Weisberg (1992)
Goodyear: Vulcanisation	Intervention	Boden (1992)
Fry: Post-It Notes	Serendipity	Weisberg (1992)
De Mestral: Velcro	Serendipity	Robinson & Stern (1997)
Lands: Instamatic camera	Serendipity	Robinson & Stern (1997)
Plunkett: Teflon	Serendipity	Robinson & Stern (1997)

1) Refer to Section 1.3 for a more detailed description.

In the analysis, note was therefore made of the different problem attributes and their application, in order to identify those that would be needed to formulate a representative systems model. More detail on this is provided in the following Chapter.

3.4 MECHANISMS

3.4.1 Function and relationships

Once the analysis of all three areas was complete, the mechanisms were grouped into conceptually distinct entities; this process resulted in a group consisting of ten mechanisms (shown in **Table 3.4**). These mechanisms, which can also be interpreted as 'keywords' that collectively encompass all the techniques, could be grouped into five 'themes' that describe the basic manner in which the attributes of the matter, time and space dimensions can be manipulated. Explanatory notes regarding the classification and grouping of the mechanisms are provided in the following Section.

Examples and typical manipulative verbs are also supplied for the reader to clearly understand the content of each theme and mechanism, and the way in which they were derived. It is of course possible that the mechanisms and their classification can be interpreted or grouped differently; for instance, the Transform mechanism could be regarded as another form of remote Association, albeit in a different domain. This is one of the inevitable problems when dealing with a topic as non-exact as inventive ideation, but in any event should not detract from the validity of the mechanisms as presented.

Table 3.5 shows how the various techniques relate to each other in terms of their key mechanisms. Rather than the subjective categorisation of techniques into the four quadrants of the Whole Brain model (Herrmann 1996), describing how various techniques might be preferred or used by people with different thinking dominances, grouping them on the basis of their dominant mechanisms highlights the types of outcome that might be expected from the various groups.

It also suggests that no single technique describes all the possible inventive approaches that can be taken on a problem, and that a more holistic understanding as presented here might therefore aid the completeness of inventive thinking. Whilst Osborn's checklist and the TRIZ invention heuristics span the broadest range of mechanisms, they both cover only half of the total possibilities. Furthermore, since they involve only sequential manipulation of individual problem attributes (i.e. both being Group A techniques), the additional ideas that may be realised by manipulation, in parallel, of more than one problem attribute (for instance by a Group B technique such as Morphological Synthesis) are not catered for explicitly.

Table 3.4 The generic mechanisms of inventive ideation.

Theme	Mechanism ('keyword')	Function	Examples	Manipulative verbs
Separate	1. Segment	1. Break something down into smaller, more flexible or independent parts or functions. 2. Make something segmentable, accentuate borders.	Mainframe computer vs PC, truck and trailer, modular furniture, Venetian blinds.	Separate, divide, segregate, dissect
	2. Re-move-ment	1. Remove: Extract useful / interfering property / part or discard / dissolve used or waste parts. 2. Move/ movement: Make something movable; allow for, or restrict, movement.	1. Play a tape of a barking dog as theft deterrent. Fibre optics producing (cold) light. Dissolving capsules. 2. Mobile banking vans. Allow parts to find their own optimum conditions.	Eliminate, subtract, take out
Change	3. Adjust	Change (increase, decrease, reverse, invert, re-orientate etc) or make adjustable, one or more attributes of the problem, satisfying a certain requirement.	In Pointilism, dots rather than linear brushstrokes are used to produce a painting. Would triangular picture frames have any value over rectangular ones ?	Adapt, reverse, submerge, alter, invert, subdue, magnify, accelerate, stretch, squeeze, freeze, rotate
	4. Distort	Deliberately provoke new directions or angles of thinking by eliminating, reversing or changing beyond normal limits, key parts, function of property of an object or process.	'Square wheels' give the idea of tyres that can change to the topography of the ground.	Provoke, reverse, exaggerate, eliminate
Copy	5. Associate	Find or develop an analogy (something that shares a specific feature(s) with the problem or meet certain criteria), copy aspects to solve or apply to the problem.	The plate glass process was born after Pilkington saw a layer of grease form on the surface of dishwashing water.	Compare, copy, borrow, analogy
	6. Random stimulation	Introduce or develop a concept totally unrelated to the problem to stimulate the thinking and provide new perspectives.	What features of an orchestra can be used to solve the problem of recruiting quality staff quickly ?	Randomise, chance, accidental

Table 3.4 (contd). The generic mechanisms of inventive ideation.

Combine	7. Re-arrange	1. Re-assemble or reconstitute parts or fragments of the problem or object in new and useful ways. 2. Pre-arrange objects or parts in the best locations or most convenient ways.	Assembling fragments of a TV screen gives the idea of a screen with multiple channels being watched simultaneously.	Re-assemble, regroup, reconfigure
	8. Add	1. Group, merge or integrate objects or features with that of others. 2. Introduce something new or multiply existing.	Boat + ski = Hydrofoil. Glass + burglarproofing = Safety glass. Combine a bookshop and coffee shop, double hull of catamaran.	Unify, integrate, interact, multiply, converge, complement, merge
Convert	9. Other - Use	1. Other Use: Use something for a purpose, or in a context, different to what it was designed or intended for. 2. Use: Exploit available or natural phenomena or energy to good effect. 3. Use Other: Use anOther (practical) format of something.	1. Dump old tyres in the ocean to form artificial reefs, use a screwdriver to open a paint tin. 2. Use phase transitions, resonant frequency or thermal conductivity. 3. Use copies instead of the real thing, use a bicycle instead of a car.	Put to Other Use
	10. Transform	Explore the problem or aspects in a different (often, dream) domain, change the medium or 'flavour' to gain fresh perspectives.	What does the colour smell like ? What clothes does the company wear ? What colour is the wind ? (Zen koan)	Transpose, symbolise, abstract, fantasy questions

Table 3.5 The mechanisms of inventive ideation – analysis of examples [1].

Theme	Mechanism	Creative thinking technique	Historical events [2]
Separate	1. Segment	-	-
	2. Re-move-ment	Osborn's checklist (eliminate)	-
Change	3. Adjust	Attribute listing Osborn's checklist (adapt, modify/magnify, reverse) Stratals Morphological synthesis Filament technique	-
	4. Distort	Lateral thinking (reverse, eliminate, exaggerate)	Lands
Copy	5. Associate	Attribute splitting Attribute analogy chains Stratals Morphological synthesis Filament technique Direct analogy	Pilkington Kekule Archimedes
	6. Random stimulation	Excursion Random stimulation Word association Forced connections Synectics	-
Combine	7. Re-arrange	Attribute analogy chains Attribute splitting Filament technique Morphological synthesis Osborn's checklist (re-arrange)	-
	8. Add	Osborn's checklist (combine) Forced connections	-
Convert	9. Other - Use	Put to Other Use Osborn's checklist (Substitute, Other Use)	Fry De Mestral Plunkett
	10. Transform	Personal analogy Symbolic analogy	Einstein

[1] The TRIZ Inventive Principles covered by each mechanism are presented in Table 4.2.

[2] Inventors as per Table 3.3.

3.4.2 Explanatory notes on Mechanisms

Separate (Segment and Re-move-ment)

The function of the Segment mechanism can be stated as a process of *physical* separation, in which the resultant parts remain in the same place. This is for instance done by increasing the modularity of an object or making it segmentable. As indicated by the hyphenated term, the second part of the theme constitutes two sub-mechanisms, namely Remove and Movement. These are both used in the sense of *spatially* separating parts or processes, either by removing them completely (eliminate), partly or temporarily from an object or their normal environment. The Movement mechanism better qualifies the process of spatial separation.

Change (Adjust and Distort)

The Change theme contains two mechanisms, the distinction between them often depending on the context or the way in which they are applied. The Adjust mechanism was named such to reflect the fact that it is used mostly to incrementally change the problem attributes, exploring the options that exist around key problem parameters. For example, the Shape of an object could be changed from round to square or rectangular, the Colour could be changed from yellow to red or blue and green. The purpose of the mechanism is to create options that can be evaluated or judged for potential benefit, and thus the thinking takes place within the immediate domain of the problem.

The Distort mechanism is a more extreme version of Adjust, and used to deliberately change parameters to outside of their normal, or 'taken-for-granted', range in order to provoke the thinking. Unlike the Adjust mechanism, the purpose is to create stepping stones or 'intermediate impossibles', i.e. the apparent outcome of the provocation must be impossible or absurd and not simply a realistic option that can be evaluated. The Distort mechanism is popular especially in lateral thinking, and although a distinction is made there between various techniques (escape, reversal, exaggeration and distort) they are all based on the same principle of upsetting the equilibrium to such an extent that the thinking is snapped out of routine ways and forced to follow new directions.

Copy (Associate and Random stimulation)

As the name suggests, the function of both mechanisms in the Copy theme is to produce alternative concepts (analogies) that have certain features that can be copied or borrowed in order to solve the problem. In most cases, these analogies are generated directly by applying Association to key features of the problem. Random (also referred to as 'remote') analogies can be viewed as a more extreme version of the direct analogies and are used in a number of techniques to provide fresh input or new perspectives on the problem. It can be generated in several ways, including for instance free association, imaginary excursions, and randomly selected words or pictures. A more detailed analysis of Random stimulation is provided in Section 4.6.

Combine (Add and Rearrange)

Rearrangement forms a key part of all the techniques in which parameters are explored in parallel, normally by either Adjustment or Association. Its main function is to form new combinations or changing the traditional relationships that exist between parts of an object, but also to stimulate new ideas by (mentally) fragmenting things and re-assembling the fragments in new ways.

The Add mechanism can be regarded as the opposite of Remove, combining existing things, introducing new things or adding features or functions. It is also used to describe actions such as converging or bringing together, merging and integrating.

Convert (Other-Use and Transform)

Like the Change and Copy themes, the Convert theme also consists of two versions. However, whereas in the former two cases the one version can be regarded as a more extreme version of the other, in this case, the one is practically-orientated whilst the other is directed at heightening sensory awareness or stimulating non-ordinary or fantasy ideas. With regard to the first, the analysis has suggested that the original Put to Other Use technique of Osborn's checklist is manifested in three different ways, *viz* (1) Other Use, (2) Use and (3) Use Other.

Although the distinction may at first appear to be of academic interest only, the examples presented in Table 3.4 illustrate that it involves different 'directions' of application. Whilst Other Use *removes* the object from its normal environment to fulfill a *different* function (e.g. old tyres being dumped in the ocean to form artificial reefs), Use Other *introduces* something new into the environment that could provide a *similar* function (e.g. a bicycle instead of a car for transport). In contrast, the Use mechanism is directed at providing *a* function by something *within* the problem environment.

As indicated in Table 3.4, the Transform mechanism is related to random or remote analogies in that it stimulates awareness of elements and features that fall outside the immediate scope of the problem. It transforms the problem or its elements to a different domain in which novel insights may be gained that can subsequently be applied to solve the problem.

Replace/ Substitute

The terms Substitute and/or Replace often occur in the creativity literature and are also used in some techniques, e.g. Osborn's Checklist (Osborn 1979). Normally this is in the context of exchanging something with another that can fulfill a function better, faster or cheaper. It is also used to convey a message in an associated or analogous way, e.g. replace the heel pad with a firemen's safety net in the Nike Air running shoe advert (Goldenberg 1999a).

In the context of this research these terms were deemed to represent the generic *outcome* of creative thinking rather than methods or mechanisms to *effect* the changes. They are conceptually not sufficiently constrained and thus were not considered as separate mechanisms. For example, the Replacement of steam by hot milk to melt out-of-specification butter patties (as used by Goldenberg *et al.* 1999b) can be described in terms of the inventive mechanisms as Using anOther thing to do the melting, or conversely, putting (the readily available) hot milk to Other Use. Similarly, but less preferable, it could be construed as Removing the steam and Adding hot milk instead. The same applies to other elements of systems or steps in a process.

The definition of mechanisms is important from the point of view of categorising them and establishing a consistent framework of understanding. Any differences in their interpretation should initiate further investigation and debate to reach consensus amongst the researchers and practitioners in the field.

CHAPTER 4

MODEL DEVELOPMENT

4.1 INTRODUCTION

Analysis of a diverse suite of creative thinking techniques, invention heuristics and a number of scientific discoveries has suggested that they can be described collectively by ten, conceptually distinct, thinking strategies or *mechanisms*, i.e. ways in which the attributes of a problem can be manipulated in order to produce novel ideas. In inventive problem solving, these mechanisms are used in various combinations and applied to different types of problems.

