Technology for Knowledge Innovation:

A Realistic Pluralist Scientific Problem Solving Capability

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Abstract

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A Realistic Pluralist Scientific Problem Solving Capability

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The aim of this study is to define and describe a scientific problem solving capability to be used by the Institute for Maritime Technology (IMT) in its Decision Support Domain in order to provide a scientific support service to decision makers in the South African Navy.

Cognisance is given to the fact that the context within which this scientific service functions is of a complex nature, and so are some of the problems which the Decision Support Domain are required to study. For this reason a methodology developed by the proponents of complexity modelling for management and organisational science, namely to approach the problem through "Perspective Filters" is used. The aim is therefore to identify emergent patterns in the development of various disciplines commonly utilised for problem solving. Their respective developments during the twentieth century are studied with this stated aim in mind. Scientific method is seen to be a dominant perspective in this pursuit.

The outcome of the study is a proposed generic, pluralist scientific problem solving process which provides a stable definition of such a service despite its constantly changing environment. This greatly enhances the robustness of the service, which makes it cost-effective to develop. The definition of pluralism which is used in this study, and which underpins the definition of the capability, differs from other current dominant views of pluralism in that it upholds the realist aim of science. Although this process is developed in the specific context of IMT, its generic nature makes it a general <u>knowledge technology</u> for any such a service with the aim of providing a scientific service, not limited to the context within which it is developed.

Key Words

Scientific Method, Pluralism, Scientific Problem Solving, Operations Research, Systems Thinking, Cybernetics, Complexity Theory, Knowledge Management, Innovation, Research and Development, Technology Management, Capability Management, Decision Support, Knowledge Society, Knowledge Technology, Knowledge Industry, Realism, Research Management.

Acknowledgements

I wish to express my sincere gratitude to the following organisations and people who have contributed (sometimes without knowing) to make this study possible:

For we know in part …

… We see in a mirror dimly…

1 Cor 13:9,12

Soli Deo Gloria

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<u>List of Abbreviations</u>

DOD   -   Department of Defence

IMT   -   Institute for Maritime

LC   -   Life Cycle

KM   -   Knowledge Management

OR   -   Operations Research

P1, P2, ...   -   Perspective 1, Perspective 2, ...

R&D   -   Research and Development

RSA   -   Republic of South Africa

SAN(DF)   -   South African Navy and/or South African National Defence Force

SA Navy   -   South African Navy

TIS   -   Technology Income Statement

TQM   -   Total Quality Management

USA   -   United Stated of America

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Chapter 1: Description of the research problem

1.1 Context description and historical development

The Institute for Maritime Technology (IMT) is a Defence Research Institute focusing on maritime defence research. Its main client is the South African Navy (SA Navy). It also provides a service to other departments of the Department of Defence where its expertise is applicable.

IMT was established in 1975 when the SA Navy recognised its requirement for operations research (OR). The initial design of IMT took into account the reality that in order to provide such a service, IMT needs to be able to do measurements, build engineering prototypes, as well as design, implement and operate maritime measurement and test and evaluation facilities. For this reason IMT has a mechanical workshop, electrical workshop, an in-house tank facility and various measuring measurement facilities, some under-water at sea.

Due to the fact that the service required by the SA Navy necessitates a multi-disciplinary approach, IMT has always employed technicians, engineers and scientists from a variety of disciplines. The challenge is then to develop these employees to be able to understand and service the maritime military requirement. In this way IMT is the place where scientific and military expertise are fused to an integrated service of defence research.

This multi-faceted face of the expertise at IMT in time led to the definition of seven domains of expertise. They represent the current SA Navy articulation of the content of the service it requires of IMT. They are under constant revision, and the current set is given here for illustrative purposes:

1. Battlefield Characterisation: A capability focusing on the understanding of the air column above the sea, the water column, sea bed and sub-surface of the sea bed.

2. Target Charaterisation: Under Water. This domain focuses on the technology, facilities and understanding of identifying underwater targets for naval purposes.

3. Target Characterisation: Above Water. This domain focuses on the technology, facilities and understanding of identifying targets above the sea surface.

4. Mine Warfare. This domain focuses on the technology for and understanding of mine warfare and its counter measures.

5. Submarine Warfare. This domain focuses on the technology for and understanding of submarine warfare and its counter measures.

6. Surface Warfare. This domain focuses on the technology for and understanding of surface warfare and its counter measures.

7. Decision Support. This domain focuses on operations research for maritime warfare, also servicing the aspects of maritime warfare not directly covered by any of the other domains. It also services the support functions of the SA Navy, including, but not limited to, management issues, logistics, human resource modelling, strategic studies.

There are two reasons for having a re-look at the required capability of the decision support domain. They are

1. New developments in the underlying scientific disciplines relevant to the domain over the last few decades potentially open new possibilities of service to the SA Navy, as well as a potentially higher quality of service.

2. Key people in the decision support domain resigned, so that new expertise needs to be developed of necessity. This, in conjunction with the first reason, provides the reason for confirming the required capability at IMT for the decision support domain both from the client's perspective (an aspect not covered in this dissertation) and the scientific support perspective (which is the underlying reason for this study).

1.1.1 Operations Research as part of the IMT mandate

IMT was established initially to provide the SA Navy with an operations research service. This was done at the peak of the popularity of operations research (see discussion on operations research in Chapter Two). Due to various internal reasons

the name of the operations research expertise domain at IMT was changed in the late 1980's to decision support. This change of name did not take place to indicate a change in focus. It is to be understood in this dissertation that decision support has this background in IMT, and as such needs to be differentiated from the use of decision support currently dominant in management literature. A more detailed description follows to clarify the focus of the decision support domain at IMT and the capability it strives to provide.

1.1.2 Decision Support Domain at IMT

The decision support domain has three main functions, in providing a scientific service to the SA Navy (and other DOD clients), namely:

1. To integrate the understanding of the other domains at IMT to provide a scientific support service for maritime warfare. While this includes integrating the technical and technological insights of the other domains, it supersedes it in that it also looks at the higher level concepts of maritime warfare paradigms as it develops globally.

2. To service the decision support requirements of the support functions of the SA Navy. This runs across the other IMT domains (e.g. logistics and human resources modelling), and requires SA Navy and scientific expertise not found in any of the other IMT domains.

3. To provide a scientific support service to naval staff on all levels of decision making.

The main aim of the decision support domain is to utilise the best that science offers to provide decision makers with as much assistance/supporting systems as possible to make more informed decisions.

1.1.2.1 Decision Support in literature

Recent literature, especially in management and organisational science, also uses the term decision support. A distinction needs to be made between what is called decision support in IMT and what the body of literature defines to be decision

support. Decision support in the literature of organisation and management sciences means mainly to

1. Extract information from corporate information systems and present results to management for more informed decision making.

2. Utilise artificial intelligence techniques to extract/create knowledge from corporate information systems and present results in a useful form for more informed decision making.

3. The application of OR is sometimes referred to as decision science and/or decision mathematics in literature, having problem-solving, optimisation, intervention and change as possible goals. This is discussed in more detail in Chapter Two when OR is discussed in more detail.

1.1.2.2 Decision Support at IMT

IMT uses the term "decision support" to describe its capability of providing the SA Navy with an "operations research" service. This includes the capability to process information and extract/create knowledge from large data systems. Yet it includes more than that – its root is found in the classical definition of operations research during the Second World War where science was utilised to assist operational officers in their decision making. <u>It utilises science and its techniques to provide scientifically informed support service to decision makers.</u>

From this description it is immediately obvious that all domains of expertise in IMT provide a decision support service to the SA Navy as part of their specific expertise. The three areas specific to the decision support domain are described in § 1.1.2 above.

For this reason the decision support domain at IMT is viewed as a "Scientific Problem Solving" capability in service of decision makers in the SA Navy, and not only restricted to data analysis, information processing or artificial intelligence for knowledge creation/extraction from information systems.   The terms *decision support* and s*cientific problem solving* is therefore used interchangeably in this dissertation.

It needs to service the total scope of possible problems the SA Navy might encounter. Providing such a service is challenging under any circumstances, but even more so in the environment of limited resources within which defence research finds itself.

Recent developments in various branches of science, especially where operations research was applied (with limited success) to fields other than the natural world, also indicate developments which could be of use to a scientific problem solving capability. The criteria by which these can be termed *scientific* are one of the concerns addressed by this study.

1.2   The research problem

The main requirement for what needs to be achieved by the research in this study into the required capability of the decision support domain at IMT remains unchanged. In broad terms it can be seen as

"the best possible definition of a scientific problem solving capability suitable for the requirements of the SA Navy within resource constraints."

Since the SA Navy is a relatively big organisation and a technologically complex organisation with all that it entails, operating in an environment (physically and organisationally) which is complex, its requirement for the service of the decision support domain is limited by available resources rather than by a limited and narrow requirement. For this reason IMT needs to take every care to optimally define and develop its capability in scientific problem solving so as to provide the best possible service (with as few limitations as possible), utilising the best science can offer (including all different branches of science).

The problem statement and research objective is as follows:

"Define and describe the structure, parameters and the interrelatedness of the various aspects of fact-based decision-making technology required to be developed at IMT in order to provide the best possible scientific decision support service to the SA Navy within the constraints of available resources."

1.2.1 Initial research strategy and its failure to provide a practical solution

The strategy for the research was initially indicated to

1. Describe the existing relevant definitions of technology and choose the one most suitable to the study.

2. Describe the existing relevant definitions of scientific method and identify the relevant aspects.

3. Describe what is meant by fact-based decision making.

4. Define the process of decision support to a client as a complete service, as opposed to an ad hoc problem solving service.

5. Describe the proposed model for decision support in IMT.

6. Test the model by conducting a case study, using mainly observation as the method of data gathering.

From this description the main areas of focus would be "technology" and "scientific method". Choosing appropriate definitions would provide the necessary context for the definition of a scientific decision support capability.

An initial literature study was conducted, looking into the proposed strategy points one and two above. It was found that, due to the open nature of decision support, it was not possible to draw boundaries around either relevant scientific disciplines, or a set of relevant fields of application of the service (to satisfy the wide client requirement for such a service). A Technology Income Statement[1] (TIS) [De Wet, 1996] was developed in order to overcome this problem, but that served only to highlight the unacceptably high level of restriction placed on the definition of such a service using the proposed strategy.

From experience IMT has learned that the development of a decision support practitioner takes a considerable effort. It is accepted in IMT that a new scientist (or

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[1] See Appendix D.

engineer) takes about three years before being able to start servicing client requirements satisfactorily. This is due to the practical nature of the service, requiring the fusion between scientific and military expertise, but also due to the fact that the decision support work is without fail interdisciplinary, or multi-disciplinary, in nature, so that purely scientific expertise is not sufficient. Such a costly investment requires a stable definition of the capability required in order to be sustainable, and the TIS did not provide that. Instead it articulated the fluidity of client requirements, the context of the SA Navy and resultant changes required in the capability. This indicated the high risk of making the costly investment of developing a specific capability focusing primarily on client application requirements for its definition – it is a sure recipe to find that by the time it becomes operational it might (already) be outdated or at least sub-optimal, because of subsequent changes in the context. The initial TIS which was developed is given in Appendix D.

1.2.2 Restating the research problem and methodology of investigation

The initial literature study indicated that the proposed strategy of the research was either too limited to provide a stable, sustainable, useful and relevant capability, or that the research objective to define such a service was too ambitious. The second possibility would leave the decision support domain with the only option of being developed ad hoc on the basis of changing client requirements, taking very long to reach a point of practical utility to a wide enough range of client requirements. If at all possible IMT would like to ovoid this situation, so the research strategy was revisited and refined using the insights created by the initial literature study:

Reading indicated that complex problems should be addressed differently from problems not perceived to be complex. The meaning of "complex" in literature varies, with little agreement as to its specific definition. Yet enough indication is found is literature (especially in systems thinking, management and organisational science) to indicate that it might prove productive to treat the problem at hand with the techniques identified in management and organisational science for complex problems. The technique of utilising "perspective filters"[2] (see chapter two for a

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[2] See § 3.4.1.1.2 for a discussion on this subject.

discussion on the work of Snowden who developed the term [Kurz &Snowden, 2003]) was chosen because of its practical success in recent literature and application, and also because of the overlap of that view with the latest perspective "windows" approach documented in systems thinking [Flood, 2000].   This means that the dissertation is a result of having approached the research problem as a complex problem, using a technique identified by management science to be appropriate for the complex world of strategy development and analysis.

In this way relevant perspectives (not only *technology* and *scientific method* as initially proposed) need to be defined, studied and the resultant emerging patterns would then ideally provide insight giving direction to IMT in its pursuit.   This problem to be solved is in essence a management problem, hence the use of a technique of management science to define the decision support capability at IMT.

1.3 Overview of the dissertation

The resultant redefinition of what needs to be included in the literature study, conducting the literature study and documenting the results is described in this dissertation. In one sense the approach of the dissertation can only be understood once the dissertation is read, because it is in itself an application of the results of the literature study, its interpretation and proposed model for the decision support capability at IMT. In itself it represents a case study of the results of the study documented in this dissertation, and is in fact used as the case study to illustrate the productiveness of the approach used.

Layout of Dissertation

Chapter 2	Criteria for Choosing Perspectives
	P1 P2 P3 P4 P5
	Conclusions from synthesis of Perspectives
Chapter 3	Finding Commonality in Pluralism
	Framework(s) for problem Categorisation
Chapter 4	Process of Scientific Problem Solving
Chapter 5	Case Study: Creating Knowledge through Complexity Methods
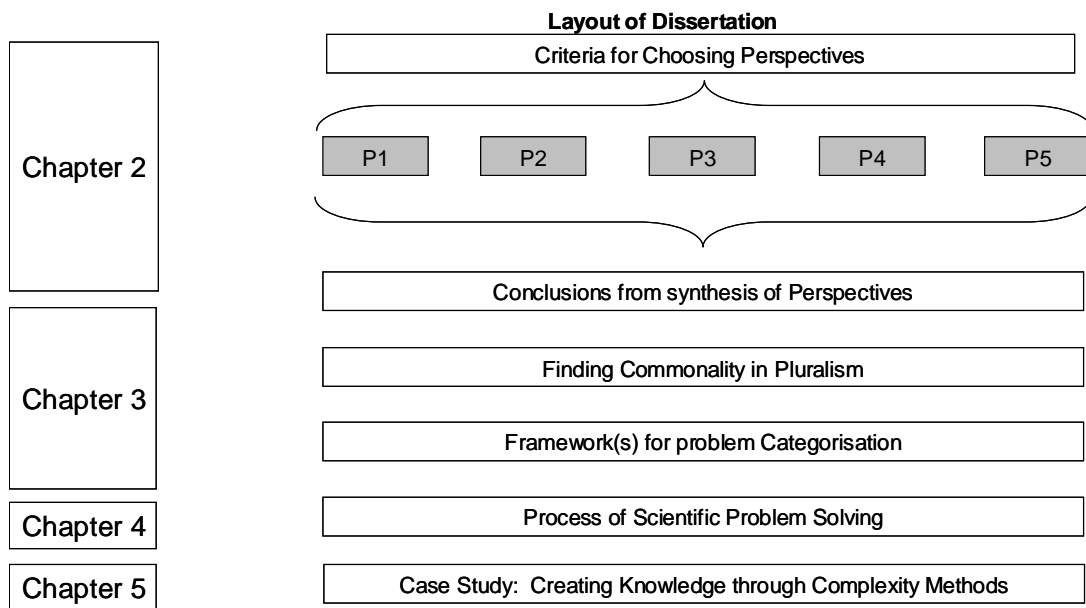
Figure 1-1 Dissertation Roadmap

The Structure of the dissertation is given in Figure 1-1. This road map is repeated in the dissertation to keep track of the methodology followed in this dissertation. From this figure it is seen that the following strategy is followed in the research:

1. Define the criteria for deciding which perspectives to develop from literature. This is a very important step, since it draws the boundaries for the problem to be solved. Anything which is relevant, but not included, will cause the results to be of less practical use. (Chapter Two)

2. Develop the chosen perspectives to a level required to understand their development from an historical angle, as well as from a development of notional understanding angle. (Chapter Two)

3. Interpret the emergent properties and patterns by documenting the conclusions from the perspectives, indicating commonalities. (Chapter Three)

4. Describe the proposed process for scientific problem solving as developed from the insights created by the study. (Chapter Four)

5. Use this dissertation as an implementation of the proposed process to illustrate its productiveness. (Chapter Five)

Chapter one is describing the context and nature of the problem, also giving an overview of the research methodology which is followed.

Chapter six summarises the dissertation in broad terms, also giving indication of possible future investigations and development.

A short summary of each chapter follows:

1.3.1 Chapter 2 overview

The criteria for choosing perspectives are given, with the five perspectives to be developed as a result.

Each of the five perspectives is developed from the following two angles:

1. Historical development
2. The growth of notional understanding during the development of the perspective

None of these perspectives is developed in much depth. The aim of this study is not to fully understand any specific one of these, but rather to give a broad overview of its development from the above-mentioned angles.

1.3.2 Chapter 3 overview

The interpretation of the overview of the perspectives is given in Chapter Three. Commonalities between them are pointed out and given meaning against the background of the dominant perspective, namely *scientific method*. The insights in this chapter do not arise from an in-depth study of any of the perspectives, but rather from the emergence of patterns and commonalities when studied together (even though terminology used to describe these notions differ in the various perspectives). This chapter serves as the conceptual seed bed for the proposed model for scientific problem solving at IMT.

The three main aspects studied in chapter 3 are

1. Describing the conclusions made from the synthesis of the perspectives.

2. Describing the Commonalities using pluralism in scientific method as basic point of reference.

3. Describing Frameworks for Problem Categorisation (categorising problems and matching them to valid/productive scientific approaches is a basic requirement of a pluralist definition of scientific method).

An important feature which characterises the literature study is the lack of coherence in terminology and concept fusion between the perspectives. Chapter three addresses these conceptually from the angle of the main perspective, *scientific method*.

1.3.3 Chapter 4 overview

This chapter describes the proposed model for scientific problem solving to be developed at IMT and how it reflects the results of the literature study and its interpretation: The notions described in Chapter three are implemented and their interrelatedness illustrated by describing a process which is not sequential, but rather characterised by multiple dynamic feedback loops.

Chapter four assumes a pluralist definition of scientific method and then implements the findings of the literature study to obtain a stable definition of the capability for scientific problem solving to be developed at IMT.

1.3.4 Chapter 5 overview

Chapter five uses this dissertation as a case study to show the superior productivity of having approached the problem to be solved (i.e. the definition of a scientific problem solving capability) as a complex problem, instead of following the classical *scientific method* as initially intended. It is done to illustrate one of the main results of this dissertation, namely that the required capability at IMT has to be able to treat problems according to their respective context and problem types, rather than to primarily identify application areas from the client's perspective and build capability to service those.

Chapter five uses the structure and flow of the dissertation, as well as the knowledge created as a result, to illustrate the unique insights which present themselves as a result of the emergent properties of the combined study of the perspectives. It also

illustrates the notion of *retrospective coherence*, which is an inherent attribute of complex problems according to Snowden.

1.3.5 Chapter 6 overview

The conclusions of this study are articulated, notably the fact that the TIS becomes useful as a management tool as part of the implementation of the proposed process.

The inherent *pluralist nature of scientific method*, which is proposed as a major result of this study, opens new areas of investigation which require further investigation, but that is not pursued in this dissertation.

The results of this study indicate that the proposed decision support capability can be viewed and managed as a *knowledge technology*. This has implications which need further investigation, but which falls outside of the scope of this dissertation.

1.3.6 Appendices

A few appendices, which provide more detailed information on certain aspects of the study, or more detailed information on aspects of the implementation of the results of this study at IMT, are given in appendices. They are referred to where applicable in the main body of the dissertation.

1.3.7 Conclusion on structure of the dissertation

An obvious feature of the dissertation is that it simultaneously describes the development and impact of multiple notions. To facilitate this process in a palatable way some notions are revisited where necessary to indicate their relevance, nature and impact in the light of the new knowledge (or new assumptions made as a result of new knowledge). This might appear like repetition at first, but it actually represents the development path of the salient notions used in chapters four and five. As such they represent the development of thought leading to the abstractions, assumptions, reductions and initial conditions stated and illustrated in those two chapters: They pave the way to define the minimum set of notions to take into account for a scientific problem solving capability.

For clarity the main flow of the dissertation is repeated at the beginning of each chapter, and also in chapter two at the beginning of each perspective.

Chapter 2: Theoretical background

2.1 Approach of theoretical background

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│           Criteria for Choosing Perspectives       │
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  │  P1  │  │  P2  │  │  P3  │  │  P4  │  │  P5  │
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┌─────────────────────────────────────────────────┐
│        Conclusions from synthesis of Perspectives  │
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│           Process of Scientific Problem Solving    │
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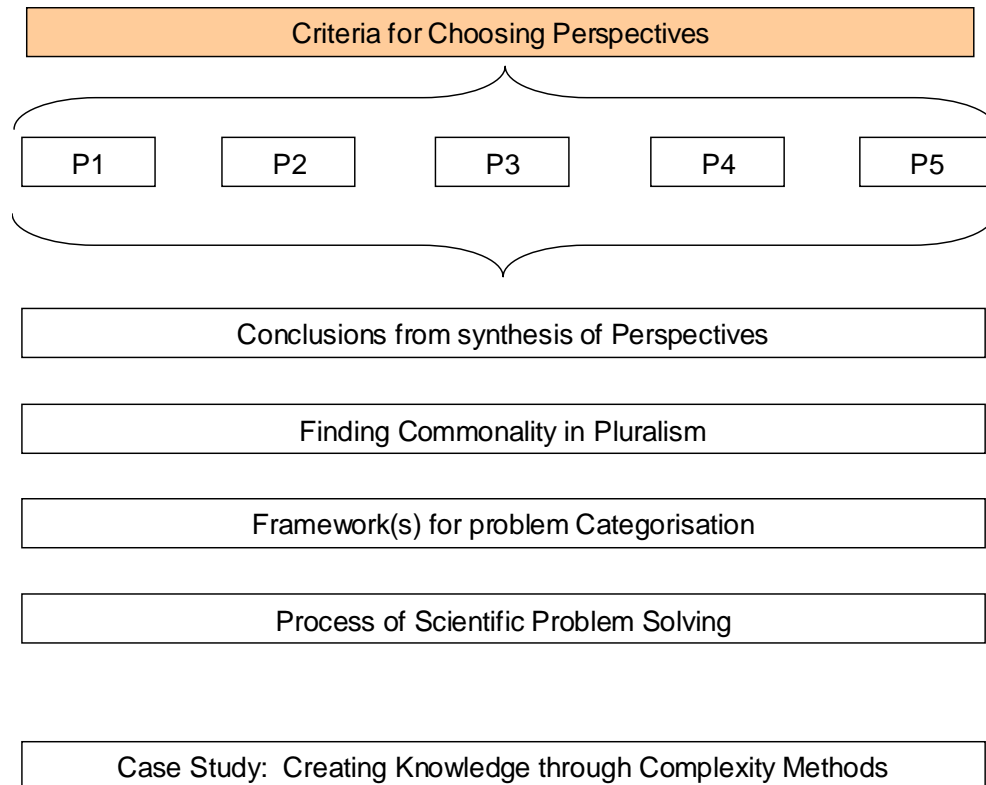
Figure 2-1: Dissertation Road Map

As already mentioned in Chapter one, the approach used for the literature scan and resultant theoretical background given in this study is based on the observation that decision making (and therefore also decision support) is complex. In Chapter one this observation was substantiated by observing that

1. The complexity of the environment to be serviced by the decision support capability at IMT requires a multi-disciplinary approach.

2. The varied natures of problems (i.e. problem types) that the decision support capability must of necessity be ready to investigate.

3. The essential requirement that human decision making is taken into account in the development of the capability further confirms the complexity of the required decision support capability.

The theoretical background is therefore approached in a way consistent with complexity theory (and also of systems thinking): Different perspectives are defined and developed with the aim of increasing the understanding of the developments in science and technology from which a decision support capability can be defined and developed. The aim is to identify possible emergent properties amongst the various approaches and to search for ways of self-organisation among these approaches.

As a result of this approach, an overview of the development of systems thinking and complexity theory introduces the theoretical study even though chronologically they are the latest developments to be taken into account. This will, however, give the necessary background to explain the structure of this study and the type of argument employed in this theoretical study. In this way the approach employed here serves as one application of the new developments in the twentieth century, showing how they add value to the insight which can be created by a decision support service: This theoretical study can be seen as a decision support product answering the question "How can I best articulate the multi-faceted wellspring of (scientific) developments in the twentieth century to highlight their individual and combined value for a scientific decision support capability?"

It is shown that especially when the "combined" value is explored, the notion of causal links (almost universally accepted in traditional scientific method) becomes vague and might even disappear altogether. The "combined" value is the synergy and "additional insight" created by another view (perspective) which might confirm, weaken or even challenge a previous insight without necessarily negating it, so that the insight from "combined" value is greater than the sum of the insights from the value of the "individual" perspectives. Decision making then becomes a balancing act without reliance on causal links. Should any perceived state be disturbed, the basic question is not "what caused it?", but rather "what can be done to diminish the magnitude of the negative impact" (so that the ongoing maintainance of the desirable state of homeostasis is ensured, or the emergence of a more desirable state is facilitated). If causal links can be identified, they can be used to maximum effect, but even if they cannot be identified the second question above can still be answered in practice through incremental intervention, diminishing undesirable changes and

supporting desirable ones. This is in essence the value added by complexity theory for decision making, which is the subject of the first perspective described here.

2.1.1 Criteria for choosing perspectives

Before the perspectives are developed, the choice of perspectives to develop has to be motivated. This section describes the rationale and criteria used for the selection of perspectives to develop.

The Decision Support Capability which IMT renders to the client is mandated to be a *scientific* capability. For this reason the study of scientific method is a prominent perspective to be developed.

Other fields are chosen as perspectives by looking at the following criteria

1. The field claims to be of value for practical problem solving.

2. The field claims to add value to the process of knowledge creation.

3. The field claims to add value where technology is taken as a broad description of the context. The definition of technology and fields applicable to those aspects are therefore taken into account. This means that if criteria one and two are met, then the field's relevance in the area of technology is used as a further filter.

It is important to note that the study does not try to use an exhaustive list of perspectives, but rather a sufficient set which is as small as possible. The following perspectives were identified using the criteria above:

Perspective 1: Operations Research, Cybernetics, Systems Thinking and Complexity Theory.

Perspective 2: Scientific Method (This is the dominant perspective).

Perspective 3: Knowledge Management.

Perspective 4: Research and Development

<u>Perspective 5</u>:   Technology (This perspective is describing primarily the context within which the decision support capability must function).

It is understood that choosing another set of perspectives would have yielded different results and highlighted other aspects, so that any new knowledge gained from the synthesis of these perspectives are highly dependent of this choice of perspectives to develop. This is accepted as an inherent reality of studying a complex problem and not as a weakness.

2.1.2 Perspectives not developed

As indicated above the perspectives investigated in this study represent a set of perspectives chosen from a more comprehensive list of possible perspectives which are relevant to a decision support capability. In order to be clear on what was evaluated for inclusion a short discussion of those perspectives wilfully excluded from this study is given. There are two basic reasons for excluding relevant perspectives from this study:

1. The perspective adds value to the <u>application</u> of the decision support capability rather than to the <u>definition</u> of the decision support capability

2. The perspective adds value to aspects of the decision support capability not directly of importance to the <u>decision support process</u> to be defined and described in this study.

The first reason given above for excluding these perspectives from the list which are taken into account in this study is that they represent possible fields of application for a decision support capability rather than necessary study for exploiting relevant theoretical developments to define and develop a decision support capability. Management decision making and organisational decision making have become major areas of study in the field of decision support. However, they do not add value to the underlying capabilities of a generic decision support capability. They are required study if any specific decision support capability is required to render a service in the areas of management and organisational decision making.

Since this study concerns itself with the developments in the twentieth century relevant to adding value to the theoretical appropriateness (as opposed to the

application appropriateness) of a decision support capability, they are not studied in further detail here. For the purposes of this study they fall into the same category as maritime warfare – they represent necessary fields of study for the decision support practitioners in IMT, since the clients of the decision support service rendered by IMT are involved in decision making in these fields. Therefore the decision support practitioners at IMT need to be adept in their theories and techniques for the purposes of serving specific client requirements, not for the purpose of understanding the underlying concepts of a decision support capability.

The following list of very active fields of research is therefore excluded from the set of relevant perspectives for the purposes of this study, and only referred to where relevant within the development of any given perspective:

1. Management Science
2. Organisational Science

The second reason given above for excluding a perspective from this study is that the list of relevant perspectives discussed in this study represents only those perspectives necessary to describe the model for the decision support process developed by IMT and to evaluate the implementation of that process. The list of perspectives detailed above is therefore not a comprehensive list of all aspects taken into account in the development of the complete decision support capability, but only those necessary to understand the decision support process at IMT.   The perspectives which were considered as relevant to a decision support capability but excluded from this study for the stated reason are

1. Decision Science. This is a broad conglomerate of techniques and approaches in the natural sciences. They do not need to be addressed separately, because the various techniques can be treated the same as the disciplines which developed them.   Statistics and discrete mathematics are of particular importance, both of which fall into the study of scientific method.

2. Decision making theory. While this is a very active field of research of which the decision support practitioners must take note of, it does not add value specifically to the process of decision support, but rather to the application of

the decision support capability in general. *This is especially applicable during the Synthesis Phase (described in Chapter Four).*

3. A model for identifying the <u>systemic positioning</u> of a specific problem case to ensure that the recommendations resulting from the scientific investigation are systemically appropriate (developed by the decision support domain in IMT). *This is important, but would serve to enrich the Context Characterisation Aspect of the Diagnostic Phase described in Chapter Four.*

4. A model for employing relevant decision making <u>experience in the field of application</u> of a specific problem case as part of the scientific enquiry of that problem (developed by the decision support domain at IMT). *This is part of the implementation of the necessary infrastructure for the proposed decision support process described in Chapter Four.*

5. A model to ensure that decision support practitioners function within the sphere of their <u>preferred problem-solving profile</u> (developed by the decision support domain at IMT). *This is mentioned in Chapter Six as a possible area of further investigation.*

2.2 Perspective 1: Operations Research, Cybernetics, Systems Thinking and Complexity Theory
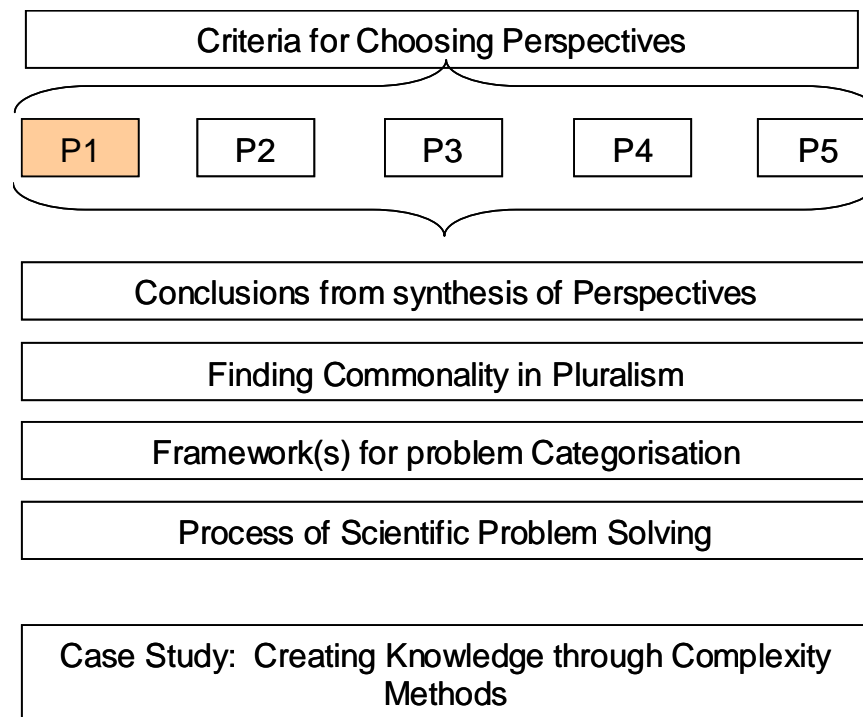
Figure 2-2: Dissertation Road Map

2.2.1 Background

Probing nature beyond the physical, inanimate world, especially biology, and later also social environments, made it clear that the accepted methods and techniques of the natural sciences did not provide a sufficient problem-solving toolbox for these other areas to be fully investigated and understood.

This led to the search for other theories. In time what was termed the very restrictive "reductionist" approach of the "scientific method" became the familiar introductory paragraphs of those who pursued a goal to solve problems which were perceived to be beyond the horizon of what could be solved by the "scientific method". This led to a family of developments which are clustered under the heading Operations Research, Cybernetics, Systems Thinking and Complexity Theory in this study.

2.2.2 Operations Research, Cybernetics and Systems Thinking

Operations Research was born during the Second World War. War time decision makers involved scientists to overcome operational problems they encountered. Examples include the birth of radars and mathematical modelling to find out why submarines were not effectively destroyed by the bombing of the Alliance. In these and other ways science added much value to the operational success of the Alliance's forces of war.

After the War many of the American war time decision makers went to study further and ended up entering business. David Callahan [Callahan, 2002] tells their story and the immense impact they had on the development of USA business success in his book "Kindred Spirits". In addition to the values of integrity and hard work they portrayed, they came with the knowledge of the value added by the scientific operations research in the war-time decision making. The success of operations research during the War caused the business world to take note and to start employing operations research in business as well to assist with the analysis for better decision making and for solving business problems. This caused Operations Research to become a sought after career, and soon it entered the curricula of the universities. In its early years it championed an instrumentalist view of science, claiming to have (or develop) the toolbox of scientific techniques which could be used to solve business problems. In the USA the view soon developed that operations research is of necessity a team-based, multi-disciplinary approach[3], contrary to what came to be called operational research in the UK, which kept the initial "toolbox" paradigm and championed operational research as a new scientific discipline.

Operations Research is still seen in the management sciences as an over-arching term for the scientific support service to management, as can be seen from the following description of its function by Pidd. [Pidd, 2004, 105-106]

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[3] For the development of the multi-disciplinary view see § 2.2.2.3 "From Operations Research to Systems Thinking"

1. OR as Decision Mathematics
2. OR as Optimisation.
3. OR as Problem Solving.
4. OR as Management Science
5. OR as a Systems Perspective.
6. OR as Intervention and Change.

This illustrates the *imperialist* claims of OR itself, where Systems Thinking is defined as one possible manifestation of OR. This tendency to absorp other approaches is seen in all the approaches studied in this section.

In this dissertation the exclusive area of OR is described, not the all-inclusive view described by Pidd, although it is understood that his definition of the word OR is still prevalent in management science. The exclusive area covered only by OR is also termed "Quantitative Management", the subject of the next section.

2.2.2.1 Operational Research (Quantitative Management)

The application of a scientific approach to business management is an ongoing programme. These days it has become a discipline in its own right at many universities (a fact often to the dismay of the proponents of its essential multi-disciplinary nature), and also in the form of what is termed "quantitative management". Fact-based decision making is the stated goal of this approach, with a "fact" being defined to be the result of scientific enquiry from measurements and modelling. In this way it claims that *objectivity* is promoted and subjectivity minimised, with a fact defined as the remaining impersonal statement of truth when the context and personal opinion are removed. This definition of objectivity follows the definition dominant in scientific method at the time, namely *logical positivism*[4]. Statistics and the methods of applied mathematics are the main pillars of this approach, with optimisation of some kind often its focus.

The mere fact that the application of scientific techniques in the business world is still pursued today shows that success has been achieved. However, the failures of the operational research departments of organisations were also many, notably when only

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[4] Logical Positivism is discussed in § 2.3.3.1.1

Arie de Geus and his team was able to predict and prepare Shell for the oil crisis while other operational research groups failed – with dire consequences for the companies. This not only made De Geus' approach of "scenario thinking" famous, but failures like these eventually outweighed the benefits in the light of the high cost of the operational research departments with the result that operations research lost its position as a mainstream practice and therefore its sought after status.

RL Flood also provides a useful explanation of how operations research failed to change its focus when business started to move its focus from product design to process design and market research[5]. He claims that this was the main reason why operations research lost out on becoming an important partner in strategic business decision making. [Flood, 2000, 46-47]

The operations research practitioners aiming to provide a scientific support service to management had to look further than the techniques of natural sciences to find reasons for the costly and embarrassing failures and increased irrelevance to management decision making in order to become more effective in their service to management decision making. This quest is obviously of much interest to this study. We are exploring the two main areas which emerged from this process, namely cybernetics and systems thinking, which are not unrelated to each other.

2.2.2.2 Cybernetics

The word *cybernetics* is derived from the Greek word *kubernetes*, which means "the pilot or rudder". It was first used by Plato in the sense of "the art to steer", or "the art to govern". Cybernetics can therefore be seen as "the art of managing and directing highly complex systems" of which organisations is one example.

Cybernetics was born in natural sciences when it was found that organisms could not be fully described by the mechanistic views of physics. Organisms portrayed attributes like the ability to adapt to their environment, the ability to learn from experience and the ability to be autonomous in their behaviour. These attributes were built into machines with the necessary new aspects (most importantly positive and negative feedback loops) being implemented to facilitate the simulation of the new

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[5] See the discussion of perspective 4 (The development of R&D) later in the study.

attributes perceived in organisms. In this way machines became more "intelligent". The best known technique stemming from of these findings in biology is undoubtedly neural networks, but the whole of artificial intelligence gives cognisance to this development.