The purpose of this chapter is to develop a suitable framework that incorporates these mechanisms and also highlights their use and relationships. In order to tailor this model to situations that characterise many typical engineering problems, this generic model will then be integrated with a simple physico-mechanical systems model.

4.2 GENERIC MODEL FOR INVENTIVE IDEATION

The ten mechanisms identified in Chapter 3 have been integrated into a generic model of inventive ideation (**Figure 4.1**). The circular format has been chosen as basis in order to reflect three key aspects of the mechanisms and the themes to which they belong, *viz*

(a) the frequency with which they occur in invention heuristics and the creativity literature,
(b) the types of problem to which they are applied predominantly, and, in conjunction,

(c) the metaphorical distance that they take the thinking from the problem.

4.2.1 Frequency

The clockwise arrangement of the mechanisms represents a decreased frequency with which they appear in the TRIZ Inventive Principles (IPs) and have been applied in the broad range of problems analysed for this thesis. Therefore, as a general rule of thumb, the model could be applied in a systematic manner by starting off the thinking with application of the Adjust mechanism and continuing in a clockwise direction.

4.2.2 Types of problem

Spatially, the model can be divided into an upper and a lower half. The three themes in the upper half, *viz* Change, Analogy and Convert, are used mostly to explore the temporal, physical and sensory-related attributes of objects, such as colour, action, function and size. The two themes in the lower half are used predominantly for spatially-based problems that involve objects and/or their parts, groups of objects or their environment.

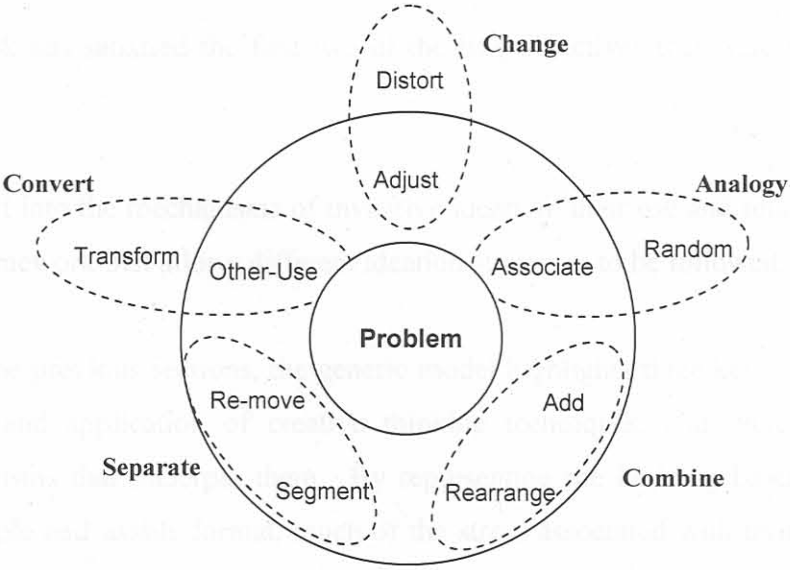

Figure 4.1 Generic model for inventive ideation.

4.2.3 Metaphorical distance

The distance from the centre of the model is representative of the metaphorical distance that the particular mechanism removes the thinking from the problem. For instance, the mechanisms positioned on the inside of the (outer) circle represent those that are associated more strongly with the so-called 'left brain' or 'engineering' approach to problem solving. These are typically mechanisms that require relatively minor amounts of flexibility and in which the value of the inventive manipulation can mostly be evaluated directly.

The three mechanisms outside the border are associated more strongly with the 'right brain' or potentially more novel type of problem solving. Contrary to the mechanisms on the inside, their purpose is not to lead directly to solutions that can be judged for value, but rather to create stepping stones and fresh perspectives that can guide the thinking in new directions. Once these new directions have been established, a substantial degree of mental flexibility and intuition is required to mould the thinking into new shapes and ideas.

4.2.4 Objectives

Thus far, the work has satisfied the first two of the five objectives that were spelled out in Chapter 2, *viz* to:

(1) provide insight into the mechanisms of inventive ideation, their use and relationships, and
(2) establish a framework that allows different ideation strategies to be followed.

As described in the previous sections, the generic model highlights three key aspects relating to the selection and application of creative thinking techniques, and therefore also the inventive mechanisms that underpin them. By representing the building blocks of creative thinking in a simple and usable format, much of the stress associated with trying to produce large quantities of new ideas is eliminated. As detailed in the following Section, positioning a graphic representation of the problem in the centre of the model would provide a detailed map, and powerful tool, to systematically explore how the various mechanisms could be applied to the problem.

Furthermore, in establishing an explicit framework for inventive ideation, the model also enables the problem solver or group to select a suitable mechanism, or range of mechanisms, that best suit their skills, needs and the particular type of problem. For example, if the problem was centred on physical attributes, the thinking might focus first on the mechanisms in the top half of the model. By the same token, if the problem could be approached linearly (for instance, trying out options sequentially), the mechanisms inside the border might be favoured. This could be interspersed with provocations and other 'intuitive' mechanisms where relevant.

The following Section is aimed at addressing Objective 3 of the research, namely to expand the generic model into one that is tailored specifically to physico-mechanical problems. This would provide the inventor with Ideation Domains, a structured approach to target specific system attributes and explore the various ways in which they could be manipulated.

4.3 SYSTEMS MODEL

In order to tailor the generic model for application to typical physico-mechanical problems, i.e. those dealing predominantly with inanimate objects, their properties and functions, a simple systems model was developed. As such, the ideation model would be applicable not only to relevant engineering problems (typically those with a mechanical or physical basis) but also to a wider range of disciplines and industries. Since it incorporates the inventive principles of TRIZ, that have already found application also in non-engineering fields, it is reasonable to assume that the ideation model should be applicable to these fields as well.

The systems model has a number of components, definitions of which are presented in **Table 4.1**. These should be interpreted in conjunction with **Figure 4.2**. The term 'object' is used here in a wide sense to include tangible things (e.g. bicycle, bank, boat) as well as for instance substances.

Table 4.1 Key descriptors of systems model.

System	Object or group of objects within an Environment
Environment	The physical, temporal, spatial and other context(s) with which an Object is associated or in which it operates, including medium, actions and resources. The Environment may vary in extent depending on the problem.
Object	A technique, its subsystem or a single element. Normally a tangible entity providing functionality derived by integration of parts or elements.
Resource	Other objects or influences, e.g. fields, energy, waste, forces
Action	Activity, motion or operation with a certain order, speed, frequency, duration, associated with the 1) preparation, 2) operation and 3) maintenance and/or repair of the Object.

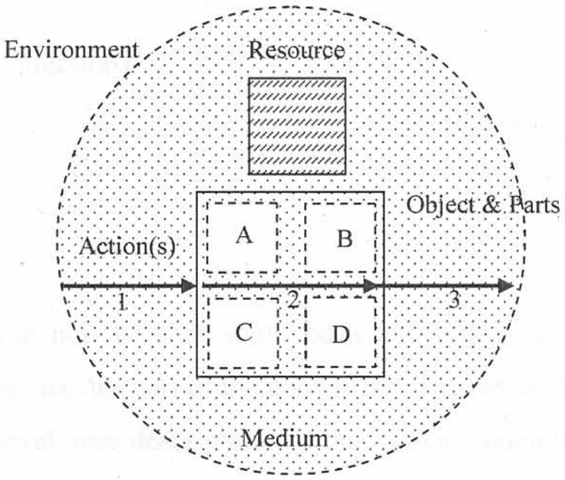

Figure 4.2 Systems model, showing object(s) and the elements of its environment.

4.3.1 Attributes

As mentioned in Section 3.4, analysis of the various creative thinking techniques and invention heuristics was accompanied by a study of the attributes to which the mechanisms were mostly being applied to. This was done in order to establish the descriptors that would adequately represent the systems model, as per the following list:

1. Object(s) (including their grouping and parts)
2. Environment (including resources and medium)
3. Function / use / usefulness
4. Quantity / magnitude
5. Material (substance)
6. Properties (physical and ambient)
7. Sensory attributes
8. Concentration
9. Curvilinearity
10. Orientation
11. Dimension
12. Symmetry
13. Actions (types and direction)
14. Order
15. Frequency
16. Duration / interval

The reader would have noticed that some basic attributes, such as shape, size (and its dimensions) and weight, are not part of the above list. The reason for this is that the attributes in the list represent level one descriptors of the system, namely, parameters that are not influenced, nor can be changed, by others at a lower level. These first-level attributes describe a range of 'meta-attributes' that include shape (which for instance could be a function of symmetry or the orientation of an object), size (which is influenced by things such as the constituent substance and its properties), and weight (which is a function of size and interaction with the environment, amongst others). By the same token, these meta-attributes describe a next level of 'meta-subjects', or broad topics, such as education, technology, transport, politics, and management.

4.4 IDEATION DOMAINS

The ideation model applicable to physico-mechanical problems, shown in **Figure 4.3**, was derived by integrating the systems model (Figure 4.2) with the generic model of inventive ideation (Figure 4.1). This was used to develop a detailed version of the ideation model, that highlights the variations that are possible within each mechanism-attribute pair. These mechanism-attribute pairs, forthwith referred to as ***Ideation Domains (IDs)***, are conceptually distinct entities that group inventive principles on the basis of the dominant inventive mechanisms and attributes that are involved. The development was done first in the form of 'first principles', i.e. each mechanism was mapped against the various attributes of the system model shown in Figure 4.2.

By way of illustration, the following two examples show how the Segment and Add mechanisms were mapped in order to establish the various ways in which they may be applied.

Segment

1. Divide an object into individual modules or parts (labeled A to D in Figure 4.2).
2. Segment an Object or process together with its Environment (e.g. so that each part can function in different, most suitable or optimised conditions).
3. Segment an Action, i.e. break a continuous action up into intermittent or periodic actions.
4. Segment Duration, e.g. instead of making something durable (and therefore, often expensive) to last for a long time, use a number of short-lived, cheap ones.

Add

1. Add together a number of (similar) objects.
2. Make a (moving) object interact with its medium (e.g. aeroplane wing).
3. Let the object interact with a resource, e.g. use a field in conjunction with field-activatable components.
4. Combine the object with others in its environment (e.g. that provide certain functions and can easily be integrated), or that are introduced from outside the environment.
5. Add an Object temporarily (e.g. to hold, carry or support something).

6. Introduce a new or different Action (e.g. to fill idle time, or to counter harmful actions).
7. Introduce an Action prior to the working environment (e.g. prepare an object for stresses or conditions it will encounter during operation.)
8. Add a Function (make something perform multiple functions, as well as any auxiliary functions).
9. Add a sensory attribute to complement or replace an existing one (e.g. sound, taste, visual).
10. Add backup (e.g. a parachute).
11. Add Action information (provide feedback or feedforward).

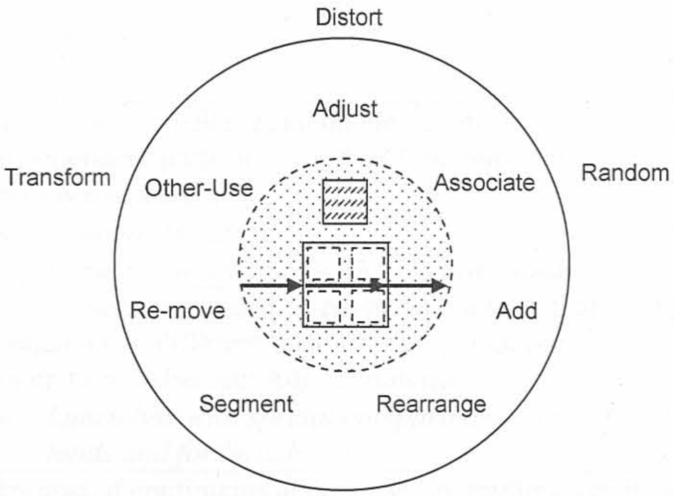

Figure 4.3 Model for inventive ideation, tailored to a physico-mechanical context.

Once the basic analysis has been done, the IPs were analysed at sub-principle level (e.g. sub-principles 10A and 10B were analysed individually rather than principle 10 being analysed as a whole) and used to populate the model.

The detailed ideation model, illustrated with examples from the creative thinking and TRIZ literature (De Bono 1993; Tate & Domb 1997) is shown in **Table 4.2**. In order to retain the conceptual identity of IDs as far as possible, several IPs have been decoupled or broken up, for example, IP17 (Another Dimension) was split between Adjust Orientation (Tilt or re-orientate object) and Adjust Dimension (Instead of a line or plane, use a plane or 3-D space). In a number of cases, a IP could be categorised into more than one ID (the same was noted with the way in which the 40 IPs are configured). However, in this first version of the model it was decided against duplication and a principle was thus represented only in the ID with which it was deemed to have the biggest commonality. For purposes of cross-reference, **Appendix 2** provides a summary of the mechanisms involved in each IP.

Table 4.2 Detailed version of the ideation model in a physico-mechanical context, grouped according to IDs.

SEGMENT		**IP** [1]
Object (& Environment)	1. Divide, or make segmentable, an object or system into independent parts or individual functions, e.g. for easy or quick removal or assembly. • *Modular furniture.* • *Replace solid shades with Venetian blinds.*	01ABC
	2. Segment object and/or environment such that each part functions in different conditions, e.g. that are most suitable for its operation. Also see: Adjust Material. • *Lunch box with special compartments for hot and cold solid foods and for liquids.*	03AB
Action	Instead of continuous action, use intermittent action, e.g. periodic or pulsating. • *Replace a continuous siren with a pulsed sound.*	19A
Duration	Replace something durable (long-lasting / expensive) with a number of short-lived (replaceable / inexpensive) ones. • *Plastic cups, disposable diapers, many kinds of medical supplies.*	27A

[1] IP(s) that matches the particular ID most closely. In the interest of brevity, no separators are used, e.g. 03AB represents principles 03A and 03B.

REMOVE / MOVEMENT		**IP**
Object	1. Allow relative *movement* between objects or parts, e.g. to find the best operational position or condition. • *Adjustable steering wheel, seat, or side mirror.*	15AB
	2. Limit (need for) *movement* (distance or position changes), e.g. pre-arrange required objects close to action. • *Kanban arrangements in a Just-in-Time factory.*	12A 10B
	3. *Remove* object partly, or completely, from environment: Make aspects of the object visible or known before (or after) its application, i.e. preview or review. Isolate an object from the medium. • *Protect parts with thin films to prevent corrosion.*	None
	4. *Remove* in space: Separate or extract a useful / functional or interfering / undesired part(s) or property from the object or its environment. • *Locate a noisy compressor outside the building where compressed air is used.* • *Use fibre optics to separate the hot light source from the location where light is needed.*	02A
	5. *Remove* in time: Discard, disperse or dissolve things that have fulfilled their functions. • *Use a dissolving capsule for medicine.*	34A
Action	Remove an action from an object or its environment: Perform, before (or after) necessary or normal, a required change of the object. • *Pre-pasted wall paper.*	10A

ADJUST		**IP**
Action	1. Change the type and direction of motion, e.g. linear to rotary or swirl motion. • *Produce linear motion of the cursor on the computer screen using a mouse or a trackball.* • *Instead of wringing clothes to remove water, spin them.*	14C
	2. Invert the action or use opposite action, make traditionally fixed (especially large or heavy) parts, static fields or processes movable or adaptive, and vice versa. • *To loosen stuck parts, cool the inner part instead of heating the outer part.* • *Mobile banks (banking vans).*	13AB 15C 28C
Sensory attributes	1. If one sensory attribute is used for a function, change to, or complement by, another. Also see: Use Other • *Use smell instead of a warning light or sound to alert people to faulty equipment.*	None
	2. Change the colour / transparency of an object, parts or its environment. • *Use safe lights in a photographic darkroom.*	32AB
Material	1. Make objects interacting with a given object (environment) of the same material, or with identical properties (e.g. polarity). • *Make a container out of the same material as its contents, e.g. to reduce chemical reactions.*	33A
	2. Use composite or smart materials instead of uniform ones. • *Composite epoxy resin/carbon fibre golf club shafts are lighter, stronger, and more flexible than metal.*	40A
Properties & state	1. Use a gas, aerosol, liquid or gel instead of a solid, change the physical aggregate state. • *Comfortable shoe sole inserts filled with gel.* • *Transport oxygen or nitrogen or petroleum gas as a liquid, instead of a gas, to reduce volume.*	29A 35A
	2. Porosity: Make a solid object porous or use porous elements, use spume or foam as a combination of liquid and gas properties. • *Drill holes in a structure to reduce the weight.*	31A 29D
	3. Change the degree of flexibility. • *Use adjustable dampers to reduce the noise of parts falling into a container by restricting the motion of the walls of the container.*	35C
	4. Ambient: Change the temperature, pressure, humidity etc. • *Lower the temperature of medical specimens to preserve them for later analysis.*	35D, 29C

Curvilinearity	Change from rectilinear to curvilinear parts, surfaces and forms, use rollers, balls, cones, spirals and domes. • *Ball point and roller point pens for smooth ink distribution.* • *Use arches and domes for strength in architecture.*	14AB
Symmetry	Change the shape or properties of an object, grouping or process from symmetrical to asymmetrical ('break symmetry'). If already asymmetrical, increase the degree of asymmetry. • *Asymmetrical mixing vessels or asymmetrical vanes in symmetrical vessels improve mixing.* • *Put a flat spot on a cylindrical shaft to attach a knob securely.*	04AB
Orientation	Tilt, rotate or re-orientate object, part or process, turn it upside down. • *Empty grain from containers (ship or railroad) by inverting them.* • *Measure the height of something by turning it on its side.*	17C, 13C
Dimension	Instead of a line or plane, use a plane or space. Use a multi-storey / layer assembly instead of single, use another side of a given area. • *Two-dimensional barcodes.* • *Use thin films or flexible shells instead of 3-dimensional structures.*	17ABD 30AB
Concentration	1. Change the concentration, composition or consistency, e.g. increase the degree of inertness, enrichment or purity. • *Treat wounds in a high pressure oxygen environment to kill anaerobic bacteria and aid healing.* • *Prevent degradation of a hot metal filament by using an argon atmosphere.*	35B, 38AB 39AB
	2. Merge or group identical or similar objects, essential resources, elements or actions in a key place and / or time. Conversely, if concentrated things cause undesirable effects, disseminate or disperse them, reduce their concentration. • *Vanes in a ventilation system.* • *Computers in a network.*	05A
	3. Place objects within each other, make one pass through a cavity in the other. Store a substance in the pores or capillaries of another. • *Measuring cups or spoons, Russian ('matroishka') dolls.* • *Store hydrogen in the pores of a palladium sponge.*	07AB 31B
Quantity / magnitude	1. Space or substance: Use slightly less or more of the same method, space or substance, if 100% is hard to achieve. • *Allow slightly more room to guide an object into a tight space, e.g. key into keyhole.*	16A
	2. Load: Make all parts perform at full load all the time. • *Flywheel (or hydraulic system) stores energy when a vehicle stops, so the motor can keep running at optimum power.*	20A

	3. Harmful effect: Amplify a harmful factor to such an extent that it is no longer harmful. • *Use a backfire to eliminate the fuel from a forest fire.*	22C
	4. Feedback: Change the magnitude, speed or influence of feedback. • *Change sensitivity of an autopilot when within 5 miles of an airport.*	23B
Frequency	1. Oscillate or vibrate object; if oscillation already exists, change the frequency. Use piezoelectric vibrators instead of mechanical ones. • *Electric carving knife with vibrating blades.* • *Distribute powder by vibration.*	18ABD
	2. If an action is already periodic, change its amplitude or frequency. • *Replace a continuous siren with sound that changes amplitude and frequency.*	19B
Order	Make objects or operations parallel, bring them together in time, perform things in a different sequence. • *Mulching lawnmower.*	05B
Duration	Conduct a process (e.g. hazardous or harmful) or stages at high speed. • *Cut plastic faster than heat can propagate in the material, to avoid deforming the shape.*	21A

DISTORT [2]		**IP**
Object (Parts)	Remove key objects or parts from the system. - *What if restaurants didn't serve food ? Or bookshops didn't stock books ?*	None
Orientation	Change the orientation of the object or key parts. - *Suppose planes landed upside down.*	None
Symmetry	Break the symmetry. - *The provocation 'Wheels are square' leads to the idea of having wheels that can adapt automatically to the topography of the terrain.*	None
Action	Remove, reverse or exaggerate key actions in normal system. - *You brush your teeth before you eat.*	None
Frequency	Increase or decrease the frequency or amplitude of actions. - *Students are examined every minute.*	None
Duration	Decrease or increase the normal duration of actions. - *A phone call always lasts only 2 seconds.*	None

[2] Whilst the Distort mechanism is, predominantly, a more 'extreme' version of Adjust, it is also related to Remove and, less often, Segment. Unlike Adjust, it is intended to provoke the thinking rather than to produce possible solutions directly. Whilst many of the IDs using Adjust may be useful for provocation, the attributes listed here normally yield particularly strong provocations.

ASSOCIATE		**IP**
Relevant system attributes	For example, Action: Utilise relationships between Action and other system attributes in things in the same or other environments. - *Cameras and guns are both aimed at targets - what features of the other can each use?*	None

RANDOM STIMULATION		**IP**
Relevant system attributes	Generate a remote analogy and force analogies and new ideas. - *What features of an aeroplane can be used to design a better stapling machine ?*	None

REARRANGE		**IP**
Object (Parts)	Re-arrange / re-position parts or concepts (physical or virtual) and their features to achieve new ideas or added functionality. • *Re-arranging 'fragments' of a TV screen gives the idea of multiple channels that can be watched simultaneously.* • *Re-arranging parts of the tail fin on an aeroplane gives the idea of drag reducers (small fins) on the tips of the wings.* • *Repositioning the eye at the tip rather than the top led Elias Howe to invent the sewing machine needle.*	None

ADD		**IP**
Function	1. Make an object or parts perform multiple functions, e.g.: Within same environment: • *Combine plate glass with burglar proofing to form safety glass.* Things that share features or attributes: • *Combining a stamp and a billboard gives the idea of putting ads on stamps or envelopes.*	03C 06A
	2. Make an object serve or organize itself by performing auxiliary helpful functions, supplementary and repair operations. • *A soda fountain pump that runs on the pressure of the carbon dioxide that is used to "fizz" the drinks. This assures that drinks will not be flat, and eliminates the need for sensors.* • *Halogen lamps regenerate the filament during use - evaporated material is redeposited.*	25AB
Object	1. Add together, use sequentially, or simultaneously, a group of uniform objects or principles instead of a single one. • *Multicylinder combustion engine.* • *Magnify the principle of a ski, thus allowing it to lift out of the water.* • *Combine a number of TV screens to form a giant screen.*	None
	2. Restore or repair (consumable) parts while in operation, or use easily replaceable parts. • *Self-sharpening lawn mower blades.*	34B

	3. Use an intermediary (temporary) carrier article or process, merge one object temporarily with another which can easily be removed, e.g. temporary insert parts or cushioning components. • *Carpenter's nailset, used between the hammer and the nail.* • *Pot holder to carry hot dishes to the table.*	24ABD
	4. When needing to merge incompatible materials or things (wrt properties, shape etc), introduce something compatible with both in between. • *Welding copper and aluminium.*	None
Action	1. External to environment: Subject something to the same action or conditions it will be experiencing during operation. Provide emergency means (backup) to compensate for the low reliability of an object. • *Pre-stress rebar before pouring concrete.* • *Back-up parachute.*	09B 11A
	2. Internal to environment: Eliminate idle time or intermittent actions, use pauses between actions to perform similar or different actions. • *Print during the return of a printer carriage, e.g. dot matrix, daisy wheel, inkjet printers.*	20B
	3. If physical actions take place close to another (either in space or time), introduce a different one inbetween. • *Computer mouse with roller wheel and clicking next to it.* • *Use different fingers to play the same key on a piano quickly after another.*	None
	4. If an action has both harmful and useful effects, add anti-actions to control harmful effects. Eliminate a harmful action by adding another harmful action. • *Buffer a solution to prevent harm from extremes of pH.* • *Add a buffering material to a corrosive solution.*	09A 22B
	5. Introduce feedback / feed forward to improve a process or action. • *Signal from gyrocompass is used to control simple aircraft autopilots.*	23A
Environment	1. Medium: Make object interact with its environment. • *Use buoyancy or Archimedes forces.* • *Hydrofoil, aeroplane wing.*	29B
	2. Resources: Merge object with others in its environment, e.g. to reduce weight. • *Use a helium balloon to support advertising signs.* • *A lift using counterweights.*	08AB