As was already the established practice of the time, cybernetics was also applied in the business world. One example is Stafford Beer who developed his "Viable Systems Model" as a scientific model for organisations based on the tried and tested "control system". [Flood & Jackson, 2002, 10-11, 87-117] Beer's model represents an important change in approach - techniques from natural science (and engineering) were not directly applied to management of organisations, but rather used as basis for developing an organisational model.

2.2.2.3 From Operations Research to Systems Thinking

In the USA Operations Research moved on to become multi-disciplinary in the 1960's, and also to insist on a systemic approach rather than the instrumentalist approach in the 1970's. Russell Ackoff and C. West Churchman were the pioneers of both of these changes. Others followed and the systemic approach gained followers like Peter Checkland and Peter Senge, who both developed systemic models to be used in organisational decision making and problem solving (although the use of the word "problem" might be an "issue" for them).

2.2.2.3.1 Russell Ackoff: From scientific method to management guru

This transition from a purely instrumentalist view of operations research to a systemic view is illustrated in the migration of Russell Ackoff from a view that rigorous application of the classical scientific method in order to optimise business operations was the playground of operations research to being a management guru far removed from that early conviction in later life.

His early views are documented in the book "Scientific Method", with the sub-title "Optimising applied research decisions" [Ackoff, 1984]. He describes research in six phases, namely

1. Formulating the problem
2. Constructing the model

3. Testing the model

4. Deriving a solution from the model

5. Testing and controlling the solution

6. Implementing the solution

While there are other possible descriptions of scientific method rather than such a sequential procedural manner and we might prefer one of those rather[6], this description by Ackoff clearly indicates his early view that the scientific method is to be used for organisational problem-solving, answering of questions, and developing more effective procedures for solving problems and answering questions.

This period in his life started to fade, as can be seen in his well-known article "The Future of Operational Research is Past" [Ackoff, 1979]. In this article he makes six points to substantiate his view that Operations Research has failed:

1. "There is a greater need for decision-making systems that can learn and adapt effectively than there is for optimising systems that cannot.

2. In decision-making, account should be taken of aesthetic values – stylistic preferences and progress towards ideals – because they are relevant to quality of life.

3. Problems are abstracted from systems of problems, which are messes. Messes require holistic treatment. They cannot be treated effectively by decomposing them analytically into separate problems to which optimal solutions are sought.

4. OR's analytic problem-solving paradigm, 'predict and prepare' involves internal contradictions and should be replaced by a synthesising planning paradigm such as 'design a desirable future and invent ways of bringing it about.'

5. Effective treatment of messes requires interaction of a wide variety of disciplines, a requirement that operations research no longer meets.

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[6] See Chapter Four for a proposed alternative to such a procedural definition

6. All of those who can be affected by the output of decision making should either be involved in it so that they can bring their interests to bear on it, or their interests should be well represented by researchers who serve as their advocates." [Ackoff, 1999, 328]

These points clearly indicate why he separated himself from Operational Research and started a graduate programme called "Social Systems Sciences" [Ackoff, 1999]. It also illustrates the aim of systems thinking to focus on systems where there is a rich interaction between machines, humans and society (a similar goal is pursued by cybernetics). Since decision making almost invariably takes place in a social system (although in a technologically rich environment like the SA Navy some decision making might exclude human intervention/interpretation on product sub-system level, for which the above-mentioned objections of Ackoff are not valid), these objections are points to be considered in designing a decision support capability at IMT. These points also illustrate the common concepts between systems thinking and complexity theory, especially in the application outside of natural sciences. Both of these are now explored in some detail.

2.2.2.3.2 The development of Systems Thinking[7]

"It is in the nature of systemic thinking to yield many different views of the same thing and the same view of many different things... " (Russell Ackoff)

The holistic approach required to understand and treat "messes" with the due respect as proposed by Ackoff was the initial focus of systemic thinking. It was soon found that such an expansive view does not allow for practical application – there is always more to be taken into account.

A system is not seen by systemic thinkers as referring to something in the real world, but rather as a way we organise our thoughts about something in the real world. It is therefore an organising mechanism, assisting us to understand something in the real world better.

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[7] This description is taken from [Flood & Jackson, 2002] in its entirety, except where stated otherwise.

A system is described as a "number of elements and the relationships between the elements" [Flood & Jackson, 2002, 5]. The relationships between elements can be a complicated network which cannot be reduced to pair-wise comparisons of relationships as commonly assumed in closed systems. A system has the following characteristics:

1. A *boundary* can be drawn where the system has weak interactions with its environment. This boundary is "open" if inputs from the environment and outputs to the environment are allowed, otherwise it is "closed".

2. *Feedback* loops exist by which the behaviour of an element in the system can be influenced directly or indirectly by that very same behaviour via the feedback loop. Thus an element can be influenced by its own behaviour. This enables the system to learn.

3. An open system has *homeostasis*[8] as attribute, which enables the system to sustain an identity by retaining a steady state in a dynamically changing environment by interacting with that environment. This is in contrast with the property of *entropy* in closed systems.

4. A system might have *transformational processes* (i.e. transforms inputs into outputs). A system is said to be

    a. *purposive* if it has transformational processes, and
    b. *purposeful* if its purpose is internally generated.

5. A system which maintains an identity and stable transformational processes over time is exhibiting some form of *control*. Essential to this is the communication of information between the elements (via the feedback loops).

6. A system is *synergetic*: A system stabilised by its control mechanisms, and possessing an identity, can further be described by its *emergent properties*. These are properties of the whole system, but not necessarily present in any of its parts. In this way the whole is greater than the parts.

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[8] It is this attribute (homeostasis) which the first attempt to define the required capability at IMT could not provide. That led to the redefined study documented in this dissertation.

7. A system is often understood to be *hierarchical*. A sub-part of the system can be "blown up" and looked at in more detail, only to find that the sub-part portrays all the attributes of a system. Flood mentions that this can be termed as "systemic reduction" [Flood & Jackson, 2002, 7]. In this way there are different *levels of resolution* in a system.

In this way systemic thinking moved on to be able to focus on a *level of resolution*, so that the expansionistic behaviour of a holistic approach is tamed. It also provides the concepts by which the complicated (or complex) system can be described. Various methodologies were developed using these broad descriptive concepts. Examples include Ackoff's "Interactive Planning" and Checkland's "Soft Systems Methodology".

Morgan [Morgan, 1997] developed different systemic metaphors by which to describe organisations. By seeing which metaphor best captures salient features, a conceptual model is thus constructed by which the organisation (or problem case) can be understood. Flood & Jackson [Flood & Jackson, 2002] mention five such metaphors:

1. machine metaphor ("closed system view")
2. organic metaphor ("open system" view)
3. neurocybernetic metaphor ("viable system" view)
4. cultural metaphor
5. political metaphor

Looking at the attributes of a specific metaphor, an organisation or sub-system of an organisation can then be understood from the insights gained from that comparison. It is to be understood that the metaphor provides a restricted view of the organisation (or its sub-system), limited by the richness of the fit between the properties of the metaphor and the organisation. Maintaining multiple relevant metaphorical descriptions of the organisation simultaneously will therefore produce better understanding. In this way the problem of being expansive by setting a goal of "a holistic treatment" is removed, since it is implicit in the metaphorical approach that partial views are produced.

In his book "Rethinking the Fifth Discipline" Flood [Flood, 2000] develops new themes in systemic thinking. He borrows from complexity theory to point to

restrictions in Senge's well-known methodology, and then proposes new developments:

1. Realising the importance of boundaries, he expands on how to go about drawing feasible boundaries, thus creating the "action area" within the boundaries. He highlights the importance of *boundary judgements*.

2. *Prismatic thought* is described as a metaphorical way to describe the creation of many different images of the action area, of which the most plausible is then used to guide the choice of an improvement strategy. He offers prismatic thought as one facilitator to guide us in "learning in the unknowable" through dialogue and the creation of ideas and images.

3. He offers four *windows* by which organisations can be understood as an ideal type useful for categorisation of organisational life. These are

   a. Systems of Processes
   b. Systems of Structure
   c. Systems of Meaning
   d. Systems of Knowledge-power

4. He proposes and describes *systemic evaluation*, which serves his goal for retaining a formalised approach rather than to digress to heuristics and trial and error.

The "four windows" he proposes as ideal types are meant to give four different perspectives on the organisation, claiming that although they are not proven to be an exhaustive list, they are sufficient (as sufficient as a library cataloguing system) to look at all aspects of an organisation. In following this approach he comes very close to a methodology in complexity science, which makes use of "perspective filters" to approach complexity. He makes very explicit use of complexity theory in many of his arguments in "Rethinking the Fifth Discipline".

Starting off with the desire to overcome reductionism by employing a holistic approach led systemic thinkers to move on the "organised complexity" (the description of the system as given above), metaphorical views and lately to employ

windows (perspective filters) to look at the whole. This migration and development shows how reduction has been spurned; only to be redefined and labelled by other terminology when the expansionist result of its removal proved to be unproductive.

2.2.3 Complexity Theory

Providing an overview of complexity theory (called by some complexity science) is not trivial. This is because (as is shown in this study) the terminology used by proponents of complexity is not uniquely defined: Different schools of thought use the same words, but with different meanings. To further complicate matters there is the ongoing debate whether complexity science is a new scientific discipline (with its resultant toolbox of techniques available for scientific enquiry), or in fact the latest manifestation of scientific method which overcomes the "reductionist" approach of "the classical scientific method". In this study this distinction is largely ignored. The quest is rather to understand the broad thinking about complexity and chaos, in order to uncover the value added for practical problem solving both from notional and toolkit points of view.

2.2.3.1 Development of Complexity Theory

From a chronological point of view the development of complexity thinking is the latest development in scientific thought to be discussed in this study. As such it portrays all the confusion of conflicting views (and terminology) and the struggle for dominance of different views and theories as described by the emerging phase of a new paradigm described by Kuhn[9]. One example is the debate which endeavours to distinguish between "complicated" and "complex" where that which are just too complicated for complete description and study is distinguished from that which is inherently complex. What is discussed in this study as deterministic complexity and chaos are often termed "complicated" by the proponents of the notion of "inherent complexity". It is, however, not easy to find a clear line of demarcation between the two, as is illustrated by the discussion to follow.

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[9] See the discussion of Thomas Kuhn's work in the perspective on "Scientific Method" (§ 2.3.3.1.3)

2.2.3.2 Lack of understanding, or inherently complex/chaotic?

Gribbin [Gribbin, 2004, 5] is careful to distinguish between the use of the word "chaos" by the ancient Greeks and the current use of the word in natural sciences. "Chaos" used by the ancient Greeks is characterised by random events with no possible explanation, at the mercy of their gods. The current use in natural science imply deterministic chaos governed by simple underlying rules (but too complicated to be calculated faster than the unfolding of events in time). He states the difference between the two views of chaos like this:

"The kind of chaos that we are talking about now, what scientists of the twentieth century mean by 'chaos', is not the same as the kind of chaos that the Ancients referred to, or what we mean by chaos in everyday life. That kind of chaos is completely random and unpredictable even in principle. But the kind of chaos we describe here is completely orderly and deterministic, with one step following from another in an unbroken chain of cause and effect which is completely predictable at every stage – in principle. It is just that in practice it is impossible to predict in detail what is going to happen more quickly than events unfold in real time." [Gribbin, 2004, 70]

Social sciences almost without exception appeal to the definition of chaos as found in the ancient writings. A good example is found in its description by Kurtz & Snowden [Kurtz & Snowden, 2003]. The problem is that both Gribbin and Kurtz & Snowden then continue to take Poincaré's work as example of their definition of chaos! This explains the ambiguity in the meaning of the word "chaos" between natural and social sciences. It boils down to a basic difference in the definition of chaos (and complexity) and hence to a difference in the view of how to approach the study of these phenomena.

A short overview of both of these developments follows:

2.2.3.3 Un-deterministic Chaos and Complexity

Flood defines a system to be complex when it exhibits the following attributes:

1. It has a large number of elements
2. It has many interactions between the elements

3. The attributes of the elements are not pre-determined

4. The interaction between the elements are loosely organised

5. The interaction between the elements are probabilistic in behaviour

6. The system evolves over time

7. Sub-systems are purposeful and create their own goals

8. The system is subject to behavioural influences

9. The system is largely open to the environment (exhibits a weak boundary)

Flood & Jackson describes "complex" by differentiating it from "complicated" in that they indicate that an aeroplane is complicated, not complex. This is imagery often used by the proponents of un-determinsitic complexity.

Cilliers [Cilliers, 1998] offers a different list of attributes for complex systems in his book "Complexity & Postmodernism: Understanding Complex Systems". Cilliers clearly adheres to the view that there are systems which are inherently complex and therefore can only be modelled by a model at least as complex as itself. His list of attributes for a complex system is [Cilliers, 1998, 119-123]:

1. Complex systems consist of a large number of elements.

2. The elements in a complex system interacts dynamically.

3. The level of interaction is fairly rich. By this is understood that not all interactions are of the same nature, and that the level of interaction are growing or diminishing dynamically.

4. Interactions are non-linear. Cilliers holds that non-linearlity is a precondition for complexity. He states that "Linear, symmetrical relationships give rise to simple systems with transparent structures" [Cilliers, 1998, 120] He describes the social system as inherently non-linear.

5. Interactions have a fairly short range. Interactions are usually with other elements around them, although that should not necessarily be understood in geographical terms.   Since   there   is   no   meta-level   controlling   the interrelationships, the behaviour of a complex system is best described in terms of a multiplicity of local "discourses". [Cilliers, 1998, 121]   He distinguishes between short range interactions and long range influences, stating that local interactions can have long range influence.

6. There are loops in the interactions. Feedback is an essential aspect of complex systems. These can be intricately interlinked loops, also feeding back to themselves.

7. Complex systems are open systems.

8. Complex systems operate far from equilibrium. A constant flow of energy is necessary in order to change, evolve and survive as complex entities. As such complex systems survive as a process, being defined by what it is doing, rather than by its origin or its goals.

9. Complex systems have histories. The history of a complex system is not an objectively given state – it is a path distributed over the system and is always open to multiple interpretations.

10. Individual members are ignorant of the behaviour of the whole system in which they are embedded. "Single elements cannot contain the complexity of the whole system and can therefore not control or comprehend it fully." [Cilliers, 1998, 122]

Complexity theory in this definition has the characteristic to seek for understanding of the system in the interaction of elements, while traditional methods seek for understanding through understanding the structure and attributes of the elements, with any interactions serving to enhance the information of elements. This difference in where to find intelligence to understand behaviour is arguably the main value added by complexity theory to the subject of practical problem solving.

For many the result of complexity theory, namely that some systems cannot be fully understood, but only locally impacted upon without fully understanding the impact on the whole system, is disturbing. Yet it also opens the door to explore ways to understand as much as possible without trying to accomplish the impossible (a quest sure to fail). In this way complexity theory directs the search for understanding to more realistic goals. Stretching these to their limits can now become the goal of investigation.

Snowden [Kurtz & Snowden, 2003] assumes an un-deterministic definition of complexity (and chaos). He does not define it in the way either Cilliers or Flood & Jackson does, but rather gives content to the word by referring to the way the ancient

Greeks defined it – as something inherently random and unpredictable. He describes complexity science in terms of its use in deterministic complexity, namely the flocking of birds as governed by only a few rules. He then continues to argue that human behaviour cannot be described in this way – there are no such underlying rules which could be identified. He provides three reasons for this:

1. Humans are not limited to one identity.
2. Humans are not limited to acting in accordance with pre-determined rules.
3. Humans are not limited to acting on local patterns.

He calls his approach, to keep the human context foremost, "contextual complexity". He distinguishes this specifically with what he calls complexity science (i.e. deterministic complexity). He refers to the emergent order of complex systems as "un-order", thus challenging the assumption that any order not directed or designed is invalid or unimportant.   His approach to complexity is then to give specific importance to the emergent order (and therefore self-organisation) of complex systems, focusing on "contextual complexity". He claims that

"Humans use patterns to order the world and make sense of things in complex situations".

When he describes the domain of complexity from this perspective, he says

"This is the domain of complexity theory, which studies how patterns emerge through the interaction of many agents. There are cause and effect relationships between the agents, but both the number of agents and the number of relationships defy categorization or analytic techniques. Emergent patterns can be perceived but not predicted; we call this phenomenon *retrospective coherence*. In this space, structured methods that seize upon such retrospectively coherent patterns and codify them into procedures will only confront new and different patterns for which they are ill prepared. Once a pattern has stabilized, its path appears logical, but it is only one of many that could have stabilized, each of which would have also appeared logical in retrospect. Patterns may indeed repeat for a time in this space, but we cannot be sure that they will continue to repeat, because the underlying sources of the patterns are not open to inspection (and observation of the system may itself disrupt the patterns). Thus relying on expert opinions based on historically stable patterns of meaning will

insufficiently prepare us to recognize and act upon unexpected patterns." [Kurtz & Snowden, 2003]

The Cynefin Framework for problem (and context) categorisation is a sense-making device developed by Snowden and his research team. This framework is used in Chapter Three[10] as one of the problem categorisation frameworks for problem categorisation.

2.2.3.4 Deterministic Chaos and Complexity

Gribbin describes the development of the study of chaos and complexity in the natural sciences, pointing out that far from inhibiting its development, Newton's theory already demonstrated its existence in the n-body problem (even where n is as small as 3). It can be demonstrated by putting two balls on a pool table touching each other, and then rolling another ball to hit them both at exactly the same moment: The resultant movement cannot be predicted by Newton's laws! If the two stationary balls do not touch each other, Newton's laws can predict the resultant movement. To state it more formally:

According to Newton's laws, if one perfectly elastic sphere strikes two touching perfectly elastic spheres simultaneously, it is impossible to predict where the three spheres will go". [Gribbin, 2004, 17]

This was known to scientists long before the formal study of complexity and chaos in natural science, and long before Einstein's results. In this way Newton's work pointed to the need for further investigation in dynamics rather than inhibiting it.

Gribbin's account of the development of science leading up to the formal study of chaos and complexity provides much insight, especially when read in conjunction with Appendix A. Only the issues relevant to this study are mentioned here:

He points out that Galileo started a movement in science to construct idealised experiments and from the results of such experiments to extrapolate to the real world using correction functions (e.g. to correct for friction, the fact that the earth was not a perfect sphere, etc). In doing this scientists know that their models do not represent

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[10] See § 3.4.1.1.2

the real world, but follow the pattern of experimenting with idealised objects under ideal circumstances in the quest to extract general laws (or rules) which can be adapted for real world application through correction functions. This was also the method Newton followed. In fact, this remained the practice in science for about 400 years.

He states that complexity (and chaos) is really nothing more than "the sensitivity of a system to its starting conditions and to feedback" [Gribbin, 2004, 3] (where feedback is facilitated by an iterative process where the result of the previous iteration feeds into the next interation). He states that

" *The great insight is that chaos and complexity obey simple laws – essentially, the same laws discovered by Isaac Newton more than three hundred years ago. Far from overturning four centuries of scientific endeavour, as some accounts would lead you to believe, these new developments show how the long-established scientific understanding of simple laws can explain ... "*(complex phenomena) [Gribbin, 2004, 3]

Poincaré discovered that many systems in the real world are very sensitive to their initial conditions, and that they move away from the starting conditions in non-linear fashion. This means that a small difference in the initial conditions can lead to very different changes of the system over time.