	3. Resources: Use fields (electric, magnetic, etc.) to interact with object, in conjunction with field-activated, e.g. ferromagnetic, particles. • *Heat a substance containing ferromagnetic material by using a varying magnetic field.*	28BD
Sensory attributes	Add coloured or luminescent tracers for things that are difficult to see. • *In murky liquids, add luminescent tracers.*	32C

OTHER USE / USE / USE OTHER		**IP**
Properties	**Use.** Exploit available or natural phenomena to good effect. E.g. exploit resonant frequency, those that occur during phase transitions, thermal expansion or contraction, heat capacity, thermal conductivity, sources of energy, etc. • *Heat pumps use the heat of vaporisation and heat of condensation of a closed thermodynamic cycle to do useful work.* • *Destroy kidney stones using ultrasonic resonance.*	36A 37AB 18C
Environment	**Other Use.** Resources: Use waste, useless or readily available resources to achieve a positive or desired effect or function. • *Dump old tyres in the ocean to form artificial reefs.* • *Use hot milk rather than steam to melt out-of-spec butter patties.* • *Use a screwdriver to open a tin of paint.*	22A 25C
Object	**Use Other.** Use an Other format or version of something. E.g. replace mechanical or physical means by sensory (optical, acoustic, taste or olfactory) means, replace an (unavailable, expensive or fragile) object or process with copies (optical, UV or IR). • *Use a bad smelling compound in natural gas to alert users to leakage, instead of a mechanical or electrical sensor.* • *Listen to an audio tape instead of attending a seminar.*	28A 26ABC

TRANSFORM		IP
Spatial - Temporal	For a spatial arrangement, find something with a similar structure in the temporal domain, or vice versa. • *The bricks in a wall are similar to the ticking of a clock, both occurring with regular frequency.*	None
Object	Convert something into a sensory attribute. • *What colour is the company ? What does it taste like ?*	None
Sensory	Allocate the properties of one sensory attribute to another. • *What does the colour smell like ?*	None

4.4.1 Objectives

With the definition of Ideation Domains, the third objective of the research is met. The inventor or problem solver is now provided with a structured way of targeting specific system attributes and to explore the various ways in which they could be manipulated by means of relevant mechanisms. As will be described in more detail in Chapter 5, this platform was also used to develop a simplified version of the TRIZ Contradiction Matrix (CM) (Ross 2006a,d). Further work (Ross 2006b) included the development of a unique graphic icon for each ID, which would enhance the teaching and application of the method.

4.4.2 Advantages

Four key advantages offered by Ideation Domains are the following:

Complementary functions

The cells without an IP (i.e. marked 'None') indicate IDs where the CM can potentially be complemented by the relevant mechanisms or the creative thinking techniques that use them. As pointed out in Chapter 2, this was one of the key motivators for integrating the two approaches. Whilst it should be noted that not all the mechanisms are applicable to all the system attributes, it is evident that application of the Distort, Association and Random stimulation, Rearrangement and Transform mechanisms in particular could be useful to complement the 'linear' nature of the heuristics.

Access similar IPs

Since an ID describes the variations that are possible within any specific mechanism-attribute pair, it provides access to a range of IPs that could effect the same, or similar, inventive outcomes. This would alert the problem solver / inventor using a particular inventive principle to others that could be used in the same context.

For example, considering the ID of Removing Object: In addition to using IP10B (Pre-arrange objects in the most convenient place so they don't lose time for delivery) the inventor may consider other related principles, *viz* IPs 12A (Limit the need for movement), 15AB (Allow relative movement between objects or parts), 02A (Remove in space) and 34A (Remove in time), or Remove an object partly or completely from its environment (which is not an explicit IP, but embedded in both 02A and 34A).

Target specific attributes

A third advantage is the fact that the IDs highlight the different ways in which an attribute could be manipulated by means of the relevant mechanisms. This enables an inventor to focus on a particular aspect of the problem and gain direct access to all the options around it.

For example, if inventive options were sought to change or use the Environment of the object in some way, the following IDs may be investigated:

- Segment Object and/or Environment such that each part functions in different conditions, e.g. most suitable for its operation,
- Add Environment (Make object interact with the medium, merge object with others in its environment, use fields to interact with object, in conjunction with field-activated, e.g. ferromagnetic, particles),
- Other Use for Environment (Use waste, useless or readily available resources, energy or substance to achieve a positive or desired effect or function).

Target specific mechanisms

Fourthly, the model also points out the ways in which a mechanism can be applied to different attributes. This provides potentially useful analogies to an inventor using a specific IP.

For example, if IP19A (Segment Action) was used to improve the visibility of an object (such as for instance by means of a flashing light), the inventor might also consider IP01 (Segment Object) as a possible analogous source of ideas. In this case, the object could for instance be broken up into smaller modules that could be spread in such a way as to provide advance visibility (e.g. the warning lights leading up to an obstacle in the road).

4.5 VERIFICATION

4.5.1 Other models

Since it has been derived from an analysis of creative thinking techniques and invention heuristics, as well as some historical events, it is problematic to verify the ideation model. None of these could be used as benchmark as that would mean that the model is essentially verified against itself. However, some measure of its ability to describe inventive ideation in a context where objects and their properties are the focus is to compare it with other models of similar complexity and application. One such model that comes to mind is ASIT (Horowitz & Maimon 1997), described in Section 1.4.5, consisting of the following five tools:

1. Unification. Assign a new use to an existing component.
2. Multiplication. Introduce a slightly modified copy of an existing object or part into the system.
3. Division. Divide an object and re-organise its parts.
4. Break Symmetry. Turn a symmetrical situation into an asymmetrical one.
5. Object Removal. (i) Remove a component from the system. (ii) Assign its function to another object existing in the close environment.

Using the 10 generic mechanisms as basis, the ASIT tools can be represented as follows:

Table 4.3 Analysis of ASIT tools in terms of generic mechanisms.

ASIT tool	Description per IDs
Unification	Other Use / Add Function
Multiplication	Adjust (parameter as per modification) and Add
Division	(Segment) and Re-arrange Object
Break Symmetry	Adjust Symmetry
Object Removal	(i) Remove Object (ii) Use Other

Even if the level of detail that is supplied in Table 4.2 was ignored, it is apparent that the ASIT tools are by comparison limited and insufficient to capture the extent and nature of the ideation model. Being a simplified (and reduced) version of the IPs, it also contains none of the intuitive mechanisms. In addition, it fails to recognise the scope of mechanisms described by the ideation model; for instance it does not describe Use Properties or Add Object.

4.5.2 Other examples

The model was also verified empirically by establishing its ability to produce ideas that were created by other creative thinking techniques, most notably Random stimulation. In this regard, the reader is referred to the examples presented in Chapter 5.

4.6 RANDOM STIMULATION

One of the objectives of this thesis is to provide more insight into the situations in which Random stimulation would offer the type of ideas that are claimed in the literature as not possible by 'any sort of logical design'. Despite some interesting examples in the literature to illustrate the application and benefit of the technique, the perception remains that, in general, they may not be representative of its usefulness (the reader is referred to Section 2.2.5 for further detail in this regard). The question arises whether there are situations in which a structured, systematic approach could lead to the same ideas more directly, and under which circumstances random stimulation would offer opportunities that other techniques could not.

In order to better understand the types of problem and conditions under which this would apply, a basic analysis of the technique was conducted.

4.6.1 Analogies

Random stimulation is one of several creative thinking techniques that use analogies as sources of new ideas. These analogies are generated in two basic ways, *viz* directly or randomly (Ross 2006e).

Direct analogy. In direct association, one or more attributes (features) of the problem serve as fixed points, or *beacons*, to identify other things that share the particular feature. This process normally starts by identifying concepts that have a strong and direct commonality with the problem, and progressively the search is moved on to concepts that are more generic or in which the relationship with the problem may be less distinct. As shown in **Figure 4.4**, direct association can thus be represented as a concept 'fan' in which, the further away from the problem, the wider the fan and the less direct the associations become. The symbols within the problem represent the conceptual structure of different parts of the problem, e.g. key features or functional relationships.

For instance, a problem that involves opposite actions such as 'starting and stopping' (such as for example in a timer switch) might have closely associated concepts such as 'on and off' or 'begin and end'. Moving further away there may be more generic concepts such as 'birth and death', 'ebb and flow', 'low and high' or 'day and night'. Each of these in turn is associated with a variety of others. The resultant concepts are then inspected for distinguishing features or relationships that could be useful to solve the problem or provide fresh perspectives.

Random analogy. A random concept is one which has no obvious or logical relation to any part of the problem. Rather than a step-wise progression in a known direction, the random concept is generated with the purpose of putting a gap, which at first would (and needs to) seem unbridgeable, between it and the problem. Exactly how big this gap needs to be and how it is determined are however not always clear.

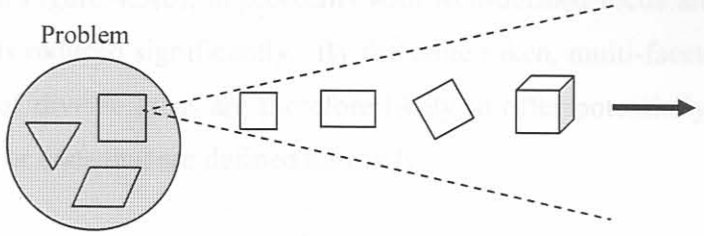

Figure 4.4. The 'fan' of direct association.

Connections are subsequently sought between the new concept and the problem. In some cases, there would be a strong and clear overlap with the problem, and the chosen feature would thus have an obvious or direct use. In others, there would be only a weak or even no real connection, in which event the thinker needs to force one through, for instance, further exploration and/or manipulation of the random concept.

4.6.2 Success of technique

The success of random stimulation can be expressed in terms of the extent to which the random concept maps, or can be forced to map, onto the problem. As shown schematically in **Figure 4.5**, this is influenced by three main elements, namely (a) the type and scope of the problem, (b) the extent (size) of the random concept and (c) the remoteness of the random concept. Again, the symbols inside the problem (circle) and the random concept (ellips) represent the conceptual structures of each.

Type and scope of problem

Open-ended problems present a comparatively large number of potential mappings as in such a case the emphasis is on the quantity and diversity of ideas that are generated. Any connection of the random concept with the problem, no matter what type of idea results, is sought. As suggested in Figure 4.5(a), the random concept can be manipulated in different ways to effect such mapping – for instance, by 'rotating' it the diamond can be made to map onto the square, or the top part of the pentagon could be forced to map onto the triangle.

However, as shown in Figure 4.5(b), in problems with well-defined focus areas the scope for successful mappings is reduced significantly. By the same token, multi-faceted problems that cover a broad range of diverse areas are therefore likely to offer potentially more mappings than simple problems or ones that are defined narrowly.

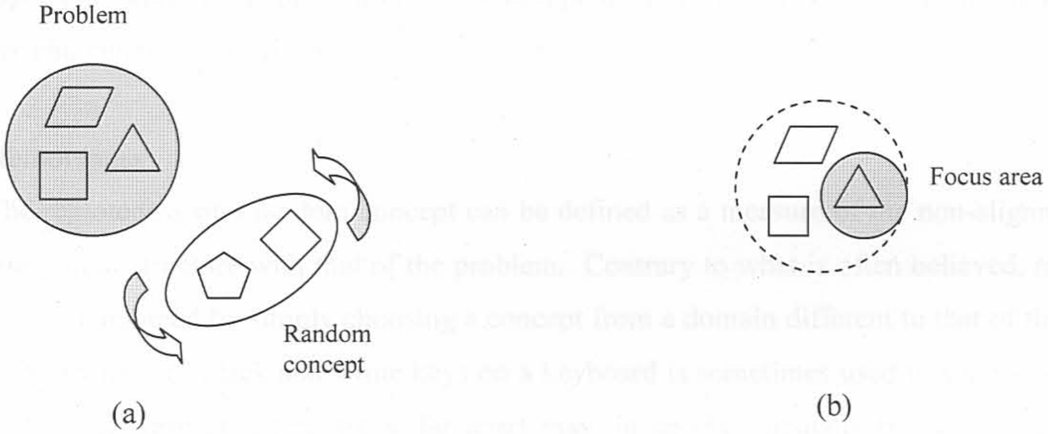

Figure 4.5. Schematic representation of a problem and a random concept. (a) Open-ended problem, (b) defined problem with specific focus area.