It was in the study to forecast weather, first developed by Richardson, that Edward Lorenz noticed in 1959 how a very small change in initial values led to large differences in the forecast. The impact of changes in the initial conditions varies from time to time. The Lorenz ("Butterfly") attractor shows that sometimes changes in the initial conditions would not have a relatively small impact (when the path of the system is in one of the stable states). But in the cases that it is moving across to the other pool, very small changes lead to considerably different end states. It is therefore possible for weather forecasters to know if they find themselves in a relatively "predictable" stage or not by varying the initial conditions slightly and calculate the differences in outcome. Figure 2-3 shows the well-known "Butterfly" in Lorenz' now famous paper in 1972 entitled – 'Does the Flap of a Butterfly's Wings in Brazil Set off a Tornado in Texas?'
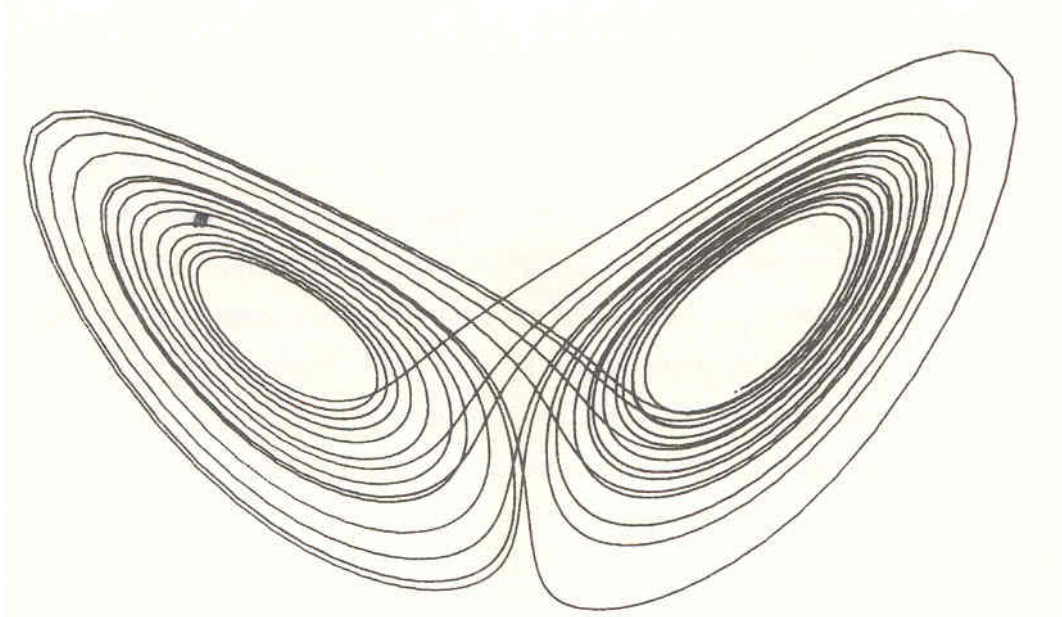
Figure 2-3 The Lorenz (" Butterfly") Attractor [Gribbin, 2004, 58]

2.2.4 Complexity Theory and Systems Thinking - Conclusions

Morgan uses the Lorenz Attractor as a metaphor to approach the complex problem of managing organisational change [Morgan, 1997, 268].   The Lorenz attractor is, however, a product of deterministic complexity, and it is not immediately clear that it can be used for induced attractors[11] [Despres & Chauvel, 2000, 237-267] to manage change in the way Morgan assumes, since it is not clear if modelling of induced (un-deterministic) attractors is similar to modelling the attractors inherent in deterministic complexity.   This illustrates the enmeshment of meaning when dealing with complexity – its actual definition is often blurred in any given text, crossing the boundaries between un-deterministic and deterministic complexity without warning or explanation, also not taking into account the difference in meaning (and therefore the possible difference in the required approach to model it).   It is more often the proponents of un-deterministic complexity that crosses this boundary without warning

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[11] Induced attractor is a term introduced here to indicate that in social complexity attractors can be introduced by the advocates of change or as a management tool. These attractors are superficial in the sense that they can be removed again at will. In deterministic complexity attractors are inherently part of the nature of the system. The fact that induced attractors can be utilised in social systems, together with the choice of perspective filters each with an appropriately chosen boundary, could possibly be a major differentiating factor between deterministic and un-deterministic complexity, but further investigation of such a postulation falls outside of the scope of this dissertation.

in the literature. It is for this reason that <u>Cilliers' description of complexity is used in this dissertation when referring to un-deterministic complexity</u>, since his definition of complexity is consistently un-deterministic.

The descriptions of the different views about complexity and chaos are given to illustrate that both social and natural science focus on "elements and the relationships between them" as systems, and complexity has emergence, feedback, non-linear relationships, etc when looking at chaos and complexity. However, the fact that the definitions of the words are different in the two disciplines makes for fundamentally different approaches: As an example note that while Cilliers states that complex systems are insensitive to their initial states and find identity in the process of interaction and evolving patterns, Gribbin states that due to the non-linear nature of complex and chaotic systems the initial state is very important and can lead to radically different trajectories.

For the purposes of this study the insight that a complex system cannot be fully modelled or understood, only partial (local) understanding is possible, even though local changes can have wide influence, is an important insight. This unsettles those who wish to fully model complex systems and upholds the ultimate goal of science to accurately describe all systems and uncovers all knowledge fully. Yet it also opens the door for a redirection of the quest to learn: Knowing this redirects the attention to *how best to explore what can be known about complex systems without claiming the impossible*. The following are taken as important insights for this study:

1. Partial knowledge is obtained by imposing the best possible reduction (even though some proponents of complexity would not easily acknowledge that their solutions do impose reduction) that seems plausible for the purpose of the specific enquiry. Examples taken from both systems thinking and complexity include

    a. As already mentioned Flood points out that the different *Levels of Resolution* of systems represent a reduction which tames the initial expansionist ideals of systems thinking into something more manageable for practical application.

b. Drawing boundaries where the links between elements are weak and exploring the action space within those boundaries to gain understanding.   This is done knowing that the boundaries are superficially imposed and only valid for a limited time due to the fact that interrelationships change dynamically in strength and richness.

c. Morgan's metaphors in systems thinking represent a way to approach systems from a plausible representation of the system (i.e. from a meta-level, a conceptual abstraction of a conceptual representation), making it (or maybe its sub-systems) more understandable from that perspective.

d. Flood proposes prismatic thought and the four windows to look at organisations as already mentioned.

e. Snowden's proposal of using perspective filters in the quest to understand complex systems and function in order to function in a complex space[12].

2. The non-linear nature of interrelationships makes for a rich and unpredictable behaviour of the system, so that it defies any attempt to predict its behaviour and project into the future what was learned from the past.

3. Care needs to be taken not to create an impression that systems which are complex (whether they are perceived to be so because they cannot be modelled faster than the rate of change in real life, or whether they are perceived to be inherently complex) can be completely modelled and fully understood through constructing a representation or model, even when both elements and interrelationships are taken into account. This fallacy is often the reason why very expensive systems fail – they do not take into account that they cannot produce a full description of the complex system.

4. Complex systems have histories and are constantly busy making history. Taking a static snapshot in time of a complex system with a view of

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[12] Snowden's Cynefin Framework is discussed in § 3.4.1.1.2.

understanding the system is only another way to impose a reduction on the system – a reduction that is very often not useful for more than a very short period of time. Studying complex systems, or trying to manage complex systems, can only be done by constantly interacting with the system and adapting to the emerging patterns and evolving nature of the system.

The way this study is conducted follows these insights regarding complex systems, namely to "try to find meaningful relationships among different discourses" [Cilliers, 1998, 118] rather than to follow a single sequential line of thought which seeks to exclude or discredit other (sometimes dissenting) voices. It develops different useful perspectives and seeks for meaningful commonalities among those which could enhance understanding relevant to defining the best description of a scientific problem solving capability taking current knowledge into account.

2.3 Perspective 2: Scientific Method

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┌─────────────────────────────────────────────┐
│         Criteria for Choosing Perspectives    │
└─────────────────────────────────────────────┘

  ┌──────┐  ┌──────┐  ┌──────┐  ┌──────┐  ┌──────┐
  │  P1  │  │  P2  │  │  P3  │  │  P4  │  │  P5  │
  └──────┘  └──────┘  └──────┘  └──────┘  └──────┘

┌─────────────────────────────────────────────┐
│      Conclusions from synthesis of Perspectives │
└─────────────────────────────────────────────┘
┌─────────────────────────────────────────────┐
│         Finding Commonality in Pluralism      │
└─────────────────────────────────────────────┘
┌─────────────────────────────────────────────┐
│      Framework(s) for problem Categorisation  │
└─────────────────────────────────────────────┘
┌─────────────────────────────────────────────┐
│      Process of Scientific Problem Solving    │
└─────────────────────────────────────────────┘

┌─────────────────────────────────────────────┐
│   Case Study:  Creating Knowledge through     │
│                Complexity Methods             │
└─────────────────────────────────────────────┘
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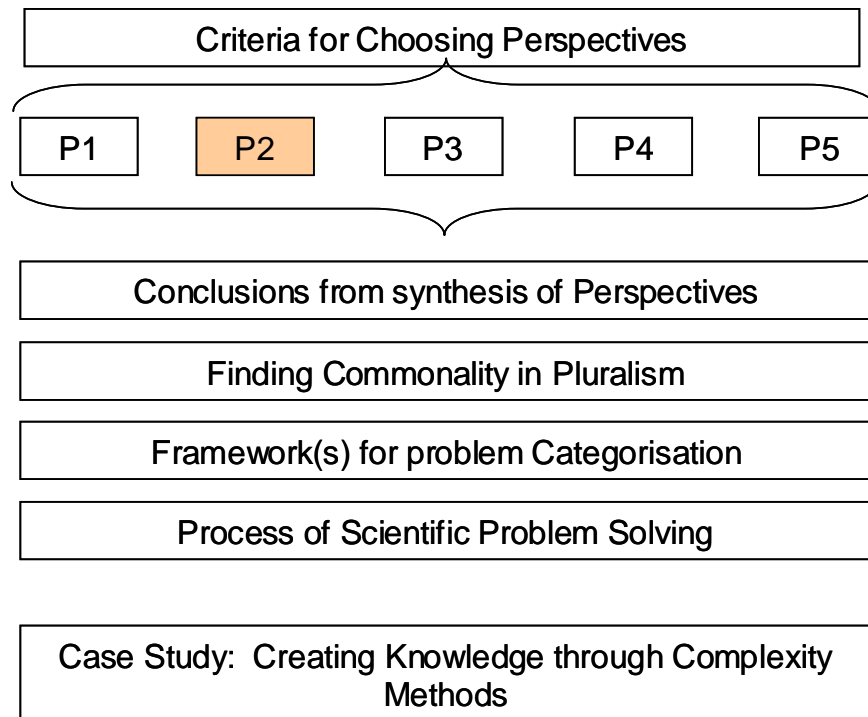
Figure 2-4: Dissertation Road Map

A study of the scientific method is included to add value in defining the process of decision support at IMT. This is done for the following reasons:

1. A problem-solving capability is one of the goals of a decision support capability at IMT, since decision support is often required where there are unresolved problems. In cases like that solving the relevant problem is a necessary ingredient of decision support. Problem-solving is a proven strength of scientific method.

2. Scientific method has proven itself to be a vehicle of unequalled success in knowledge creation. This would add value to IMT's mandate of assisting the client in maintaining appropriate professional independence.

3. Assuming on the basis of the previous two points that a _scientific_ decision support capability will provide the best possible value for the client, the question arises "When is a decision support service scientific?"   Studying the nature and method of science is therefore included in this study to give content to the understanding of this question.

2.3.1   Historical development

It is intriguing to find that over the centuries many different thinkers came to the same conclusions again and again, namely that we are unable to prove something to be true and to conclusively justify any specific theory or hypothesis. The quest to resolve this perceived weakness remained the pivot point around which different views of scientific method structured themselves until very recently, even for most part of the twentieth century:

1. Bacon (1561 – 1626), who can rightly be called the father of induction, believed that we can build knowledge from *previously established truth* in an ever increasing way through keen observation. The previously established truth was also found through the same method of keen observation.

2. Descartes (1596 – 1650) believed in the infallibility of knowledge, and ascribed error to sin. He believed that through questioning everything that has not been proven as truth we can, in a deductive way, not only find all the underlying facts, but also build from that the objective truth. His is a mixture of deductive reasoning and a definition of truth which are linked to observation.

3. Hume (1711 – 1776) posed for the first time the serious concern about the fact that we cannot argue from observations to a justified conclusion, thus questioning the foundation of induction. He maintained that induction provides psychological justification of theories only, not logical ones, but nevertheless maintained that psychological justification was sufficient, since "our reason ought to be the slave of our passions".

4.   Foundationalists (like Kant (1724 – 1804)) believed that we have a priori knowledge of the truth. He believed that truth was absolute and knowledge infallible.

5. Institutionalists (like Kuhn (1922 – 1996)) believed that since we cannot justify our basic foundation, we need to adhere to a belief system based on authority, group acceptance and its customs and habits. In this view science is a process of establishing paradigms, which are unjustifiable, but eventually accepted by the majority through 'persuasion' and 'conversion'. They have given up on the search for truth, and are guided by acceptance of the paradigm as basic framework. They hold

to the requirement that theories must be justified. They therefore distinguish between "normal science", which is a puzzle-solving activity within the accepted paradigm, and "scientific revolutions", which take place from time to time when the anomalies become so numerous that the accepted paradigm can no longer be tolerated, and is replaced by an alternative paradigm which provides a new framework and removes the anomalies. It is important to note that they do not see any paradigm as an improvement on the previous, but the change from one paradigm to the next as discontinuous, hence the term 'revolution', i.e. growth of scientific knowledge takes place within a paradigm, and is not transferred from one paradigm to the other.

6.   Critical Rationality as proposed by Popper (1902 – 1994) turned away from justification as a requirement to prove theories; He retained objective truth as a regulative ideal, while criticism becomes the way we interact with our theories in order to refute them, rather than trying to justify them. His turning away from justification proposed a feasible way to retain rationality, while retaining our commitment to be guided by a commitment to the truth as a guiding ideal even though we are aware of the fallibility of all theories. He defines truth as being "in accordance with fact". He proposes a method of trial and error for theory choice, where our 'conjectures' (i.e. hypotheses) are guesses, which must be tried through empirical methods to test and 'refute' them. In this way we are ever learning more.

A more detailed discussion of the historical development of scientific thought and the method of science follows:

2.3.2 Developments prior to the twentieth century

Even though it might be possible to give a description of how the views on scientific method developed in chronological order, it would prove to be very difficult to give a purely sequential and logical development of thought, due to the fact that there were various lines of thought, often opposing each other actively, developed simultaneously. For the most productive scientists their goal was often not to describe their method as much as to actually "do the work of science". They sometimes described their method in very little detail, only giving enough information to answer queries that came after the publication of their discoveries (e.g. Newton). Yet there were also those who spent most of their time thinking about the method of science. We include both these groups in this discussion, because the word "scientist" is

relatively new, introduced for the first time in the 19th century by Whewell [Alexander, 2001, 11]. The work which we call science today was called "natural philosophy" until the nineteenth century, with the word "natural" denoting the study of nature. Therefore the philosophy of science plays as much a role as the practice of science in the development of useful views of scientific method. With this in mind we probe history from various angles, which, with hindsight[13], can be identified as important for the development of notional understanding and practice in scientific method, as we know it today. These include

1. The quest for truth (or, for much of the twentieth century, some abandoning that quest)
2. Mathematics, geometry and logic
3. The rise of Empiricism and realistic Mathematical Models
4. Probability and certainty of knowledge gained from scientific endeavour

However, a few notable descriptions of scientific method, documented in the course of history, are also included as part of the historical overview.

The quest for truth, how certain knowledge is defined, and which criteria for truth are accepted, run like a thread through the discussion, and in fact serves as the backbone for the various views of scientific method. As scientists' and philosophers' views change on this subject, so do their views of scientific method.

2.3.2.1 Mathematics, geometry and logic.

The ability to write is important to document scientific discovery, but it was the numeric notation that was important for the development of science. Although the Greeks developed the first alphabet, their practice of assigning numeric values to the alphabetical symbols was not a workable numerical system for arithmetic. Consequently the Arabic numerals (actually developed in India) were introduced into the West in medieval times.[Crump, 2002, 20]

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[13] Note the illustration of *retrospective coherence* in complex systems.

Legend has it that Thales (624 – 545 BC) correctly predicted an eclipse. His most important contribution was that he propounded a cosmology identifying water as the original substance and the basis of the universe. In doing that he initiated a trend in thinking about matter which has lasted to today.[Crump, 2002, 25]

Pythagoras lived in the sixth century BC. He was impressed by two discoveries, namely the fact that musical harmonies were based on numerical ratios, and the fact that the "right angle" was connected to the ratio 3:4:5. This led him to the generalisation that all things were, in essence, numbers or ratios of numbers. From this he devised a system based on the so-called *gnōmōn*, from which he was able to relate forms to numerical sequences. 'Forms' are thus numbers or ratios of numbers. It is important to see that for Pythagoras arithmetic was basically counting of dots rather than measuring. [Popper, 1996, 75 – 93]

He is credited with the famous Pythagoras theorem, and his followers were the first to recognise that the earth was a sphere, and they later also derived for the first time the square root of 2, which is an irrational number. (It is interesting to note that Pythagoras responded to the discovery of irrational numbers by having the disciple who discovered the square root of 2 drowned!). The existence of irrational numbers overthrew his arithmetical system of describing the 'form' or 'true and certain knowledge' (*epistēmē = scientia = science*) of the 'Unchanging and Real Universe' in

Prime Numbers
1, 3, 5, …

Numbers
1, 2, 3, 4, …
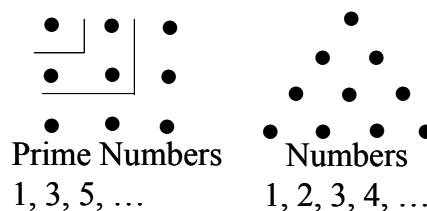
Figure 2-5 Pythagoras' Numeric System

terms of arithmetic, but not before Democritus (460 – 370 BC) developed his theory of atomism from it where the world consisted of empty space (void) and of atoms. According to his model the atoms do not change – all change is because of the arrangement of atoms in space. He derived his theory from the deductive theory of Parmenides, whose theory made it difficult to understand change. Unfortunately all that is available of Democritus' work today is as much as was documented by Aristotle, and Aristotle came to the conclusion that he was wrong. Nevertheless, his

was a marvellous achievement, providing a theoretical framework for the explanation of most of the properties of matter such as compressibility, hardness etc. Archimedes (287 – 212 BC) later acknowledged Democritus as the first one to formulate the theory of volumes of cones and pyramids. His most fascinating achievement was his doctrine of "shortest distance" and "smallest time interval".

However, the existence of irrational numbers overthrew both Pythagoras and Democritus' theories. It is possible that Democritus was not aware of this development, since he never mentioned irrational numbers. Plato (428 – 348 BC) realised this, and sought to replace the arithmetic model with geometric models, especially models explaining the planetary movements. While he changed the underlying mathematical model from an arithmetical one to a geometrical one, he continued to hold the view that the 'form' denotes the 'true knowledge'. Euclid, a student of Plato, developed in his 'Elements' an autonomous geometrical method for the description and explanation of the world. In this way he provided Newton and also Einstein with the seed of their intellectual toolbox. In fact, it is important to note that the influence of the ancient Greeks in the development of scientific method that withstood the test of time is basically their focus on and development of mathematics. Another of Plato's students, Aristotle (384 – 322 BC), influenced the development of thought regarding science and scientific method profoundly for almost 2000 years. Bertrand Russell held that everything that Aristotle said on scientific matters ultimately proved an obstacle to progress [Russell, 1946].   However, Aristotle's impact on the development of scientific method was immense.

Aristotle became more influential than Plato, writing on many subjects including amongst others physics, astronomy, ethics, biology, politics, logic, and rhetoric. His view was that everything could be explained from understanding the cause of it. Everything had a cause. He therefore valued proof by demonstration (i.e. arguing from first principles) above experimentation and mathematical proof for all areas except the natural world. Syllogism became a very important logical way of reasoning from first principles. He constructed a model for astronomy in which the earth is the centre, with spheres around the earth for the moon, planets and sun. The outer sphere (these spheres fit into each other like Russian dolls) contained on its surface the stars. Although this model was refined later by Ptolemy's model, the view

that the earth was the centre and that all heavenly bodies circle around the earth remained the accepted view when Copernicus started his work, showing that the earth was not the centre, but rather introducing a helio-centric model which fitted observations better. It was common practice to rely on observation through the senses to find the causes with logical reasoning as the only way to argue from those observations. Mathematics was seen to be applicable only in describing abstract concepts, training the mind, but not in deriving any meaningful results regarding the real world. The views of Aristotle and his followers dominated many areas of human thinking for almost 2000 years to come. Especially the role of experimentation, the use of instruments for observation, and mathematical proof claiming relevance to the real world, were resisted for a long time. Aristotle's main achievement relevant to scientific method was his focus on logical reasoning from first principles (which he called causes) and mental experiments.

2.3.2.2 The rise of empiricism and realistic mathematical modelling

The toolbox of science looked very much like Aristotle left it when Galilei appeared (1564 – 1642) on the scene, although a helio-centric model of astronomy was already constructed by Copernicus (1473 – 1543), and the elliptical model for planetary movement by Kepler (1571 – 1630). He not only introduced the use of instruments (the telescope) into scientific observation, but also experimentation and resultant mathematical modelling to explain the results. He also built on the work of these two men in using the predictive power of mathematical models to add to their weight, because he was able to make more accurate measurements using the telescope. This set the scene for Newton (1642 – 1727), whose success with a model of mechanics transformed natural science. Newton's method was essentially hypothetico-deductive, making extensive use of experimentation and mathematics to test his hypotheses, but not to construct his hypotheses. His introduction of gravity[14], a force not observable with the senses, was largely because of his vigorous experimentation, mathematical modelling and the success of using accurate instruments for measurement and the predictive power of his models. This conclusively overthrew the notion to prefer observation by the senses. Newton was highly successful, and

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[14] Gravity is an example of what Gribbin calls "correction terms" to make ideal models realistic, as discussed in § 2.2.3.4

only after more than 200 years, when instrumentation became accurate enough, were Einstein (1879 – 1955) able to produce a more accurate model for dynamics. This model superseded Newton's model, but contained it.   Testing theories by a combination of good experiments (not limited to passively observing nature, but also probing it by controlled and planned experiments), accurate measurements, mathematical modelling with accurate predictive power proved very successful to provide useful models of the natural world.

From the time that instruments were introduced into science, development in natural science was marked by development in accuracy of measurements.   Notably the telescope and the microscope had major impact. So since then physical sciences have focused on the very big and the very small, the very hot and the very cold, probing nature at its limits.   Instrumentation became very expensive while this quest continued. Yet it enabled the discovery of the four physical forces governing the properties of matter, namely gravitation, electromagnetism, and the weak and strong nuclear forces as more and more accurate measurements were possible.

This interaction between hypothesis, experiment, logic and mathematics continued in various forms, with disagreement on the role and prominence of each of these. The main difference was articulated by the views of the schools of thought in scientific method that developed. There was classical empiricism, seeing observation as the ultimate source of knowledge, of Bacon, Locke, Berkeley, Hume and Mill which was prominent in Britain.   In Europe classical rationalism or intellectualism, seeing intellectual intuition as the ultimate source of knowledge, of Descartes, Spinoza, and Leibniz prevailed. Empiricism conquered the USA, and also became increasingly important in Europe, driven by developments of measuring instruments as described above, with further successes as more accurate measuring instruments became available enabling experimenters to probe the limits of the very big, the very small, the very hot and the very cold.

The prominence of empirical method made inductive reasoning (i.e. reasoning from observations to general principles) a very important part of scientific method. It is important to note that empirical methods became not only a way to test hypotheses, but that increasingly new hypotheses were constructed from empirical work through inductive reasoning. At the same time the question of how true such generalisations

were, became a point of much debate. While deductive reasoning provides true conclusions from true premises, the same cannot be said about the results of inductive reasoning. A whole new field of development began, trying to overcome, or at least quantify, this problem of induction. This is discussed under the subject "Bayesian Reasoning as Scientific Method" later in the study. This problem has proven to be one of the main dividing lines of different views of scientific method, together with the problem of the role of rational and objective knowledge in scientific method.

2.3.3   Scientific method in the twentieth century

A short overview of the development of scientific method in the twentieth century is given.

2.3.3.1 Induction

Since the time when Pythagoras generalised his few observations of numerical order to view all phenomena as numerical ratios, induction (i.e. reasoning from the specific to the general) has been an intuitive way to reason. Yet by the rules of logic, the truth of a conclusion reached by this way of reasoning cannot be shown from the truth of the specifics it was generalised from. Hume's objection to induction poses an additional problem; it cannot be used where consistency, i.e. no change in space and time, is not present. Although induction became the preferred way of arguing when empiricism gained ground, these objections remained.

2.3.3.1.1 Logical Positivism

Rudolph Carnap (1891 – 1970) was part of the Vienna Circle. (The Vienna Circle acknowledged Ludwig Wittgenstein as one of their three most prominent thinkers, but he was never really part of the group. While his views influenced their work, his focus was not scientific method, but rather the role of philosophy. His work is therefore not discussed in any detail here.) The Vienna Circle developed logical positivism, which tried to make a clear distinction between science and metaphysics, accepting only that which can be verified through observation. They accepted only two kinds of statements, namely those that were true or false by virtue of the meaning of their own terms (including also equations and logic), and those who were empirical and therefore open to verification. Thus all moral, ethical, religious and other metaphysical statements were seen to be meaningless. Only the material world could

be described in this way. While their interest was a philosophical one, their views are relevant to this study because they held that the main function of philosophy was to sharpen and clarify concepts employed by scientists. Yet they soon ran into trouble when it became clear that defining what can be accepted as verification was not that easy. So instead of solving the problem of uncertainty by their restrictions, they merely shifted it. Indeed, it was found that the very claims of logical positivism could not be validated empirically, so the theory fell because of its own internal inconsistence.

Rudolph Carnap's hypothesis was that just as there exists a formal logic for deductive reasoning, which provides absolute certainty of results, so there also exists a formal logic for inductive reasoning. Defining this logic was his main focus. Should he succeed, the results of induction could finally provide validity similar to deductive reasoning rather than only a probability.

Gower [Gower, 1997, 213-233] discusses the work of Carnap at length, giving the main goal of constructing a meta-language giving the formalised structure of inductive reasoning. However, he emphasises the difficulties that Carnap ran into, of which the two most prominent ones are that

1. The probability for all natural laws must be zero according to Carnap's hypothesis, and

2. The observer remains free to choose from an infinite set of possible hypotheses of an inductive logic. Different from deductive logic, not only hypotheses (which are the equivalent of premises in deductive logic according to Carnap) are required in inductive logic, but also degrees of belief (probabilities) in each hypothesis as a starting point.

Carnap failed to produce an inductive logic, so that the "feet of clay" of induction remained a problem.

2.3.3.1.2 Bayesian reasoning as scientific method

The historical background for the issues discussed in this section is given in Appendix A under the heading "Probability and (Un)certainty". A short overview of Bayesian

Reasoning is given there. Here only the significance of its role in defining scientific method is discussed.

Gower concludes his study of scientific method as follows:

"*It is, however, by no means clear that the practice of scientists ... can be reconciled with a Bayesian account of reasoning.*"

Yet Gower continues to accept Bayesian reasoning as the best current description of scientific method anyway, defending this by saying

"*... And even if there is some difficulty in accepting this, we face an even greater difficulty if we reject it. For by accepting it we are able to claim that the reasoning used in science is, in essence, Bayesian. By rejecting it we imply that some alternative account of reasoning is needed, and currently there is no such account that has so many of Bayesianism's advantages and so few of its disadvantages.*" [Gower, 1997, 233]

This resignation of Gower illustrates the magnitude of the problems encountered in the study of scientific method during the twentieth century.

Quite apart from the fact that Bayesian Reasoning is inductive, and therefore shares the weakness of induction, probability itself also poses a problem. Since statistics (probabilistic modelling and/or reasoning) developed and became a formidable contender for prominence in scientific method during the twentieth century, a short overview of the main issues are given here.

Salsburg [Salsburg, 2001] describes the spectacular rise of statistics to permeate common culture as much as it came to dominate science in the twentieth century. What is of interest here is the conclusion he provides in the last chapter "The Idol with Feet of Clay". He discusses statistics from a philosophical perspective and points out that

1. Cohen showed that decisions based on probabilistic argument are not logical. His two paradoxes illustrate the problem of inductive reasoning already described above.

2. Kolmogorov's definition of probability is "Probability is a measure of sets in an abstract space of events." When we wish to apply probability to real life situations, that abstract space needs to be identified for the problem at hand. Fisher proposed what is called the "permutation test", which requires random sampling. This resolves the problem of identifying the abstract space for a designed experiment, provided that the sampling is random. This does not apply to observational data, however. Sample Survey Theory provides a second possible way to define the abstract space, which is a common way to employ statistics. However, Salsburg points out that statistical models are used more and more for observational studies to assist in social decisions – this practice is dubious, as the abstract space cannot be defined for observational data, so that different models will yield different conclusions.

3. JM Keynes developed a personalised definition of probabilities not linked to Kolmogorov's definition. According to Keynes, decisions can be made if it is known that the probability for one event to take place is higher than for another event. For Keynes' probabilities to be useful, the person who invokes them still have to meet Savage's criteria of coherence. However, Kahneman and Tversky investigated in the 1970's and 1980's whether or not people met Savage's criteria of coherence. They found no-one did (which shows that human reasoning is not according to Bayesian reasoning). In addition, they found no consistency in people's ability to keep a consistent sense of what different numerical probabilities meant. (That means that according to their results the weather forecaster trying to explain what the difference is between a 90 percent probability for rain and 75 percent probability does not really consistently interpret that in the same way.)

4. He points out that the idea of distribution can exist outside of probability theory, and that examples of that already exist in quantum techniques and in some Bayesian techniques. He argues that it should be possible therefore to redefine the foundation of statistics so that it would not rest on probability, but that remains to be done.

Having pointed out these problems in statistics, Salsburg concludes with

"As we enter the twenty-first century, the statistical revolution in science stands triumphant. It has vanquished determinism in all but a few obscure corners of science. It has become so widely used that its underlying assumptions have become part of the unspoken culture of the Western world. It stands triumphant on feet of clay. Somewhere, in the hidden corners of the future, another scientific revolution is waiting to overthrow it ...". [Salsburg, 2001, 309]

2.3.3.1.3 Thomas Kuhn (1922 – 1996)

Thomas Kuhn was the first to approach scientific method not from a methodological perspective, but from a sociological perspective. He observed that history records "scientific revolutions" [Kuhn, 1996], which causes dominant scientific thought to move from one paradigm to another. He describes a paradigm as follows:

" ... I mean to suggest that some accepted examples of actual scientific practice – examples which include law, theory, application, and instrumentation together – provide models from which spring particular coherent traditions of scientific research." [Kuhn, 1996, 10]

He observed from his case studies that science moves from paradigm to paradigm, preceded by a crisis. A crisis develops when the current paradigm consistently fails to resolve some anomalies. While the presence of anomalies are part of the "normal science" practice (i.e. the normal work of the scientific community while a specific paradigm is firmly established), ongoing failure to resolve anomalies lead to a crisis. This crisis is preceded by pronounced professional insecurity due to the failure of the accepted paradigm to resolve the anomalies. To describe this in Kuhn's words:

"As one might expect, that insecurity is generated by the persistent failure of the puzzles of normal science to come out as they should. Failure of existing rules is the prelude of the search for new ones." [Kuhn, 1996, 68]

A crisis leads to the search for new theories, techniques and instruments to resolve the crisis. New candidates, which can solve the anomalies, but also most of the important puzzles which the previously accepted paradigm has solved succesfully, become contenders for the position of the new "accepted paradigm". The new contenders grow stronger by acceptance of the relevant scientific community. He makes it clear

that giving up adherence to one paradigm is often a time-consuming effort, characterised by much professional turmoil. He states that changing a paradigm is

" *... a reconstruction of the field from new fundamentals, a reconstruction that changes some of the field's most elementary theoretical generalizations as well as many of its paradigm methods and applications. During the transition period there will be a large but never complete overlap between the problems that can be solved by the old and by the new paradigm. But there will also be a decisive difference in the modes of the solution. When the transition is complete, the profession will have changed its view of the field, its methods and its goals.*" [Kuhn, 1996, 85]

He describes the turmoil during the process of changing a paradigm as follows:

"*Confronted with anomaly or with crisis, scientists take a different attitude toward existing paradigms, and the nature of their research changes accordingly. The proliferation of competing articulations, the willingness to try anything, the expression of explicit discontent, the recourse to philosophy and to debate over fundamentals, all these are symptoms of the transition from normal to extraordinary research.*" [Kuhn, 1996, 90,91]

He introduced the concept of incommensurability, stating that knowledge is not built across paradigms, only within a specific paradigm. That is because

"*... the reception of a new paradigm often necessitates a redefinition of the corresponding science. Some old problems may be relegated to another science or declared entirely 'unscientific'. Others that were previously non-existent or trivial may, with a new paradigm, become the very archetypes of significant scientific achievement. And as the problems change, so often does the standard that distinguishes a real scientific solution from a mere metaphysical speculation, word game or mathematical play. The normal-scientific tradition that emerges from a scientific revolution is not only incompatible, but often incommensurable with that which has gone before*". [Kuhn, 1996, 103]

In essence Kuhn describes the development of a scientific discipline as a series of S-curves, each called a paradigm. Each S-curve (showing growth of the discipline by its success rate in solving the puzzles the paradigm presents when compared to reality)

has an emerging, growth, mature and decline phase. While knowledge is grown within a paradigm, it is not necessarily grown across paradigms due to the inherent difficulty to communicate properly across the boundaries of paradigms as described above.

A short description of each of these phases as described by Kuhn is given below:

Emerging Phase:

This is the phase when new theories compete for dominance. It is the transition phase characterised by Kuhn as described above. Kuhn does not believe that scientists reject the old paradigm, but rather that they embrace the new paradigm. Letting go of the old always entails embracing a new paradigm.

Growth Phase:

A new theory becomes dominant when it is accepted by the majority of the scientific community and start to embody the accepted scientific view. During this phase research is very productive as many new puzzles are solved. The new generation scientists find a career in the new paradigm rather than the old, because it provides more research opportunities.

Maturity Phase:

When most puzzles are solved, and the paradigm is thoroughly entrenched in scientific thinking, this phase is entered. The anomalies which prove to resist repeated effort to resolve them become prominent, so that the build-up to a new crisis is started.

Decline Phase:

When new theories start to prove more productive in research, able to solve some of the anomalies, the old paradigm starts to lose its support. However, it does not lose its appeal until one of the new theories start to become dominant and enter its growth phase. It is by accepting the new paradigm that the old falls into disfavour.

Response to Kuhn

Kuhn's work gained prominence during his active career and also in the latter half of the twentieth century. He is a pluralist, and an inductionist. It is only in the last decade that a response to his work started to erode his popularity.

Forster [Nola et al, 2001] remarks that

"*Kuhn was mainly interested in the social psychology of science, while philosophers of science look to science as an objective source of knowledge. Rationality in this objective sense is not about what scientists believe. The question is not settled by taking a survey of scientists asking 'what is the goal of science' or 'what are the standards of the scientific community'. Nor is it concerned with what scientists think science <u>ought</u> to be. It is about the <u>achievements</u> or the potential achievements of science, and the causes responsible for those achievements*". [Nola et al, 2001, 246]

He concludes his discussion with

" *Is there progress in science? Is there any sense in which science provides knowledge of the real world using methods that are reliable to some degree in achieving those goals? These are the hard problems in the philosophy of science, and they will never be answered if the philosophy of science is left in the hands of social psychologists*". [Nola et al, 2001, 248]

Kuhn's influence on thinking about science and scientific method in the latter part of the twentieth century is undisputed. Recent readings of his work like the above brings new perspective: While he provides insight to understand the current development phase of a discipline (which is very valuable for this study), he does not address the issues which are at the heart of the debate about the scientific endeavour.

2.3.3.2 Deduction as scientific method

Since Kant and Descartes were discredited by the successes of twentieth century scientific discoveries (notably Einstein's relativity theory and the subsequent rise of relativism in scientific thinking), deduction was not seen as important by many of the scientists and philosophers of science in the twentieth century. Popper is a thinker who is best understood by reading his own writings, rather than by reading

contemporary critiques of his work. He was a controversial person who was misinterpreted and misrepresented by many of his contemporaries. For that reason his views are discussed in some detail.

2.3.3.2.1 Karl R. Popper (1902 – 1994)

Having read most of Popper's works, and also many of the works of his critics, it became clear that a more detailed overview of his viewpoints would be necessary in this study, due to the many misrepresentations of his views in the literature of his contemporaries.

The other reason for giving a thorough overview of his work is that he successfully crossed the boundary between natural sciences and social sciences, providing a formalised way of argument where truth defined as "according to fact" remains the guiding ideal. This is of much interest in a study where the client asks for "fact-based decision making", coupled with the awareness that a multi-disciplinary approach is required for a capability providing such a service.