Extent of random concept

The greater the extent or conceptual 'reach' of the random concept, the bigger the probability that some part of it would map, or could be made to map, onto the problem. Whilst concepts normally have only a limited number of key elements that are central to the main theme, each of these are linked to a host of secondary ones. It is therefore unlikely that no connection whatsoever can be made between a problem and any given concept, however remote it may be, if the search for instance also included secondary elements. De Bono (1993 : 177) for example states that '*it has never happened to me that the random word is too remote...what happens quite often is that the random word is so closely connected to the focus* (i.e. the problem) *that there is little provocative effect*.'

However, systematically exploring the resultant 'cloud' of random concepts becomes laborious and difficult to manage and thus may prove detrimental to a focused thinking process rather than aiding it. Importantly, it can also affect the motivation of the thinker adversely if useful ideas are not forthcoming, and it is widely accepted that under such circumstances it is better to rather start with a new random concept. Also, these far-flung searches are unlikely to provide deep insights or illuminate new directions of thought - as Hofstadter (1982) observes: '*The most reliable kinds of genuine insight comes from strong analogies in which one experience can be mapped onto another in a pleasing way. The tighter the fit, the deeper the insight, generally speaking.*'

Remoteness

The remoteness of a random concept can be defined as a measure of the non-alignment of its conceptual structure with that of the problem. Contrary to what is often believed, remoteness is not guaranteed by simply choosing a concept from a domain different to that of the problem – the analogy of black and white keys on a keyboard is sometimes used to suggest that things that in one respect appear to be far apart may, in another, actually be very close. In the technique of word association (Nolan 1987) for instance, three successive steps are normally considered sufficient to generate a concept which structure and features are not traceable to that of the problem.

Finding a strong connection between the random concept and the problem becomes increasingly difficult the less their conceptual templates have in common. Even though the mental flexibility and creative experience of the thinker can effectively reduce remoteness by forcing more mappings and perhaps better identify areas of potential benefit, the ideas resulting from this would tend to be weak or not specific to the problem.

4.6.3 Application

To summarise, the above observations suggest that, in situations where key attributes or features of the problem are readily apparent, e.g. such as in simple, well-defined problems, direct association should be more efficient and easier to use than random stimulation. The advantage of the 'fan' in such a situation is the fact that a range of concepts that already share a specific feature(s) with the problem are generated directly, thus increasing the probability of useful relationships being identified. The level of skill and the effort to do this are also low in comparison to that of random stimulation, where various features of the random concept often need to be considered from a number of different angles.

In situations where harmful factors or undesired effects need to be overcome, the creative thinking mechanism of reversal could be applied first to create a (positive) beacon(s) for subsequent association. Other mechanisms could also be used in conjunction with association. A simple invention heuristic often used in physical problems is for instance to introduce a sensory attribute (e.g. smell, sound and taste) in situations in which it was not prevalent.

Random stimulation is potentially more useful for fuzzy problems or ones that are broadly defined and involve a wide and diverse array of interrelated issues, e.g. reducing unemployment, increasing levels of education, or reducing crime. Under these circumstances, direct association may be ineffective since it may be difficult to identify the beacons (key concepts and their attributes, as well as the links between them) distinctly. However, it should be noted that each random stimulation will typically address only a particular aspect of a problem, and as such a large number of these may be necessary in more complex situations to address the full scope of a problem. The technique may also be applied in cases where the strategy is to deliberately produce far-out solutions that can later on be trimmed down or made more practical (Souder & Ziegler 1977).

4.7 FLOW TECHNIQUES

Once a new concept has been created by the application of one or more inventive mechanisms, different routes are followed to bring it to a new idea. In the case of linear techniques such as Attribute Listing, where the thinking is done within the problem space, this is normally a simple case of evaluating the alternative option for its direct value. If no such benefit is obvious, the thinking moves on to produce another alternative. For example, if a triangular picture frame does not appear to offer direct value, the next step would be to assess whether a hexagonal one would, and so on.

In contrast to the linear techniques, the non-linear ('intuitive') techniques rely largely on the principle that stepping stones (also called springboards, intermediate impossibles or random juxtapositions) are created which allows the thinking to follow new directions. For instance, as was shown in Section 3.1.1 for Group C techniques, the techniques of Movement (De Bono 1993) are advocated to be used in conjunction with deliberate provocations.

In the course of this work, a number of additional techniques have been identified which are useful to build on initial concepts and thus create new ideas. Reflecting the role of 'freewheeling' in brainstorming, a flexible and fluid way of building on basic concepts, they have been named Flow techniques. They are loosely based on the premise that if one mechanism was used to create a stepping stone, applying the same mechanism again is likely to lead to an idea. By way of brief illustration, the Flow techniques as follows:

4.7.1 Adjust other

The Adjust mechanism is often useful to generate ideas after Distortion was used to create a provocation, by tweaking other attributes of the problem to normalise the situation as far as possible.

For example, the provocation '*Wheels are square*' may point the thinker to other attributes of a wheel that can be adjusted to minimise the bumpy ride. One idea would be to make very soft tyres, or for instance tyres that can adjust to the topography of the terrain.

4.7.2 Add

Similar to Adjust, the Add mechanism is often useful in conjunction with Distortion. A new thing or function is introduced to a situation that was deliberately distorted, in order to restore the original function as far as possible. For example, if wheels were square, adding something (in this example, a self-adjusting suspension) would smooth the bumpy ride.

4.7.3 Associate

As a Flow mechanism, Association is useful in conjunction with itself, or either the Adjust or Add mechanisms.

An advertising company needs new ideas. One medium to consider would be sound, e.g. Associate television. One person talks while others listen and watch; this is interrupted by adverts, which subsidises the subscription.

Considering a different situation where one person talks and others listen, direct Association leads to concepts such as a telephone conversation, a public speech, a church sermon and so on. Selecting the first option leads to the idea of having adverts on the telephone line, subsidising the call.

4.7.4 Transform

If the Transform mechanism was used to develop new insights through changing the domain or level of the problem, applying the same principle again returns the thinking to the original domain or level of the problem.

New ideas are needed for improved bricklaying. The bricks in a wall are similar to the homing of a pigeon, both occurring with regular frequency. The homing of the pigeon suggests something that always knows its correct place, no matter from which direction it approaches. Transforming this concept back to the problem gives the idea of putting some kind of pattern or protrusions on the bricks which would always allow them to be aligned easily and in the same manner.

CHAPTER 5

APPLICATION

5.1 INTRODUCTION

In the previous chapter, the generic model of inventive ideation has been integrated with a physico-mechanical systems model, which renders the resulting ideation model applicable to many engineering problems. This model was then used to establish, for each mechanism, the range of inventive ideas that could potentially be created by applying it to key attributes of such a system. Subsequently, the 40 Inventive Principles of TRIZ were analysed in terms of these mechanism-attribute pairs (referred to as Ideation Domains) and used to populate and further qualify the model.

So far, the work has satisfied three of the five objectives that were spelled out in Chapter 2. These are:

1) Provide insight into the mechanisms of inventive ideation, their use and relationships.
2) Produce an explicit framework that allows different ideation strategies to be followed.
3) Establish Ideation Domains, i.e. the various ways in which each mechanism can be applied to the range of physico-mechanical system attributes.

The above objectives represent the major focus of the research. However, it was also proposed that the model would be applied in practical situations to illustrate its value in enhancing the capability of inventors and problem solvers in inventive ideation. This will be done by the following three applications, *viz*

1) Using the Ideation Domains to develop a simplified version of the Contradiction Matrix, in which the need to define problems in terms of their system contradictions is eliminated.
2) Auditing ideas that have been produced by brainstorming, and augmenting these by means of the model.
3) Provide a better measure of the real value offered by Random Stimulation, i.e. whether novel ideas can be created by following a structured approach rather than relying on 'off-the-wall' analogies and other input.

5.2 SIMPLIFIED VERSION OF THE CONTRADICTION MATRIX

Different strategies can be followed in developing a contradictionless matrix. One approach could be to use the *invention mechanisms* as the basis for identifying promising principles. This would for instance be done by identifying the mechanisms that underpin the principles that are used most frequently in improving a particular engineering parameter. Although the mechanisms would be simple to apply (since in the case of the 40 IPs there are only five of these) and provide at least some degree of guidance to the inventor as they would be parameter-specific, they would lack the necessary conceptual resolution that is provided by the relevant attributes. In some cases, especially using the Adjust mechanism, the inventor might therefore have to try out a fairly large number of possible attributes (and hence, principles) before hitting on a useful one.

An alternative option would be to utilise the, say, four *Ideation Domains* that are most prominent in improving each parameter. However, the fact that this will provide the greatest resolution means that the success rate could be expected to be relatively low, in the same region or perhaps only slightly better than that of the CM.

A third option would be to focus on the, say, four *attributes* that underpin the most frequently used principles. An advantage of such an approach is that it would strike a good balance between the number of possible options that have to be considered and the efficiency of problem solving. **Table 5.1** presents a first attempt in this direction, called the 4-Attribute Matrix (4-AM). As shown in **Appendix 3**, this matrix was derived by applying the classification of IPs according to Table 4.2 to the frequency with which particulr IPs are used in the classic CM to improve an engineering parameter. This in effect represents a different version of the Contradictionless Matrix (CLM) of Liu & Chen (2001), based not on the frequency of individual IPs that are associated with each parameter, but on the attributes that link them. Being a contradictionless matrix, the 4-AM guides the inventor only according to the parameter to be improved, and not the deteriorating parameter as well.

The 4-AM was subsequently applied to a random selection of 40 mechanical engineering patents, extracted from the list compiled by Mann (2002) for assessing the efficiency of the classic CM. In each case, **Table 5.1** was used to determine, for the parameter to be improved, the four system attributes that could most likely solve the particular problem. For example, in the first patent in **Table 5.2** (no. 4966257), the parameter to be improved was identified as #10 (Force). The inventor would use this information to identify, from Table 5.1, the four attributes that could most likely yield a solution. In this particular example, in order of priority, these were Properties, Object, Frequency and Action. A solution to the problem is found in Move Object (IP15A and 15B), i.e. allowing relative movement between objects or their parts to find the best operational position or condition.

As shown in **Table 5.2**, applying the 4-AM to the 40 patents produced an overall success rate of 79%, defined as the number of IPs used by the inventors and also suggested by Table 5.2, as a fraction of the total number of IPs (i.e. 69) used by the inventors. This figure compared favourably with the 54% achieved by the classic CM for the same suite of examples.

Collectively, the four attributes cover a wider range of (sub)principles than the classic CM, which, for each contradiction, lists only up to four principles. It could therefore be argued as only logical that the likelihood of a successful match would be higher. However, it should be recognised that the attributes and the inventive principles are similar conceptual entities and thus can be considered equal in terms of their application. It may reasonably be assumed that

Table 5.1. The 4-Attribute Matrix: Attributes most likely to satisfy the engineering parameter to be improved.

Parameter to be Improved	Attributes			
1. Weight: moving object	Properties	Object	Environment	Concentration
2. Weight: binding object	Properties	Object	Action	Duration
3. Length: moving object	Object	Properties	Symmetry	Action
4. Length: binding object	Properties	Object	Curvilinearity	Frequency
5. Area: moving object	Object	Dimension	Action	Properties
6. Area: binding object	Frequency	Properties	Concentration	Dimension
7. Volume: moving object	Properties	Object	Symmetry	Function
8. Volume: binding object	Properties	Object	Frequency	Curvilinearity
9. Speed	Object	Properties	Action	Concentration
10. Force	Properties	Object	Frequency	Action
11. Tension, pressure	Properties	Object	Curvilinearity	Action
12. Shape	Object	Action	Curvilinearity	Properties
13. Stability of object	Properties	Object	Material	Action
14. Strength	Object	Material	Curvilinearity	Duration
15. Durability: moving object	Properties	Frequency	Object	Duration
16. Durability: binding object	Quantity	Material	Object	Concentration
17. Temperature	Properties	Action	Object	Concentration
18. Brightness	Action	Sensory	Object	Properties
19. Energy spent: moving object	Properties	Action	Frequency	Object
20. Energy spent: binding object	Object	Properties	Action	Frequency
21. Power	Properties	Frequency	Object	Sensory
22. Waste of energy	Properties	Object	Action	Frequency
23. Waste of substance	Object	Properties	Frequency	Duration
24. Loss of information	Object	Properties	Environment	Sensory
25. Waste of time	Properties	Object	Frequency	Symmetry
26. Amount of substance	Material	Object	Frequency	Curvilinearity
27. Reliability	Properties	Object	Action	Duration
28. Accuracy of measurement	Sensory	Object	Function	Action
29. Accuracy of manufacturing	Sensory	Object	Frequency	Properties
30. Harmful factors on object	Environment	Material	Object	Action
31. Harmful side effects	Material	Environment	Object	Concentration
32. Manufacturability	Object	Properties	Action	Quantity
33. Convenience of use	Object	Action	Properties	Sensory
34. Repairability	Object	Properties	Action	Sensory
35. Adaptability	Properties	Object	Quantity	Action
36. Complexity of system	Object	Action	Properties	Duration
37. Complexity of control	Properties	Object	Duration	Action
38. Level of automation	Properties	Object	Action	Frequency
39. Productivity	Properties	Object	Environment	Frequency
Version 1.0				

Table 5.2. Analysis of patents in terms of system contradictions.

Ex. no.	**Patent no.** [1]	**Contradiction** [2]	**Inventor used** [3]	**CM suggested**	**CM score** [4]	**4-AM includes**	**4-AM score**
1	4966257	10, 05	15	19, 10, 15	1	15	1
2	5485307	35, 12	01	15, 37, 01, 08	1	01	1
3	5485359	18, 19	25	32, 01, 19	0	-	0
4	5493580	23, 22	01, 35, 31	35, 27, 02, 31	2	01, 35, 31	3
5	5543179	30, 14	16, 10, 01	35, 18, 37, 01	1	10, 01	2
6	5568961	14, 01	01, 15	01, 08, 15, 40	2	01, 15	2
7	5569009	27, 36	01	13, 35, 01	1	01	1
8	5680467	28, 13	32, 25, 13	32, 35, 13	2	32, 35, 13	3
9	5694827	15, 09	03, 35, 05	03, 35, 05	3	03, 35, 05	3
10	GB2312704	01, 30	22	22, 21, 27, 39	1	22	1
11	GB2315973	23, 17	31	21, 36, 39, 31	1	31	1
12	GB2315980	12, 08	02, 35	07, 02, 35	2	02, 35	2
13	GB2315994	26, 07	25	15, 20, 29	0	-	0
14	GB2316044	10, 33	01, 15	01, 28, 03, 25	1	01, 15	2
15	GB2350145	33, 35	15, 01	15, 34, 01, 16	2	15, 01	2
16	GB2350268	24, 27	10	10, 28, 23	1	10	1
17	WO01/13760	07, 05	17, 04	01, 07, 04, 17	2	-, 04	1
18	WO01/70445	28, 03	05, 26	05, 16, 26, 28	2	05, 26	2
19	5746360	07, 31	02, 30	17, 02, 40, 01	1	02, -	1
20	5992588	10, 03	17	17, 19, 09, 36	1	-	0
21	6099658	09, 31	24	02, 24, 35, 21	1	24	1
22	6299550	03, 09	13	13, 04, 08	1	13	1
23	6272687	14, 33	03, 40, 15	32, 40, 25, 02	1	03, 15, 40	3
24	GB2307485	15,10	04, 18	02, 16, 19	0	18	1
25	6296160	31, 36	08, 05	19, 01, 31	0	05, 08	2
26	5493551	33, 36	17	32, 26, 12, 17	1	-	0
27	6293565	09, 31	17, 14, 03	02, 21, 24, 35	0	03, 14, -	2
28	GB2309876	36, 30	02	22, 19, 29, 40	0	02	1
29	5999869	31,15	23	15, 22, 33, 31	0	-	0
30	5651055	33, 24	10, 28	04, 10, 27, 22	1	10, 28	2
31	5650990	10, 13	15	35, 10, 21	0	15	1
32	5650983	02, 24	05	10, 15, 35	0	05	1
33	5543179	37, 18	32, 23	02, 24, 26	0	23	1
34	6220333	24, 27	17, 28, 13	10, 28, 23	1	-, 28, -	1
35	GB2303376	13, 26	35, 24	15, 32, 35	1	35, 24	2
36	6176374	11, 14	09, 03	09, 18, 03, 40	2	09, 03	2
37	6065555	19, 22	23	12, 22, 15, 24	0	23	1
38	5824184	33, 03	03	01, 17, 13, 12	0	03	1
39	6099018	31, 12	01, 17	35, 01	1	01, -	1
40	6098208	05, 01	14, 30	02, 17, 29, 04	0	14, 30	2
Total			**69**		**37**		**55**
%			**100**		**54**		**79**

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[1] From the list of Mann (2002).

[2] Contradictions are presented in the format: Parameter to be improved, deteriorating (worsening) parameter.

[3] According to the analysis by Mann (2002).

[4] The score is determined as the number of principles suggested by each tool, that matches the inventive principles used by the inventor.

an inventor would have a similar task scanning (in a worst case such as the Object attribute) four IDs for solutions than considering for instance the same number of sub-sections of an inventive principle (e.g. IP17 - Another dimension). The higher success rate of the attributes should therefore not be attributed solely to the increased number of principles that are covered, but also to the grouping of similar principles, which in this case is based on clear criteria.

The '4-AM includes' column of Table 5.2 also shows the cases in which it was unable to predict the IP used in the particular patent. As is clear from the Table, these constituted mainly two system attributes, namely Dimension (IPs 17 and 30) and Function (IP25). If these attributes were for instance used as an alternative option in situations where the 4-attribute strategy was unsuccessful, the success rate for the suite of patents could be improved substantially.

5.2.1 Improvements

As mentioned earlier, Table 5.1 represents only the first version of the 4-AM, and scope therefore still exists for improvement. One such enhancement that has been effected since (Ross 2006b) was to provide better resolution around the Object and Action attributes. In most cases, each attribute involves at most two IDs, and thus the inventive options can be interpreted easily. For example, if the Sensory attribute was indicated as a possible source of inventive solutions, the inventor has a simple choice between (1) Changing the colour or transparency of the object or (2) Adding luminescent or other tracers to improve visibility. The Object and Action attributes, however, each involve four IDs, and thus the search process has been simplified by determining, for these attributes, the two mechanisms that in each case are most likely to solve the particular problem.

A further improvement to this first version of the simplified CM was to develop a unique graphic symbol for each ID. This effectively turns the CM and IPs into a visual tool, which has been dubbed VizTRIZ (Ross 2006b). In addition to the fact that the number of principles have been reduced significantly, an advantage of the visual format is that it could enhance training of the tool as well as its user-friendliness.

The improved 4-AM tool was applied to a range of 60 physico-mechanical engineering patents (i.e. the original 40 in Table 5.2, plus an additional 20 that were also obtained from the list compiled by Mann (2002)). In order to assess its effectiveness against other similar tools, the classic (4-principle) Contradiction Matrix, the six inventive principles used most commonly in the CM (Top6) as well as the Contradictionless Matrix of Liu & Chen (2001) were applied to the same examples (Ross 2006b). In the case of the latter, in order to facilitate direct comparison with the Top6, the 6 IPs that are associated most frequently with each engineering parameter were used.

For the patents that were analysed, the inventors employed a total of 106 IPs. Of these, VizTRIZ, the Contradiction Matrix, Top6 and the Contradictionless Matrix were able to achieve success rates (effectiveness) of 79%, 51%, 41% and 32% respectively; i.e. using VizTRIZ, in approximately three quarters of the cases the inventor would have been able to reach the eventually patented solution (Ross, 2006b). The first two figures compare well with the results shown in Table 5.2.

5.3 IDEA AUDITING

A key premise of brainstorming is the notion to put quantity before quality, i.e. to produce as many ideas as possible. If run correctly, i.e. if people focus on building on the ideas of others and witholding judgement, this objective can normally be achieved. However, being largely an unstructured approach – the grouping of similar ideas normally happens only after the thinking session - there may be parts of the problem space that remain unexplored. The ideation model was therefore tested for its ability to analyse the outcome of a brainstorm and, on the basis of this, identify areas where additional thinking could prove useful.

By ways of illustration, a simple case study '*How to dispose of 1 billion paperclips profitably*' was used. **Table 5.3** shows the ideas that were generated in the brainstorming (Majaro 1992), as well as an analysis, as per the ideation model, of the mechanisms and attributes that were involved. **Table 5.4** presents the additional ideas that have been generated from the analysis.

Table 5.3 Case study: Analysis of ideas.

No.	**"Use as ..."**	**Mechanism**	**Attribute**	**Based on:**
	Mechanical cleaners			
1	Pilot light cleaners	Adjust	2-D shape $^{1)}$	Physical property (bendable) & 1-D shape $^{1)}$
2	Spark plug cleaners	Associate	Function	Idea #1
3	Pipe cleaners	"	"	"
4	Drain cleaners	"	"	"
	Physical cleaners			
6	Ear cleaners	Associate	Function	Ideas #1 to 4
7	Nose cleaners		"	
8	Tooth picks		"	
9	Back-scratchers		" (and Shape)	
10	Belly button		"	
11	Nail cleaners		"	
	Toys			
	Magnetised toy	Add	Properties & Colour	
	Desk display			
12	Coloured clips	Associate	Colour & Function	
13	Urgency sign	Associate	Colour	Idea #12
14	Suction clips	Add	Function	Idea #12
	Jewellery			
15	Wedding rings	Adjust	2-D shape	1-D shape & physical property
16	Brooch	Add	Object	Shape & Size, associate with metal bracelets
17	Bracelet	Associate	Function	Idea #16
18	Banglets			
19	Buckles			
20	Necklaces			
21	Ear-nose rings		Shape	Idea #15
	Gifts			
22	Christmas gifts	Associate	Context	Toys
	Tokens			
23	Money	Associate	Action and Number	Idea #22
24	Luncheon vouchers		"	Idea #23
25	Poker tokens		"	"
	Games			
26	'Clippy winks'	Associate	Environment	Idea #12
27	National game	"	"	"
28	Painting set	"	Colour	Possible uses.
	Miscellaneous			

29	Homing device	Associate	Shape & Material	TV 'bunny ears'
30	Anti-stress activity	"	"	"
	Fashionable clothing			
31	G-string	Add	Object	2-D shape & size, associate with clothing
32	Dress studded with clips			
	Conference aids			
33	Name tags	Associate	Function	-
	Functional clothing			
34	Decorative caps	Add	Object	2-D shape & size, associate with clothing
35	Helmets	Associate	Function	Idea #34, 'wearable accessories'.
36	Veils			"
37	Money belts			"
38	Bras			"
39	Suits of armour			"
40	Flak jackets			"

1) The term 1-D shape refers to the steel wire of which the clip is made, while 2-D shape refers to the shape of the clip itself.

Table 5.4 Additional ideas generated by use of the ideation model.

No.	Mechanism	Attribute	Based on:	Idea
41	Adjust	Size	Material & 1-D Shape	Make small bicycles, flagpoles for food, bristles for steel brushes etc.
42		1-D shape	Property (resistivity)	Make 'cultured pearls' (3-D, by melting with high voltage), use in jewellery.
43	Associate	Lustre (shiny)	Traffic / clothing	Use as reflectors or fashion accessories.
		Material & 1-D shape		Use to stitch, weave or sew. Use as ring binders, or clips / hooks for photo film / X-rays, fishing hooks, xylophone needles etc. Pin cushion for sticking on things
44		Property (conductivity)		Use as electrical fuses.
45		Property (resilience)		Use as small springs.
46		2-D shape		Use as a miniature race-track (e.g. for ants)
47	Add	Object	Shape & Colour	Use as Christmas decorations, bottle jackets
48	Other Use	Object	Cost of Material	Sell as scrap metal.
49			Colour & Shape	Use to makes pictures or signs.

5.4 'LOGICAL DESIGN' vs 'OFF-THE-WALL'

In Chapter 2, the issue was raised of whether Random stimulation really offers the prospect, as is claimed, of producing ideas that would not have been able to be generated in a more structured manner. The question was to what extent a systematic design process, such as was followed by mapping the generic mechanisms of inventive ideation against the attributes of a simple model, could have produced similar or the same outcomes directly. In Section 4.6, a brief analysis was made of the mechanism of Random stimulation and how it relates to using (direct) Association. From this analysis, it was concluded that in situations where the key attributes of the problem could be readily identified, a combination of the Reversal and Association mechanisms may yield the same results directly and with a higher chance of success. This would apply especially to open-ended problems where there are a large number of options that can be explored.

In order to test the ideation model and the above hypothesis, a number of examples were sourced from the creativity literature. These included Random stimulation, provocation and other techniques.

Example 1 - Random stimulation

The example presented in Chapter 2 used the Random analogy of a 'traffic light' to generate ideas that could be used for cigarettes. The idea was to print a red band close to the butt end of the cigarette, indicating where it becomes (even more) dangerous to smoke further.