Overview of Popper's philosophy

Popper was, like all other philosophers in the twentieth century, confronted by the fact that foundationalism was shattered, i.e. that the possibility that absolutely certain a priori knowledge existed had to be discarded.

While some then settled for irrationality in the form of either

1. inductivism (also called irrational dogmatism, of which uncritical empiricism, i.e. the criterion of truth as sense-experience-only, is one example), or

2. denying the existence of absolute truth altogether and building philosophy on relative truth (also called irrational relativism),

Popper had the intellectual courage to take these challenges head-on and in doing so provided new possibilities for overcoming these challenges. His proposed solution was so far removed from what was commonly accepted that most of his contemporaries misunderstood and therefore misrepresented his work. The first aim

here is therefore to present his views in a concise way and to show where he departed from traditional views in order to explore new avenues.[15]

Popper's philosophy offers a way to show how knowledge can be rational and objective without being certain, without appealing to induction, without appealing to expert opinion, consensus and the solidarity of belief. It offers an account in which truth, and not authority, is still the regulative ideal of scientific inquiry and rational discussions. [Notturno, 2000, xix]

Popper calls his philosophy Critical Rationalism in order to highlight its main features. The most distinctive feature of Popper's philosophy, and in fact key to understanding his views on rationality and objectivity is to understand that it does not regard scientific knowledge as justified true belief. This is in contrast with what most philosophers still believe, and in doing so they continue to see justification of theories as being the goal of science: The idea that we could give objective and rational justifications of our theories that would be compelling to others is the aim of science according to their claim.
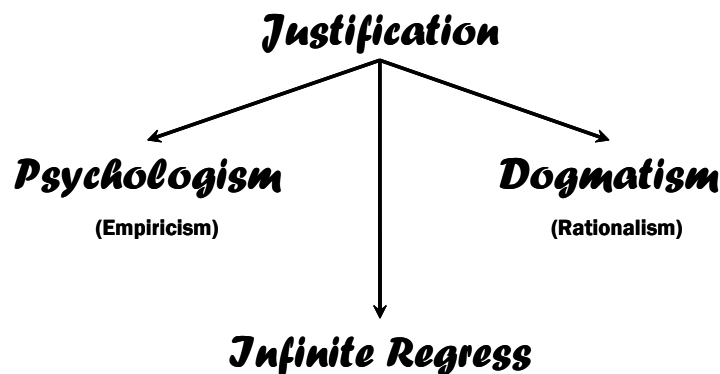
Figure 2-6 Justification as Goal of Science

To hold to justification of our theories as the goal of science, there are only three possible avenues to follow, namely Psychologism (Empiricism, as Hume argued), Dogmatism (rationalism), or Infinite Regress. Dogmatism could range from insisting

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[15] This section entitled 'An overview of Popper's philosophy is taken almost entirely from the Introduction of Notturo's book "Science and the Open Society" [Notturno, 2000].

on *a priori* valid truths (e.g. Kant) to the dogmatism of the conventions of the scientific community (e.g. Kuhn).

When Popper was faced with these alternatives in the face of the challenges of the twentieth century, he is almost alone in having given up the idea that justification is a necessary condition for scientific knowledge. But, in contrast with the sceptics, he does believe that we do have rational, objective scientific knowledge. Since no statement can be justified, Popper's philosophy implies that

1. Scientific knowledge can no longer be regarded as justified true belief.

2. The rationality of scientific knowledge can no longer be regarded as a product of its justification.

3. The objectivity of scientific knowledge can no longer be regarded as a product of its justification.

4. Scepticism, i.e. the denial that we have knowledge, can no longer be regarded as the thesis that no statement can be justified.

5. Justifying theories can no longer be regarded as the task of philosophy and science.

6. Logical arguments can no longer be regarded as the attempt to justify statements.

7. The criticism that a theory or statement is not justified can no longer be regarded as a criticism.

So what is objective and rational scientific knowledge if it is not justified true belief?

Foundationalists hold that

Rationality = justification = logic

Popper holds that

Rationality = criticism = logic

where 'logic' refers to 'deductive inference only' for Popper.

Popper criticised induction as logical inference, as methodology and as psychology. He saw it as an invalid way of arguing which subordinates our reason to custom and habit (and he upholds reason to be prominent, contrary to Hume, who saw the passions, therefore custom and habit, to be prominent). He insisted that deductive inference only can be used to grow our knowledge, because only deductively valid arguments preserve truth from premise to conclusion.

Rationality, for Popper, is not so much a property of knowledge, as it is the task for humans. We are rational to the extent that we are willing to appeal to reason and argument, as opposed to violence and force, to resolve our disputes.

Popper on objectivity

Popper's view of objectivity is that our theories can be articulated in language, and as such can be understood and criticised by others.

His view that objective, rational knowledge is inherently fallible - and that we can never justify, but only criticise, it – is essential to Popper's philosophy of science.

Popper believes, like Kant, that we do have a priori theories when we go about our empirical work, but unlike Kant he does not believe that our a priori knowledge is infallible. He believes rather that such knowledge is fallible and the aim of our empirical work is to test our a priori theories. It is important to note that Popper places a high value on empirical testing of theories, but does not subscribe to deriving facts from empirical work, unless we can do so by deductive argument.

In this way Popper opened the way for science not to have a view of objectivity as "knowledge without context and devoid of human interpretation/opinion" but rather as an articulation of our theories in a way that would make our inherent subjectivity visible and therefore open to criticism. It is this change that makes Popper's work of much value in the pursuit to build the bridge between natural and social sciences – a strength he himself already exploited and illustrated.

Science as problem-solving

Popper turned away from the search for certainty in induction, as well as from the search for certainty in verifying a theory. His view was that scientific method is a deductive process. Science starts with a problem, not with unprejudiced observation. We only become aware of a problem when something presents itself to us that does not fit our theory. So even if we might not realise it, we have some theory by which we observe, and problems present themselves to us as those phenomena that do not fit our theory. In this way he agrees with Kant that there is a priori knowledge, but it is important to note that he does not agree that such a priori knowledge is true.

In Popper's view science grows from problem to problem. To solve the problem we make a conjecture based on our current understanding. These conjectures remain hypotheses, and can only be refuted, not verified. Some theories are better corroborated than others in that they have withstood more severe tests, but still remain only hypotheses.

Popper on the creation of new knowledge

Popper turned away fundamentally from the usefulness of probability in growing scientific knowledge. He demonstrates his reason for this by stating that we would always prefer a theory which provides us with more information to a theory that provides us with less information. It is obvious that if we have two true facts *a* and *b*, then the conjunction of the two *Ct(ab)* has more informative content than the informative content of any one of them, i.e.

(1) $$Ct(a) \leq Ct(ab) \geq Ct(b)$$

This contrasts with the corresponding law of the calculus of probability

(2) $$p(a) \geq p(ab) \leq p(b).$$

Together these two laws (1) and (2) state that with increasing content, probability decreases, and vice versa. "This trivial fact has the following inescapable consequences: if growth of knowledge means that we operate with theories of increasing content, it must also mean that we operate with theories of decreasing probability (in the sense of the calculus of probability)." [Popper, 1996, 218]

The statement that increasing content coincides with decreasing probability is the reason why Popper turned away from all reasoning based on probability, explaining his fundamental rejection of not only induction, but also of Bayesian reasoning.

Science is also a search for truth [Popper, 1996, 229] in the way Tarski [Tarski, 1956] defined it. In accepting the existence of absolute truth we can search for mistakes through a process of critical rationalism in order to eliminate as many mistakes as possible. In this way we move closer to the truth. But science searches for more than mere truth – it searches for *interesting truth*, i.e. truth with a high degree of explanatory power (high information content). From (1) and (2) above it follows that such truth is logically improbable.

One theory can therefore correspond better to the facts than another theory. Say we have two theories t_1 and t_2. Then Popper provides the following 6 "types of case" in which we can say that t_2 corresponds better to the facts than t_1. [Popper, 1996, 232]

1. t_2 makes more precise assertions than t_1, and these more precise assertions stand up to more precise tests
2. t_2 takes account of, and explains, more facts that t_1
3. t_2 describes, or explains, the facts in more detail than t_1
4. t_2 has passed tests that t_1 has failed to pass
5. t_2 suggests new experimental tests, not considered before t_2 was designed (and not suggested by t_1, or maybe not even applicable to t_1) and t_2 has passed these tests.
6. t_2 has unified or connected various hitherto unrelated problems.

It was shown soon after he proposed this way of theory choice that these criteria as stated above are themselves not falsifiable (and therefore in Popper's own terms not scientific). Popper himself accepted this criticism, but he nevertheless pointed out that this does not distract from his main point, namely that rationality is not to be found in verifying a theory, but rather by critically testing it with empirical science. He invited further work to refine or change these "types of case".   Niiniluoto [Gavroglu et al, 1989] has since shown that it is possible to define a way by which the truth-likeness (called *verisimilitude*) of two theories can be compared, so that this objection does not exist any more.

Duhem (in what is often referred to as the Duhem-Quine principle) also pointed out that a theory cannot be conclusively refuted, due to possible errors in measurement of the experiment which seems to refute the theory. Popper referred to Duhem in this context, but never addressed this specific claim. He might have been unaware of it, but from his writings it seems more likely that he did not see it as a challenge to his views since he never claimed that a theory is completely discarded when refuted: Increased accuracy of future instruments might cause us to revisit the theory. New knowledge in future might cause a re-evaluation of current results. In this way he strives to always identify the best possible selection of theories (hypotheses) according to current understanding.

Through testing theories as Popper proposed, the ideas 'information content' and 'correspondence to the truth' are linked, so that we can legitimately speak of one theory having a greater (or lesser) likeness or similarity to the truth. This describes the idea of (degrees of) *verisimilitude* (in contradistinction to probability). Also, when a statement is true, then it can contain only true facts. But if a statement is false, then it can contain both true and false facts. This can be called the "truth-content" of a statement. In this way one statement can have a higher truth-content than another. Popper claims that from early times there was an intuitive confusion between *verisimilitude* and probability, and that this confusion led to the futile discussions of probability and verification in scientific method.

Induction, even if it were to produce new knowledge, would therefore promote un-productivity. The discussion of Popper's views showed that induction and Bayesian reasoning by definition take the smallest possible steps forward in finding new knowledge (since that is in accordance with the highest probability): High probability has the definite consequence of low information content. Both Lakatos and Kuhn called this 'normal science', where puzzle-solving is the goal, not creation of new knowledge. They accepted an inductive methodology of science, and therefore described it in this way. Popper responded by saying that what they called 'normal science' is really bad science, claiming that the scientists involved in this practice were not trained to be critical.

Popper on induction.

All scientific theories must be testable. Not all theories are equally testable, so that there are degrees of testability. Yet those that are not testable at all (i.e. cannot be refuted) are of no interest to science. They fall into the category of the metaphysical, which does not make them meaningless, merely non-science. Only theories that are refutable (and preferably state under what circumstances they will be refuted) can be studied by science. Simple theories are to be preferred, because they are more testable [Popper, 2002, 151].

While weakness in consistency gives enough reason to look at induction with suspicion, it is not the main reason why Popper and others argue against the validity of scientific methods that make use of inductive inference. He objected to using induction as scientific reasoning because it is inherently illogical. (for detailed description on logical difference between deduction and induction, refer to Appendix B).
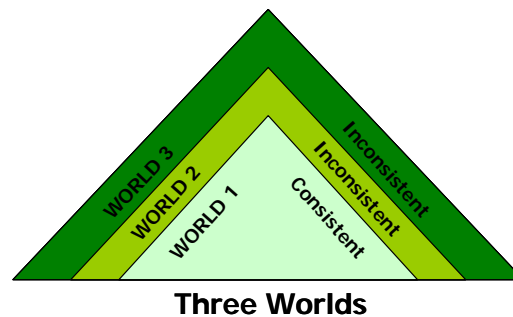
Three Worlds

Figure 2-7 Popper's Three Worlds

Popper's three worlds.

Popper also accepted the view of Bolzano and Frege, who described reality in terms of three worlds [Popper, 2002, 210-217], namely

World 1: The physical, material world

World 2: The inner world of subjective experiences

World 3: The world created by human endeavour, but able to exist autonomously, e.g. music, theories. World 3 is essentially the product of the human mind.

Figure 2-7 is a representation of these worlds, also indicating their relation to consistence. Popper was criticised especially for the addition of World 3, because it accepted those things which were not sense-experience-only. Those that criticised him did so because they confused his reason for introducing it with Plato's theories of eternal and immutable ideas, and with Frege's theory of eternal and immutable thoughts. In doing so, they claim that the existence of the third world contradicts Popper's insistence on fallibility. They fail to make the necessary distinctions though. While it is true that Popper introduced it to provide for the existence of objective knowledge, they fail to notice that Popper does not see scientific knowledge as certain. The problem for Popper was not to explain how objective knowledge could be certain. It was to explain how fallible knowledge could be objective. His solution was that the objectivity of knowledge hinges on its susceptibility to criticism, and world 3 is introduced to provide the means by which to criticise.

Popper's critics

As an example of how his contemporaries criticised Popper, the following discussion of Notturno is given, describing four reasons why some philosophers rejected Popper's introduction of world 3 apart from simply misunderstanding it as described above, namely

1. They regarded it as superfluous, saying that it violated the principle of parsimony, also known as Okham's razor. In response to this Notturno points out that not Plato, Frege or Popper introduced it at the outset. They were all led to it reluctantly because of repeated failure to explain objective knowledge in another way. It is therefore a necessary feature, not superfluous.

2. The second objection raised by some philosophers was that it violated the principle of materialism, meaning that everything that exists exist of matter and must be explained in terms of matter (as described by the sense-experience-only view of the Vienna Circle). Notturno points out that the error is with materialism, not with Popper. The definition of matter was originally "something extended in space". But later discoveries led physicists to believe matter to be space filled with electromagnetic waves. He points out that recent materialists have changed the definition of matter to incorporate this change, but then points out that if that method

is employed, we can redefine any term to mean anything we want. This change in the definition of matter can also be seen as an example of a refutation of the initial theory instead of, like materialists prefer, the evolution of concepts.

3.   Popper's talk of the interaction between the three worlds seems to violate the principle of causality. Here, Notturno argues that we simply do not know how an immaterial object can cause a material thing to change. This, however, has nothing to do with Popper's work; it is something that is universally not understood. We do not even really understand how material objects interact so as to cause movement (without introducing anything, like a force, which is not material). Yet we know that they do interact.

4. Some philosophers argue that World 3 is a philosophical theory designed to solve a philosophical problem, but since philosophical theories and problems do not exist, there is no reason for introducing world 3 (this was the view of followers of Wittgenstein). Notturno responds to this objection by pointing to the inconsistencies in Wittgenstein's philosophy, arguing that a philosophy containing such consistencies is faulty rather than Popper's introduction of the third world.

Popper and a multi-disciplinary approach.

Popper developed his philosophy of science by studying the methods employed by successful scientists like Einstein. However, he applied his views of specifically the demarcation between science and meta-physics to the theories of Marx and in doing so provided a critique of the work of Marx which pointed out that some aspects of his work for which he claimed scientific status really wasn't scientific at all: Popper provided in his two-volume work "Open Society and its Enemies" the most complete exposition of the weaknesses of Marxism's claim to be scientific.

Popper holds to a naturalistic view of science, namely that the methodology of science is the same for natural sciences and social sciences.

While he was severely criticised by both of the other contemporary prominent schools of thought on scientific method, namely the Vienna Circle and Kuhn, more recent readings of his work provide increasingly a more favourable evaluation. An example is Fuller [Fuller, 2003], concluding that the fact that Kuhn's work became widely

accepted and practiced in science might not have been in the best service of scientific development in his book *Kuhn vs Popper: The struggle for the Soul of Science"*.

2.3.3.2.2 Developments in logic

Logic is essentially the study of the representation of truth. It describes how to prove from one true statement the truth of the next statement. The way of proving a new statement from a statement already known to be true is called Proof Theory, i.e. the proof theory of any logic is the "valid way to reason" in that specific logic.

Leibniz's proof theory, showing something to be true by proving its opposite to be false, was the most common way to prove new statements at the beginning of the twentieth century. This was essentially an extension of Euclid's logic where Not(Not A) = A, and is now known as classical logic.

One of the accomplishments in the twentieth century was to provide other proof theories, of which the following are examples:

1. Hilbert set out to redefine the foundation of mathematics to be not logic (i.e. proving mathematics using purely logic), but mathematics itself (i.e. proving mathematics from within mathematics itself). What is known as Hilbert spaces stemmed from this work.

2. Brouwer developed Intuitionism, in which Not(Not A) is not equal to A. This allowed for handling infinite sets. It means that a constructive proof to be certain that a statement is true was necessary; proving its negative false cannot be taken as proof of its truth.

3. Lukasiewicz introduced a logical system where more "truth values" than the customary "true" and "false" were present. As such he developed the foundations of what is now known as "fuzzy logic".

4. Putnam developed quantum logic, which differs from classical logic in that what is known as the "distributive law" exists as part of the proof theory.

Not surprisingly, the role of truth was also studied and challenged in the twentieth century. Quine developed what he called "belief webs", a relativistic view of truth.

This view holds that science is "underdetermined", i.e. we do not have enough information to fully describe every fact of science from first principles, and that our experience only touches the edges of our whole web of belief. This opened the way for Feyerabend to conclude that there is no such a thing as scientific method. Davidson, while accepting the underdetermined nature of science, did not agree with Quine's relativistic view, but used Tarski's definition of truth to show that scientific method does exist, and is directed towards the truth.

Another important accomplishment of the twentieth century was the work of Gödel, who's Second Incompleteness Theorem showed that <u>a system with structure cannot be described both completely and coherently</u>. It means that if an entirely coherent description is given, it will be an incomplete description of the system, and if an entirely complete description is given, it will be incoherent. Gödel's work cannot be used, as some have tried, to argue that mysterious intuition must replace cogent proof, nor is it proof that there are inherent limits to human reasoning, since no-one knows if human reasoning falls under Hilbert's rules. So it does not mean that there is no hope of describing thought in physical terms, but it does cast doubt on the possibility of any system of rules to fully describe any sentence. (This of course reminds immediately of Heisenberg's uncertainty principle and reflexivity[16] in social science). His work has implications for the required capability at IMT, which is discussed in chapters four and five. This work of Gödel might bring us closer to understanding why induction and deduction just cannot deny each other the right of existence in scientific method, but also individually fails to fully describe all there is to scientific method.

At the end of the twentieth century there are therefore more than one logical system by which truth can be represented, depending on the context of the problem. Classical logic is not the only logical system by which truth can be represented. *In this way a "pluralistic" view of logic further underpins the view at the end of the twentieth*

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[16] Reflexivity is the term used to describe the phenomenon that whenever knowledge, information or even data becomes known to a person, it changes the future response of that person. In this way human response is never consistent. Any interaction always changes the outcome. Completely objective observation or fact-finding is therefore almost impossible in social and human sciences in term of the meaning of the word "consistency" as defined by the natural sciences.

century that scientific method does indeed exist and is essential for scientific discovery, but it is not monistic.