As stated above, in a situation like this it is suggested that Association could be used efficiently. For this problem, the Action of 'lighting and extinguishing' a cigarette is chosen. Moving out into the association funnel, similar paired opposites such as 'starting and stopping, birth and death, on and off, opening and closing' would be produced. Applying Association to establish concepts that fall within this funnel (*What else can be thought of that starts and/or stops things?)* would have led directly, amongst several other concepts, to 'traffic light'. The strong relationship between the Action (stopping) and the Colour (red) would have led directly to the idea of a red band around the cigarette.

Several other concepts and useful ideas can be generated from the same 'starting and stopping' focus, including:

- Fire extinguisher (the cigarette extinguishes itself)
- Brake pedals (squeezing the cigarette to allow through an adjustable amount of air)
- Speedometer (have a line printed along the length of the cigarette which changes from green to yellow to red to black)
- Timer switch (automatic starting and stopping of some sort, allow cigarette to burn only for certain intervals).

As stated in the hypothesis, an undesired or harmful factor could be turned first into a positive factor by Reversal, and followed by Association to produce matching concepts. In this case, focusing on the undesired feature of the smoke burning the smoker's throat:

Reverse Action (burning) = cooling - Associate = water - Associate : dilute. This creates the idea of diluting the smoke, e.g. having perforations that would allow through more air.

Example 2 - Random stimulation

Another example of Random Stimulation, *Office copier* po *nose*, is presented by DeBono (1993). The term 'po' is a short way of indicating 'hy(po)thesis, sup(po)se' or '(p)rovocation (o)peration'. [According to De Bono (1993), the word 'could not exist in any language… it is a non-language word.' The Oxford English Dictionary however gives the meaning as 'chamber pot' ;-)]

The idea produced from this stimulation was to replace the traditional visual warning signal (e.g. a red light) with a particular type of smell. This would be done for instance by a cartridge that releases a certain smell to indicate a particular type of problem with the copier.

Using the ID of Adjust Sensory attribute, i.e. "If one sensory attribute is used for a particular function, complement by, or switch to, another; if none are used, introduce a new one") would have led directly to the idea of having smell, sound or perhaps even taste introduced as a new feature.

Example 3 - Random stimulation

The novel provocation *Cigarette* po *Flower* is another example of Random stimulation (De Bono 1993), leading to the idea of putting seeds in the butt of a cigarette, so that flowers will grow (at least theoretically) where the butts are discarded by inconsiderate smokers.

If the problem is for instance posed as '*Find ways to reduce the litter caused by discarding cigarette butts*' (i.e. overcoming an undesired factor), the analysis of Section 4.6 suggests combining the mechanisms of Reversal and Association. Reversal of this undesired factor leads to the concept of something smelling and/or looking good. Associating it with the Environment in which cigarette butts are found (e.g. pavements, flower beds), gives the idea of turning the butts into flowers, trees or compost, e.g. by inserting seeds into the butts.

Example 4 - Reversal

The statement '*I have orange juice for breakfast*' is reversed as the provocation '*Orange juice has me for breakfast*' (De Bono 1993). This led to the idea to have a cartridge in a shower head that scents the water.

Applying the ID of Associate Environment to the problem statement '*Find new ideas for showers*' leads to things such as a basin, bath, soap, shampoo and deodorants. The concept of bath salts that scent the water would have led to the same idea of a scented shower. Alternatively, Adjusting Sensory attributes as in Example 2 would have produced the same outcome directly.

Other ideas that can be generated include for instance:

Associate Action (water falling) leads to 'waterfall', 'rain' etc. Picking 'waterfall', and focusing on Shape, leads to the idea of shower heads in the shape of famous waterfalls (Niagara, Victoria etc.), naming the range after the particular falls. Focusing on Action, *viz* a strong flow and mist spray, leads to the idea of adjustable sprays at different levels of the shower.

Associate Size (and/or) Shape leads to the concept of a 'telephone booth'. Ideas stemming from this include a telephone shower head, dialing the water temperature, public shower booths, waterproof telephones and so on.

Example 5 - Morphological synthesis

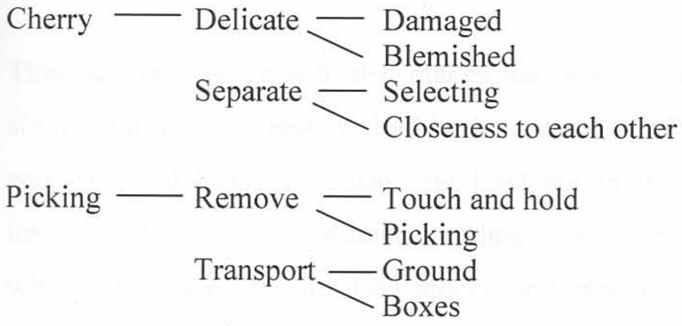
Morphological synthesis was used to find a solution to the problem "*Improve the design of laundry hampers*" (Michalko 1991: 119).

Direct Association of the Action of throwing dirty laundry into a bin (*Where else do people pass (throw / kick / pull / hit) things into a receptacle ?*) leads to concepts such as rubbish bins, basket ball nets, clothes donation bins, soccer nets, tennis courts, etc. Matching this with the preferences of young kids would produce the idea of a hamper in the form of a basket ball net, located for example behind a bedroom or bathroom door.

Example 6 - Attribute splitting

In Chapter 3, the following example was used to explain how the mechanisms of inventive ideation were identified; for ease of reference, it is repeated here.

A farmer requires new methods to harvest cherries (Michalko 1991: 60). The two keywords for this open-ended problem were chosen as 'cherry' (noun) and 'picking' (verb). Selecting one attribute, for example 'delicate', gives the idea to create a new type of cherry with stronger skin, to better withstand handling. Re-assembling 'blemished', 'closeness' and 'transport', one might look for a way of satisfying these three attributes. Another idea may be to shake the tree and catch the cherries in nets to minimise bruising.



By means of illustration, applying the ID of Re-move Object leads to the same and other additional ideas:

- Movement of Object (easily derived from 'pick cherry') suggests, amongst others, limiting (the need for) movement or position changes. This leads to the concept of something that would be either able to remove the cherries *in situ*, or minimise their drop height.
- Remove Object in time, i.e. 'Discard, disperse or dissolve things that have fulfilled their functions', leads for instance to the idea of a cherry harvesting itself, e.g. engineered such that the stem deteriorates and detaches when the cherry is ripe.
- Remove Object in space suggests that the cherries are separated from the environment by covering them in something that would allow easy and gentle removal.

Associations with the Action of cherries dropping from a tree, leads to concepts such as using a type of safety net or mattress to catch them, or a safety harness of some sort to prevent them from falling.

5.5 SUMMARY

The few examples presented above, by way of illustration, suggest that the ideation model is capable of producing a variety of ideas in a systematic fashion, including some that are claimed to be the unique outcome of Random stimulation. Furthermore, rather than elaborate techniques or provocations, these ideas were created in a simple and direct fashion, based on easily identifiable attributes.

This structured approach also makes the process of provocation more acceptable - people simply don't sit in creative thinking sessions and offer statements such as "Po, Elvis is alive and well and living in Texas" (at least not in the sessions in which the author has been involved in to date ;-)). Rather than just asking participants to state provocations 'boldly and without thinking', the ideation model, and especially the range of IDs based on the Adjust mechanism, provides guidelines to do it systematically and effectively. As Goldenberg *et al.* (1999a) point out, 'a number of researchers indicated that ... techniques that promote total freedom – no directional guidance, constraints, criticism or thinking within bounded scope – are not effective, and that the performance of problem solvers instructed to 'break the rules, get out of the square, and change paradigms', was not better than that of individuals who were not given any instructions at all. Adherence to a cognitive frame of reference involves sensitivity to the 'rules of the game' and, by functioning within a frame, one achieves a better position from which to notice or recognise the unexpected'. Similarly, Scott *et al.* (2004: 377) highlight that successful creativity training courses devote less time and resources to techniques that stress unconstrained exploration; in their words, *'the use of techniques that stress analysis of novel, ill-defined problems contributes to success'*.

An important principle underlying creativity and the emergence of truly novel ideas is the fact that, very rarely, these are the result of a number of small tweaks that are re-arranged into some new format, as several of the creative thinking techniques advocate. As the innovation theory would have it, a large number of incremental steps do not add up to one step change. A novel idea has as its essence one feature that rises sharply above the threshold of normal or accepted practice; the rest follows (is drawn along) automatically, and naturally. A big bang is not created by a thousand pellet guns.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 BACKGROUND AND MOTIVATION

Over the past six decades, significant progress has been made in the development of techniques to enhance the skills of problem-solvers and inventors. However, because of the plethora of options available, users of these techniques are not only faced with a dilemma as to which technique to apply and how to go about making the selection, but also how to assess the quality and completeness of the thinking.

Whilst invention heuristics offer engineers, inventors and technologists guidance on approaches that may solve certain types of problems, they are not always efficient. A recent study on a diverse range of 130 mechanically-based engineering patents for instance estimated the efficiency of the classic TRIZ Contradiction Matrix (CM) to be around 50%. In addition, they utilise only a limited range of creative thinking mechanisms, are sometimes cumbersome to use and difficult to interpret.

Objectives

The purpose of this research was therefore to develop a rigorous and more scientific approach to inventive ideation techniques which would integrate the two areas and thus provide an enhanced inventive ideation capability. The objective was thus stated as:

"To develop a generic model that improves the understanding of the mechanisms that underpin inventive ideation techniques, as well as their use and relationships. The model should be tailored for application to physico-mechanical problems and demonstrate its value as a tool that enhances inventive ideation in such a context."

6.2 RESEARCH AND OUTCOMES

Analysis

The above objective was accomplished by firstly analysing the mechanisms used in a wide range of popular creative thinking techniques as well as the 40 inventive principles of the TRIZ invention heuristics. The creative thinking techniques included the so-called 'linear' techniques in which the attributes of the problem are explored incrementally within a range of viable options, as well as 'intuitive' or 'random' techniques where new ways of thinking are for instance stimulated through provocation and random analogies. The techniques were grouped into three categories, based (1) on the *metaphorical distance* that they remove the thinking from the problem space, and hence the degree of intuition that is required to create an idea, (2) the *number of steps* involved in creating the idea, and (3) whether these occur in parallel or in sequence.

Inventive mechanisms

The results suggested that the entire range of techniques analysed are based on a total of only ten conceptually distinct mechanisms, which can be grouped into five 'themes'. The themes (and the mechanisms that relate to them most closely) are: Separate (Segment and Remove), Change (Adjust and Distort), Copy (Association and Random analogy), Combine (Add and Re-arrange), and Convert (Other Use and Transform). These mechanisms may be used in different combinations and applied to one or more attributes of a problem.

Ideation model

A model for inventive ideation in physico-mechanical contexts has been developed by integrating the generic mechanisms with a systems model describing the major physical, temporal and spatial attributes of objects and their environments. In the ideation model, the mechanisms have been positioned such as to reflect their respective themes, the degree of intuition that they require, and their relative frequency of use, as determined from the literature survey of creativity techniques and heuristics. These features assist the user in following a systematic approach to inventive ideation.

Ideation Domains

The ideation model was used to develop a detailed picture depicting the full range of inventive ideation options that exist within the defined system and thus can be used to solve problems. For this purpose, 26 Ideation Domains (IDs) were identified by applying each of the inventive mechanisms to the attributes of the systems model. By way of example, the ID of Re-moving Object, *viz* the various ways in which an Object can be modified by either using Movement or Removing parts, includes: (a) removing the object from its environment, (b) extracting or separating useful or interfering parts or features away from the main body of the object; extracting only required parts, (c) removing (discarding or dissolving) used or spent parts, (d) allowing relative movement between parts, or (e) preventing movement of the object or between parts.

Verification and application

The ideation model was verified by testing it against examples sourced from the literature and elsewhere, supplemented by expert opinion and comparison with another model derived from the TRIZ invention heuristics. These have suggested that the model is comprehensive and conceptually sufficiently robust to be regarded as a valid new ideation tool. The practical value of this tool has been demonstrated by application to a range of examples sourced from the literature.

6.3 CONTRIBUTIONS

The ideation model offers a number of advantages; the following being considered the most significant.

Framework of understanding

The major emphasis of this work was on theory building, in providing a structured and comprehensive map of the inventive ideation landscape. This work not only elucidated the mechanisms of inventive ideation, their use and relationships, but also provided a basis of understanding that future studies in this area can conceivably draw upon.