2.3.4 Monistic vs. pluralistic view of scientific method

Feyerabend is perhaps the best example of a thorough-bred monist, although he would be the first to object to such a view. Yet his bewilderment when he concluded that there was no such a thing as THE scientific method, but that different cultures and disciplines devise their own methods, shows how deeply ingrained the view was even in him. What is more – he concluded from this observation that if there is not ONE scientific method, then there is NONE! This shows how pluralism came as a total surprise and was accepted only reluctantly in the natural sciences.

The work of the mathematician Gödel provided the first foundation for the fact that no one method can be expected to completely and coherently describe all knowledge. His Second Incompleteness Theorem proved that no coherent theory can be complete, and that any complete theory would be incoherent. Together with the work of Quine, who postulated that science is under determined (i.e. cannot be fully proven from first principles), it would explain that many coherent, but incomplete theories of scientific method are not unreasonable to expect.

2.3.4.1 Complexity Science as scientific method

There is a body of literature, (e.g. Wolfram [Wolfram, 2002]), which claims that complexity science supersedes science and makes for "a new kind of science". Wolfram is adhering to the view of complexity which is defined as deterministic complexity by Gribbin.

It is true that concepts like emergence, self-organising, non-linear feedback relationships are all new to science, and they came with the development of complexity theory and complexity science. Yet complexity science itself is not taken as a "new science" in this dissertation. It is taken to merely be a new manifestation of the ongoing development of science – a new discipline with its own techniques and body of knowledge. Note that its value is not to be found only in a toolbox of techniques, but also in the body of knowledge which embodies the study of complexity, thus the notional description of complexity.

2.4 Perspective 3: Knowledge Management

Criteria for Choosing Perspectives

P1	P2	P3	P4	P5

Conclusions from synthesis of Perspectives

Finding Commonality in Pluralism

Framework(s) for problem Categorisation

Process of Scientific Problem Solving

Case Study: Creating Knowledge through Complexity Methods
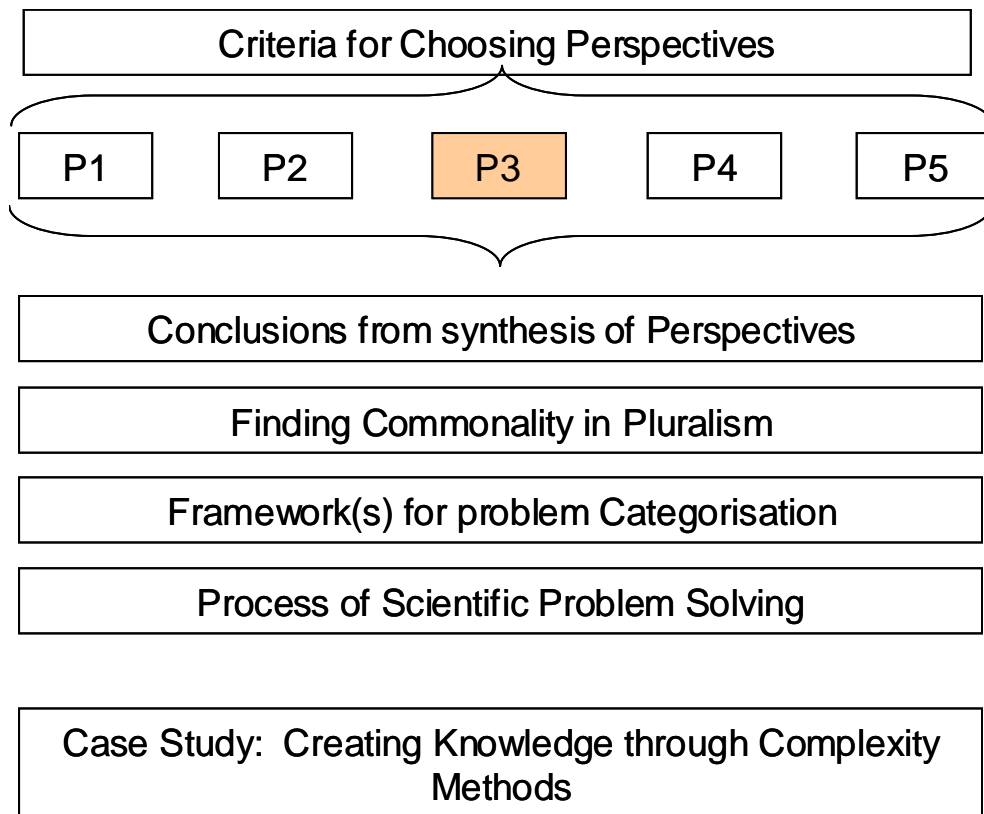
Figure 2-8 Dissertation Road Map

Knowledge Management (KM) has developed through the following phases. They are not sequential, and all of them are still actively pursued as part of knowledge management. The categorisation given here serves to categorise the subject, but the phases do indicate development of thought in that the initiation of each phase was later than the previous phase.

2.4.1 Development Phase 1: Getting the right information to the right people at the right time.

During this phase it was assumed that poor decisions were made primarily because the decision-makers did not have all the relevant information at their disposal at the time of making the decisions. This was a major driver behind the boom of Information Technology with its large, enterprise-wide information systems. Currently this belief still persists in the prominence given to knowledge portals, with its obvious disadvantage of misinterpretation of knowledge without context. The internet also thrives on this paradigm. While it is a very useful tool, it can also prove

to lower productivity with the laborious search for relevant information in the unstructured results of search engines. There is still ongoing research to ensure better results from internet searches.

2.4.2 Development Phase 2: Making tacit knowledge explicit.

As the fact that knowledge without context often leads to wrong understanding, or misinterpretations, became apparent, the KM specialists realized that the human element in knowledge cannot be ignored. The work of Polanyi, especially his distinction between explicit and tacit knowledge, then became important. Elaborate and varied methods of how to make tacit knowledge explicit and how to effectively communicate it became the seedbed for techniques used during strategic sessions.

Very soon KM was seen as capturing the implicit, unspoken knowledge in an organization by making it explicit. Business rules, documented processes, etc became very important. The main aim of KM became to stimulate people to make their tacit knowledge explicit and accessible to their colleagues. Mind maps, soft systems methodologies, etc became very important. Complicated networks of interrelationships between knowledge nodes were created in order to capture the implicit, tacit knowledge of an organization.

2.4.3 Development Phase 3: Managing the process of knowledge creation.

It became apparent that the processes and techniques which were used to facilitate the process of making tacit knowledge explicit were time-consuming and therefore expensive, because it used the most productive people for the process. They were therefore not repeated often enough for the documented knowledge base to remain valid. Documenting the dynamic, ever-changing processes and constantly growing and changing knowledge of decision-makers as they interact with a dynamic context, proved to facilitate stagnation instead: Once documented, a full revision is often too expensive, leaving piecemeal changes to the documented processes as the evolutionary way to "keep up with the changes". In time this causes incoherence and a mismatch between actual processes followed and documented processes. This led to the third and current phase of KM, namely to manage the process of knowledge creation, which is perceived to be less changeable.

Pro-active understanding of and facilitation of knowledge creation became the focus of KM. The latest methods employed in KM are to enhance innovation, to encourage new ideas, to experiment with new groupings of existing knowledge in order to arrive at new insights. A rich body of literature exists, trying to formalize the management of the process of knowledge creation.

2.4.4 Scientific method and knowledge management

It is in the context of the development phase three that the scientific method and KM overlap, and where some KM experts are trying to implement the ideas of for instance Popper, who was a philosopher on scientific method, in organizational and management science. Examples are the work of McElroy (focusing his attention on organisational knowledge creation) and Notturno (focusing his attention on societal knowledge creation). Noting that Popper claimed that "science starts with a problem" (i.e. focuses on problem-solving) and that the scientific method has everything to do with the "Logic of scientific discovery" (i.e. the logic of discovery of new knowledge), the similar focus is immediately obvious.

2.5 Perspective 4: Research and Development

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│           Criteria for Choosing Perspectives     │
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   │  P1  │  │  P2  │  │  P3  │  │  P4  │  │  P5  │
   └──────┘  └──────┘  └──────┘  └──────┘  └──────┘

┌─────────────────────────────────────────────────┐
│        Conclusions from synthesis of Perspectives│
└─────────────────────────────────────────────────┘
┌─────────────────────────────────────────────────┐
│           Finding Commonality in Pluralism       │
└─────────────────────────────────────────────────┘
┌─────────────────────────────────────────────────┐
│        Framework(s) for problem Categorisation   │
└─────────────────────────────────────────────────┘
┌─────────────────────────────────────────────────┐
│          Process of Scientific Problem Solving   │
└─────────────────────────────────────────────────┘

┌─────────────────────────────────────────────────┐
│  Case Study:  Creating Knowledge through Complexity│
│                      Methods                      │
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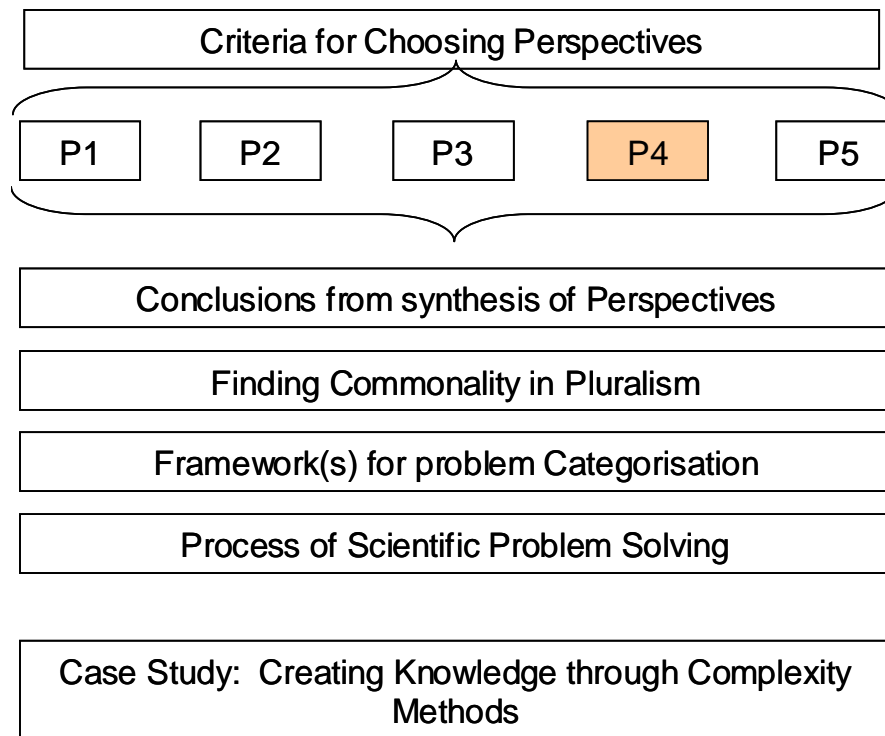
Figure 2-9 Dissertation Road Map

Miller and Morris [Morris & Miller, 1999] provides an overview of the development of research and development (R&D) in the twentieth century. Figure 2-10 gives a schematical representation of this development.

In this paragraph the discussion focuses on the development of technological research and development in what is commonly called first generation, second generation, third generation and now also fourth generation research and development.   These are defined as follows: [Morris & Miller, 1999]

1. First Generation R&D: Focus on Products: Basic and Applied Science researching scientific and technical issues, designing new products from scientific breakthroughs. [Morris & Miller, 1999, 11-17)

2. Second Generation R&D: Focus on Processes: Methods of project management formalised.

3. Third Generation R&D: Focus on Management: Technology management in the context of financial risk, strategic planning and technology road maps.

4. Fourth Generation R&D: Focus on Social and Human Factors: Customer involvement in R&D, the synthesis of new technical knowledge with knowledge of emerging markets.
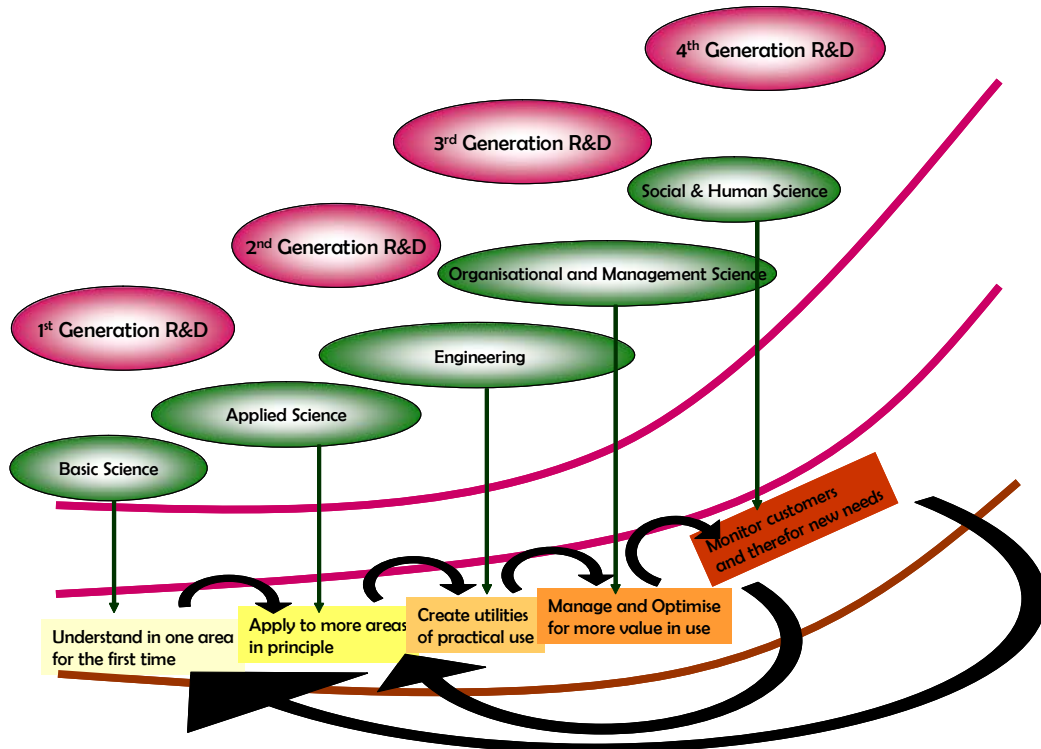
Figure 2-10 Development of R & D

While the western world produced the new knowledge in first and second generation R&D, it became apparent over the last few decades of the twentieth century that it was the oriental world (notably Japan and Taiwan, South Korea, and lately China) that seemed to be able to exploit the knowledge in order to create more wealth quicker. This led to much searching and analysing of the techniques employed by the successful companies (in financial terms), comparing them with the less successful companies.

It became apparent that some companies started off by introducing new technologies representing completely new paradigms, only to be overtaken by rivals exploiting their ideas better than they themselves were able to. A more global view showed the same trend, where the new knowledge created by the West was exploited by the oriental world with much more success in terms of creating wealth in a shorter time. This observation led to studies in order to find the reasons for the phenomena, which

led to the descriptions of the third and fourth generations of R&D. Figure 2-10 gives an overview of this shift in focus of R&D.

Mass production became the norm, as new technologies were standardised, engineered and processes formalised to enable more to be manufactured in a shorter time. Being a leader in the marketplace meant to be faster and to shorten the time for moving new successful products into the market. In order to be more effective in supplying the customer with more relevant and wanted products, fourth generation R&D now aims at making the customer (consumer) part of the R&D process, so that less effort is spent on products that would fail in the market. An understanding of what the consumer would buy if it were available is seen to be the answer to decrease the high failure rate of new products. In this way modelling the future needs of consumers becomes the focus of R&D.

This development of new focus areas in R&D indicates that development of new approaches in R&D were also necessary. This underscores the fact that a pluralistic approach is necessary and that a multi-disciplinary analysis is imperative. As already mentioned, it is Flood's view that failure to move on from the strictly natural sciences approach, and following the move of focus in business to process research, was one of the reasons why operations research failed to retain its high profile.

2.6   Perspective 5: Technology

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│            Criteria for Choosing Perspectives         │
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  │ P1  │   │ P2  │   │ P3  │   │ P4  │   │ P5  │
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┌─────────────────────────────────────────────────────┐
│         Conclusions from synthesis of Perspectives    │
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│            Finding Commonality in Pluralism           │
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│         Framework(s) for problem Categorisation       │
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│          Process of Scientific Problem Solving        │
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│    Case Study:  Creating Knowledge through Complexity │
│                        Methods                        │
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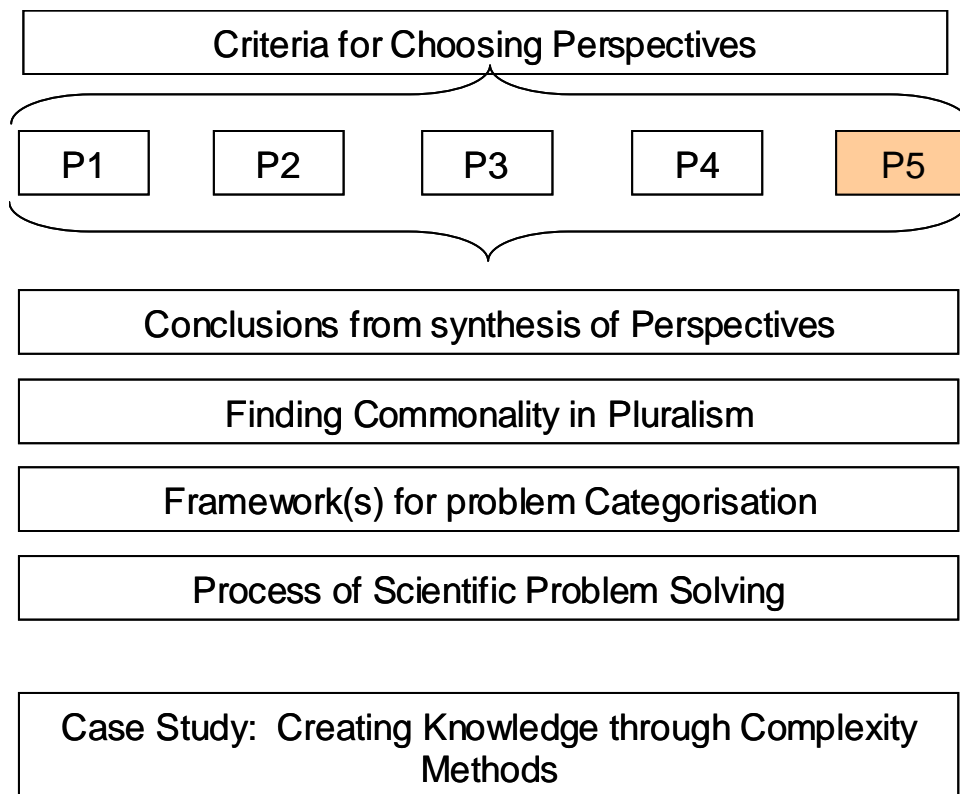
Figure 2-11 Dissertation Road Map

Technology, management of technology, and all aspects of technology are very necessary to incorporate as part of a decision support capability at IMT. Any valid issues which the study of technology brings to the table regarding the type of problems the decision support service of IMT might encounter is of much importance in the definition of the capability, and also for the process to be followed. This is so because the SA Navy is technologically highly complex in all layers of management and operation.