Enhanced ideation capability

Secondly, the model enhances inventive ideation in some key respects. This includes:

(1) The application of ideation strategies best suited to the skills and needs of the individual or problem solving group and the type of problem. The model has been structured such that the relative position of a mechanism guides the user on the type of problem to which it would be applicable, the degree of creative intuition that would be required in using it, as well as the frequency with which it is used elsewhere (and hence, an indication of the likelihood of an inventive idea being produced).

(2) The use of IDs, detailing the full range of ideation possibilities that pertain to each attribute of the system. These provide a framework for the inventor to target specific areas for thinking, and detail the options that are available in doing so. It also highlights inventive mechanisms that may complement the TRIZ inventive principles and thus expand the scope of ideas; it has for instance been shown that the TRIZ heuristics account for only five of the ten inventive mechanisms.

The IDs were subsequently used as basis to develop a simplified version of the CM. This '4-attribute matrix' (4-AM) defines the four system attributes that are used most frequently for each engineering parameter, thus eliminating the need to define problems in terms of their technical contradictions. The tool was applied to 40 randomly selected mechanical engineering patents, which resulted in an overall success rate of 79%, i.e. in about three quarters of the cases the inventor would have reached the same idea by using the 4-AM. This compared favourably with the 54% achieved by the classic CM for the same examples. Complementing this strategy with an algorithm involving two additional attributes, *viz* Dimension and Function, increased, for the suite of examples, the success rate significantly.

(3) A methodology to audit the ideas that have been produced during brainstorming or other thinking sessions. Thus, inventive mechanisms and areas of the problem that may yield additional ideas can be identified.

(4) An ability to create novel ideas systematically, rather than relying on 'off-the-wall' approaches such as Random stimulation. To this end, it has been demonstrated that for simple, open-ended problems, direct association would be a more efficient approach than Random stimulation.

Importantly, this work supports the view that creative thinking does not need to be a random, chaotic process. Ideas can be generated by following a structured approach of 'forward thinking', which allows the parameters of the problem to be explored systematically and comprehensively. This structured approach may make creative thinking more attractive to people who prefer exploring and extending the known rather than using ‘off-the-wall’ or ‘out-of-the-box’ approaches that have no proven record of being more efficient.

Finally, an added advantage of using such a visual tool is that it removes people’s minds from the immediate area of the problem. The fact that they can keep track of their thinking and try out new options or combinations brings an element of fun and experimentation to inventive problem solving. This is an essential ingredient of true and successful creative endeavour.

Sources of inventive ideation

A secondary contribution of the work lies in the formulation of a consistent definition of the sources of inventive ideation, based on the degree of problem definition and the nature of the ideation process. This framework explains the nature of the four sources of inventive ideas, *viz* Inspiration, Serendipity, Experimentation and Intervention, and has provided a platform for understanding the role of 'deliberate creativity' – the application of creative thinking techniques, heuristics and other tools to create ideas. This framework could improve the understanding of the different types of creative outcomes in organisations and thus form an important part of a creativity management programme.

6.4 RECOMMENDATIONS

The research has highlighted a number of areas that should be investigated to further improve the understanding and use of inventive ideation.

(1) First, the analysis of a range of creative thinking techniques has highlighted the fact that they possess distinct structures. A general model that describes these could not only simplify their application but also further help to clarify the usefulness and/or validity of such a large number of techniques.

(2) More work is required to improve the first version of the '4-attribute' contradictionless matrix. Whilst significant progress has already been made by the author in this regard, including the development of a unique graphic icon for each ID (Ross, 2006b), further qualification of the attributes in terms of the dominant inventive mechanisms could possibly render the tool even more powerful.

(3) Third, this work has been one attempt at providing a more generic framework for inventive ideation techniques. The further testing - such as by empirical investigation - and refining of the model should be an on-going process, and include the development of system models for a wider range of disciplines.

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APPENDIX 1

ACRONYMS AND DEFINITIONS

1-1 ACRONYMS

CM	Contradiction Matrix
CLM	Contradictionless Matrix
4-AM	Four-Attribute Matrix
ID	Ideation Domain
IP	Inventive Principle

1-2 DEFINITIONS AND TERMINOLOGY

Mechanism

An operator that can be applied to an *attribute,* feature or characteristic of the problem in order to create an alternative.

Ideation Domain

A conceptually distinct entity that highlights the different mechanisms that can be applied to certain system attributes to produce inventive ideas. It also groups the inventive principles on the basis of the dominant inventive mechanisms and attributes that describe them collectively.

Attribute

A key or distinguishing aspect or part of the problem, to which one or more thinking *mechanisms* are applied to arrive at inventive ideas. The term is used interchangeably with 'feature', 'aspect' or 'characteristic', and is interpreted to mean the same thing.

The term 'change *the* attribute' is used to indicate the different 'values' that the attribute can assume, for instance changing the Colour from yellow to blue to red. In contrast, the term 'change *from* one attribute to another' indicates that a different aspect of the problem is considered, e.g. focusing on Shape instead of Sound.

Empirical

Based or acting on observation or experiment, and not on theory, deriving knowledge from experience alone (Oxford Concise Dictionary)

1-3 TRIZ DEFINITIONS

The following definitions of the TRIZ engineering parameters are provided by Savransky (2000).

Weight

The mass of the subsystem, element or technique in a gravitational field. The force that the body exerts on its support or suspension, or the surface on which it rests.

Length

A geometric characteristic described by the part of a line (straight or curved and not necessarily the longest) that can be measured by any unit of linear dimension, such as meter, inch etc.

Area

A geometric characteristic described by the part of a plane enclosed by a finite continuous line that can be measured in a square unit of dimension.

Volume

A geometric characteristic described by the part of a space that can be measured in a cubic unit of dimension. The part of a space, either internal or external, occupied by the subsystem.

Speed

The velocity of the subsystem. The rate of a process or action in time that can be measured by any linear unit of length divided by a time unit.

Force

Any interaction that can change the subsystem's condition due to the interaction between subsystems.

Tension, pressure

Tension on or inside the subsystem.

Shape

The external contours or boundaries that separate the subsystem from the environment or other subsystems. The appearance of the subsystem in space.

Stability

The ability of the subsystem to keep its integrity (wholeness). Steadiness of the subsystem's elements in time. Wear, chemical decomposition, disassembly and growth or entropy are all decreases in stability.

Strength

The ability of the subsystem to resist a change in response to force, resistance to breaking.

Durability

The time during which the subsystem can perform useful and/or neutral functions. It can be estimated as the average period between failures, or the service life.

Temperature

The thermal condition of the subsystem. Includes other thermal parameters such as heat capacity and ones that affect the rate of temperature change.

Brightness

Light flux per unit area. Also any other illumination characteristics of the subsystem, such as light intensity, degree of illumination.

Energy

The subsystem's requirement (such as electricity or rotation) to perform a particular function. Often energy is provided by the technique or super-system.

Power

The time rate of energy usage due to which the functions of the subsystem are performed.

Waste of energy

Use of energy (such as heat) that does not contribute to the job being done. Reducing energy loss sometimes requires actions different to those that improve energy usage.

Waste of substance

Partial or complete, permanent or temporary loss of some of the subsystem's materials or elements.

Loss of information

Partial or complete, permanent or temporary loss of data or access to date in or by the subsystem. Frequently includes sensory data such as aroma, texture etc.

Waste of time

Time is the duration of an activity. Improving the loss of time means reducing the time taken out of the activity.

Amount of substance

The number of the subsystem's materials or elements that might be changed fully or partially, temporarily or permanently.

Reliability

The ability of the subsystem to perform its intended functions in predictable ways and conditions.

Accuracy of measurement

The closeness of the measured value to the actual value of the subsystem parameter.

Accuracy of manufacturing

The closeness of the actual characteristics of the subsystem to the specified or required characteristics that can be achieved during production of the subsystem.

Harmful factors (acting on object)

Susceptibility of the subsystem to externally generated harmful effects.

Harmful side effects

A harmful effect that is generated by the subsystem as part of its operation within the technique, and that reduces the efficiency or quality of the functioning of the subsystem or whole technique.

Manufacturability

The degree of facility, comfort, ease, or effortlessness in manufacturing or fabrication of the subsystem.

Convenience of use

Simplicity and ease of operation. The technique is not convenient if it requires many steps to operate or needs special tools, many highly skilled workers, etc.

Repairability

Quality characteristics such as convenience, comfort, simplicity, and time to repair faults, failures or defects in the subsystem.

Adaptability

The ability of the subsystem to respond positively to external changes, and the versatility of the subsystem that can be used in multiple ways under a variety of circumstances.

Complexity of system

The number and diversity of elements and interrelationships within the subsystem.

Complexity of control

Measuring or monitoring the subsystems that are difficult, costly, and require much time and labour to set up and use, that have fuzzy relationships between components, or that have components that interfere with each other.

Level of automation

The ability of the subsystem to perform its functions without human interface.

Productivity

The number of functions or operations performed by the subsystem or whole technique per unit of time.

APPENDIX 2

RELATIONSHIPS BETWEEN IPs AND INVENTIVE MECHANISMS

Table 2-1 Summary of relationships between the IPs and inventive mechanisms.

IP	Segment	Re-Move-ment	Adjust	Add	Other - Use
01	ABC				
02		A			
03	AB			C	
04			AB		
05			AB		
06				A	
07			AB		
08				AB	
09				AB	
10		AB			
11				A	
12		A			
13			ABCD		
14			ABC		
15		AB	C		
16			A		
17			ABCD		
18			ABD		C
19	A		B		
20			A	B	
21			A		
22			C	B	A
23			B	A	
24				AB	
25				AB	C
26					ABC
27	A				
28			C	BD	A
29			ACD	B	
30			AB		
31			AB		
32			AB	C	
33			A		
34		A		B	
35			ABCD		

36					A
37					AB
38			AB		
39			AB		
40			A		

APPENDIX 3

PROCEDURE TO ESTABLISH 4-ATTRIBUTE MATRIX

The major problem in compiling the 4-Attribute Matrix (4-AM), i.e. establishing the attributes that are used most frequently to improve each engineering parameter, is the fact that they comprise of different sub-IPs. Had the Contradiction Matrix suggest the specific sub-IPs that are used most frequently to solve certain contradictions, it would have been easy to determine to what extent certain attributes were associated with these parameters. However, this not being the case, and the fact that attempts by the author to obtain such information were not successful, a different approach had to be taken.

This was done by determining a cumulative score for each attribute by multiplying the frequency with which an IP is used to improve an engineering parameter with the number of times that the sub-IP appears in a particular attribute. In the absence of more detailed information, an equal weighting was allocated to all sub-IPs. For example, as shown in **Table 3-1**, to improve engineering parameter #1 (Weight of moving object), IP35 appears a total of 13 times in the classic CM. The Properties attribute contains three of the sub-IPs, *viz* 35A, 35C and 35D. The same attribute is also described by sub-principles of IP18 (one), IP40 (three), IP29 (three), and IPs 31, 36 and 37 (one each).

Thus, the following scores were calculated for the various attributes:

Table 3-1 Most frequently used IPs and attributes for engineering parameter #1 (Weight of moving object).

IP	Frequency of use	Attribute and (number of sub-IPs)
35	13	Properties (3), Concentration (1)
28	8	Environment (2), Action (1), Object (1)
26	6	Object (3)
18	7	Properties (1), Frequency (3)
02	5	Object (1)
08	3	Environment (2)
10	5	Object (1), Action (1)
15	3	Object (2), Action (1)
40	4	Properties (3)
29	6	Properties (3), Environment (1)
31	6	Properties (1), Concentration (1)
27	5	Duration (1)
34	6	Object (2)
01	4	Object (3)
36	3	Properties (1)
19	3	Frequency (1), Action (1)
06	2	Function (1)
37	3	Properties (1)
38	3	Concentration (3)

Properties : 13x3 + 7x1 + 4x3 + 6x3 + 6x1 + 3x1 + 3x1 = 88

Object : 8x1+ 6x3 + 5x1 + 3x2 + 6x2 + 4x3 = 61

Frequency : 7x3 + 3x1 = 24

Environment : 8x2 + 3x2 + 6x1 = 28

Duration : 5x1 = 5

Function : 2x1 = 2

Action : 8x1 + 5x1 + 3x1 + 3x1 = 19

Concentration : 13x1 + 6x1 + 3x3 = 28

The four attributes with the highest cumulative scores were included in the 4-AM. Therefore, in order of priority, the four attributes for improving engineering parameter #1 were: Properties (88), Object (61), Environment (28) and Concentration (28). The same process was repeated for each of the other engineering parameters.