2.6.1 Background

The strictly technical understanding of technology, which prevailed in the western world, provided the input for the oriental world, with its more holistic approach and customer focus, to exploit the inventions and technologies developed in the western world more successfully in financial terms than the western world was able to do. It is against this background that an appropriate definition of technology is sought.

2.6.2 Definition of technology

Development and creation of wealth was seen as the result of the spectacular development of technology. This led to defining technology to encompass all other aspects traditionally overlooked by those who saw technology as technical artefacts only. A group of definitions which tried to break out of this technical deadlock are given.

1. Technology is the complex of human knowledge, skills and tools applied to create, use, maintain and dispose of items of utility (Artifacts)   (Definition of Republic of South Africa Defense Community)

2. "Technology is the art of applying know-how for development, manufacture, use and/or maintenance of articles of utility (products and services)." [Steyn & Schaeffer, 1975, 21]

3. "Technology is created capability. It manifests in artefacts, the purpose of which is to augment human skill." [Van Wyk, 1988]

where Van Wyk uses the following meanings for the words:

Created	Technology does not come about by itself. It is the product of deliberate action. If technology is to be employed as a resource, it has to be cultivated, nurtured and supported.
Capability	This refers to a particular kind of handiness, namely that of manipulating aspects of the physical world.
Artefacts	This is a generic term for all devices, tools, instruments or machines. Artefacts are the repositories of capability. They are to the study of technology what organisms are to the study of biology.
Augment	This concept is used to convey two meanings: on the one hand such as enhancing ability such as adding instrumentation to human activity, and on the other hand replacing human activity, by substituting it with artefacts.

4. In order to fully understand the aspects impacted upon by technological development, the most complete definition of technology, encompassing all the possible areas that need to be studied when technological advance it to be

managed, is found in the definition provided by the University of Eindhoven in the Netherlands. The first broader definition is broken down into another level of detail when the "restricted" (technical) definition of technology is further explained. This definition is given in schematic form in Figure 2-12 for the more general definition, and Figure 2-13 for the zoomed-in view of the technical definition.
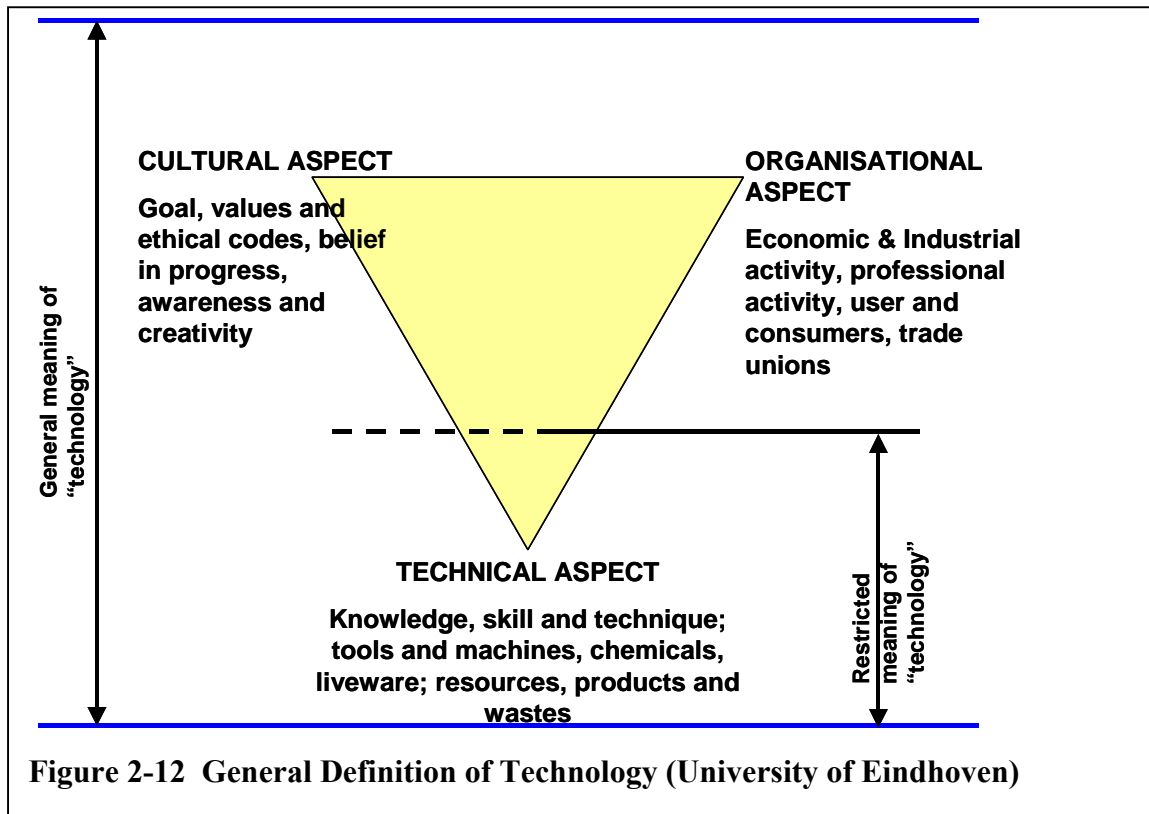
Figure 2-12 General Definition of Technology (University of Eindhoven)

DIAGRAMMATIC DEFINITION OF TECHNOLOGY
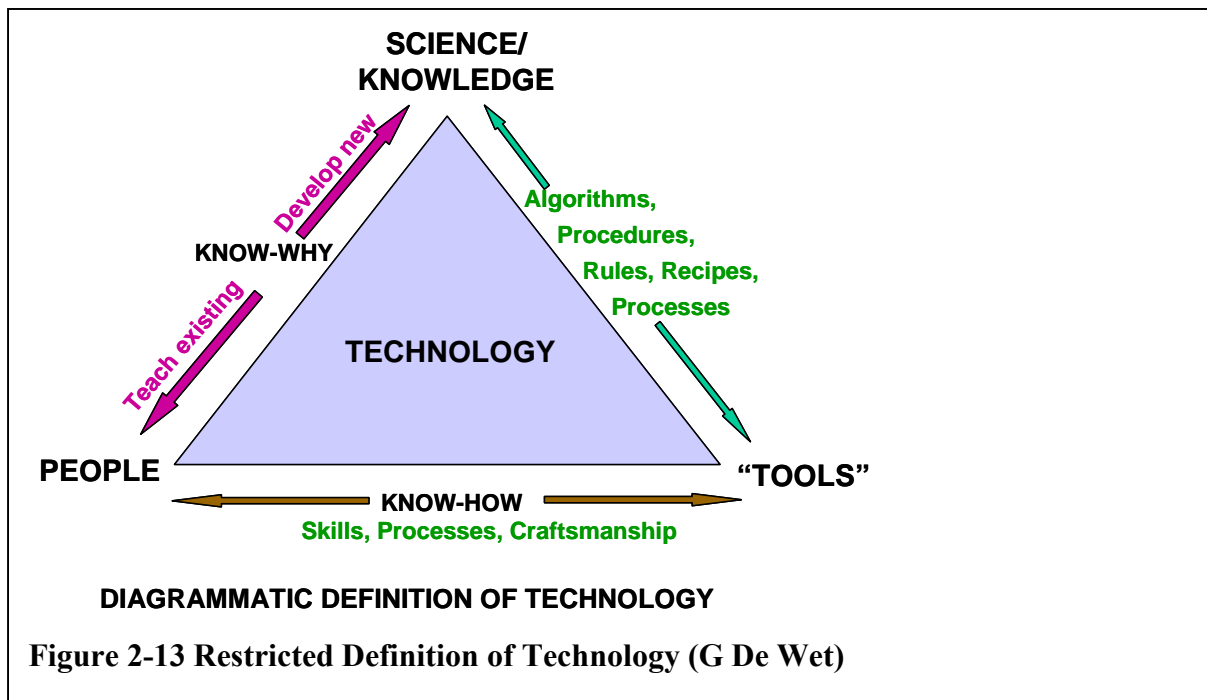
Figure 2-13 Restricted Definition of Technology (G De Wet)

This last definition of technology (in Figures 2-12 and 2-13) compels us to study all aspects of technology and areas of influence when we desire to manage technology efficiently. It is against this background that the next section explores the movement from technology management to competence (and capability) management as time passes and different aspects of technology becomes dominant.

2.6.3 From technology management to competence (capability) management

IMT developed a model of technology management and capability management from the stated definitions of technology (as described in § 2.6.2, especially Fig 2-12 and Fig 2-13) with a view to be able to know which aspects need to be taken into account when decision support needs to be rendered in applications where technology implementation or management is dominant. This was done from the observation that during different stages of technology management the various aspects of technology as described in the definition of technology do not have the same prominence in effort required for management and implementation. This is given in Fig 2-14.
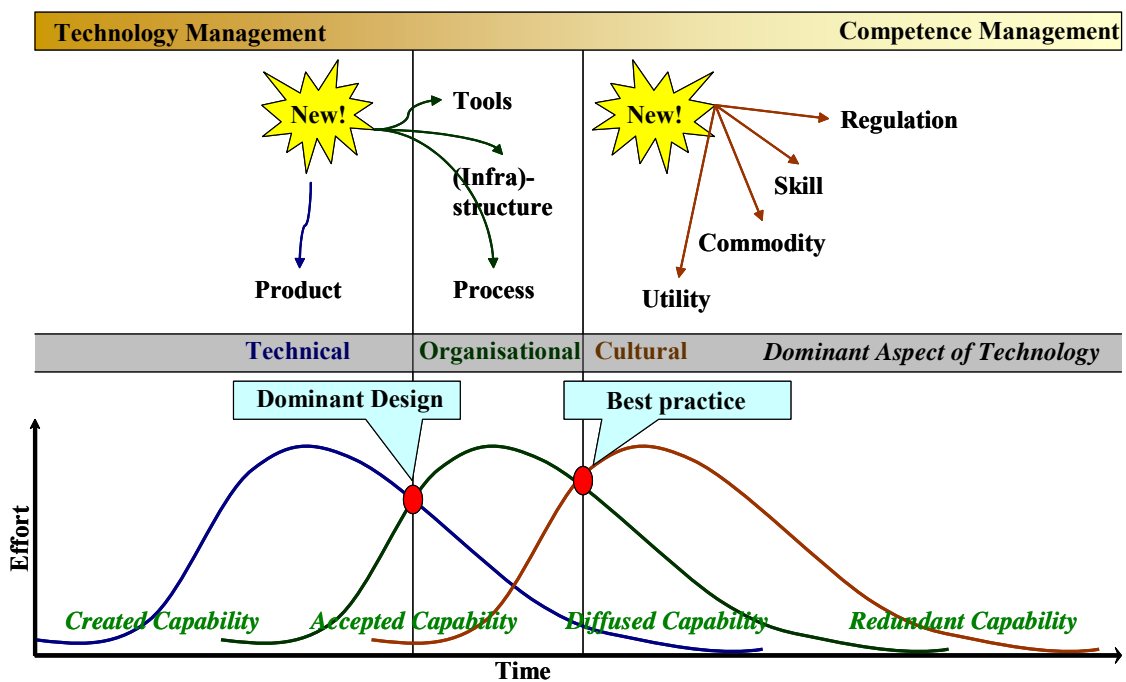
Figure 2-14 Technology Management to Capability (Competence) Management

This graphical representation is in essence a "Time Elapsed" and "Effort Required" relaxation of the general definition of technology, showing that as technology becomes more accepted, so Organisational (Process) issues become dominant in managing (or implementing) technology, which leads to impacting on the organisation (Human and Social) by creating new values and accepted ways of pursuing success, thus highlighting the cultural issues. This was developed from a

synthesis between the definition of technology and the development of R&D from the insights of Miller and Morris [Miller & Morris, 1999].

Technology has three aspects, namely Technical, Organisational and Cultural according to the definition given above. A simple extrapolation from Figure 2-14 shows that there are therefore three possible "product types" to be managed. They are "technical products" (usually hardware products), "organisational products" (usually a process, therefore also called a "process products" in this dissertation), and "cultural products" (usually some kind of agreement to define cooperation between parties who would otherwise not cooperate).

From this extrapolation it is then possible to articulate how the limited view of R&D which the USA held was exploited by Japan to create wealth from new products developed in the USA: The USA saw new technology only from a hardware perspective, while Japan recognised that a "product" could also be a process. In doing this Japan could take the "hardware products" of the USA, develop "process products" (like Total Quality Management - TQM), and in doing so produce far more productive business models to exploit the "hardware products" produced by the USA more profitably. Another example of "process products" includes ISO procedures.

Examples of "cultural products" would include Memorandums of Understanding, Business Alliances, etc. (where mutual trust and common values and practices are described and pursued for the benefit of all parties involved).

In this way it becomes clear that a "process product", e.g. TQM, would require a Process Phase of dominance during implementation where it is tailored and integrated into the organisation's processes and structures, possibly requiring new tools. The Cultural Phase is the entrenchment of common values and practices to ensure high quality service in all its activities.

This description indicates how the results of R&D on (organisational) Processes and Culture can be handled in the same way as hardware products – they can be treated and managed like any other technology for management or implementation purposes. In this way Figure 2-14 describes the generic phases of technology implementation, diffusion and replacement of one S-Curve of technology development, be it a hardware, a process or even a cultural product.

The mere fact that *technology is defined as containing technical, organisational and cultural aspects*, with different aspects becoming dominant as time elapses, once again points to the fact that different problem types will be encountered in any organisation managing the implementation of technology over time. This confirms the need for a variety of approaches to remain relevant in supplying decision support to any client (like the SA Navy) where technology management is important for its ongoing success.

Chapter 3: Interpretation of perspectives
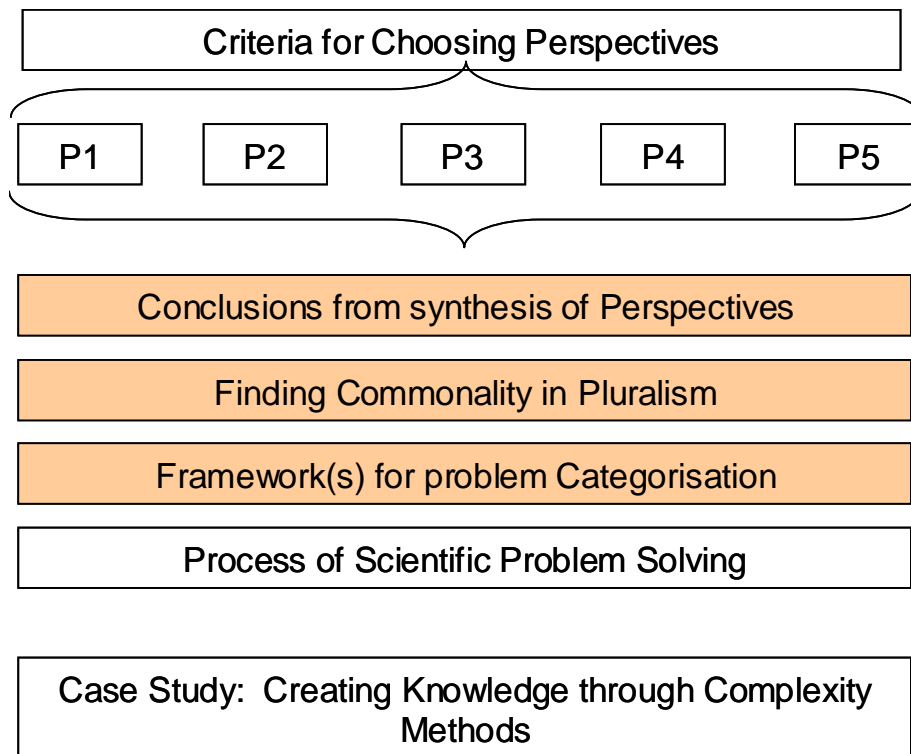
Figure 3-1 Dissertation Road Map

A short discussion of the issues which emerge from the development of the perspectives follows. This chapter illustrates Snowden's remark that problems which are complex allow only for retrospective coherence: Coherence cannot be projected into the future, or even perceived in the present time, only hindsight provides coherence, with the understanding that there could have been a number of other possible trajectories of development, each of which would have left a development trail of different, but equally valid expressions of coherence [Kurtz & Snowden, 2003, 8]

3.1 The struggle for dominance

It is important to note from systemic thinking how cybernetics is stated by Flood to be "one metaphor" and therefore one possible application of systems thinking. The same is found when his System of Systems Methodologies is discussed later where complexity becomes one possible extreme on a continuum of system types, so that complexity theory becomes part of systems thinking as well. This is in spite of his

insistence that the philosophy he adheres to is "critical systems thinking" with complementarism as one of its basic positions. Complementarism states that

1. the "pick and mix" strategy of *pragmatists* are to be opposed in systems thinking. Rather the different rationalities stemming from alternative theoretical positions must be respected and applied only to suitable problem cases, i.e. where the underlying assumptions of the methodology and the problem space are respected.

2. the restrictive approach of *isolationists*, who apply their limited repertoire of methodologies (often only one) to all problems they encounter must also be avoided, and

3. the tendency to absorb all other theoretical positions (i.e. *imperialism*) must also be avoided.

It is argued that his inclusion of cybernetics and complexity theory in systems thinking (which could be seen as *imperialism* on research programme level, if not on methodological level) is significant in order to understand what is happening regarding the current status of the development of problem-solving methodology. Flood and Jackson also includes OR as a relevant approach for Simple-Unitary problems in "Creative Problem Solving", while, as already mentioned, Pidd includes Systems Thinking as part of OR!

3.2   The emergence of pluralism

Flood & Jackson introduce their book "Creative Problem Solving" with the following

"*In the modern world we are faced with innumerable and multifaceted difficulties and issues which cannot be captured in the minds of a few experts and solved with the aid of some super-method. ... It is the argument of this book that the search for some super-method that can address all these problems is mistaken ... It would be equally wrong, however, to revert to an heuristic, trial and error approach and seek to solve problems in that way. We need to retain rigorous and formalised thinking, while admitting the need for a range of problem-solving methodologies, and accepting the challenges which that brings.*" [Flood & Jackson, 2002, xi]

In making this statement they articulate the requirement for a pluralist approach to a "problem solving methodology". No doubt their reference to a "super-method" refers (also) to *the* scientific method, which claimed its dominance and uniqueness as *the* problem-solving methodology for centuries, especially since the enlightenment.   In the twentieth century the claim of the empiricist manifestation of this method peaked due to its spectacular success, but was also challenged as a result of the consistent failure to remove the "feet of clay" from scientific method, be it in the form of

1. providing an "Inductive Logic" (Carnap's quest)
2. removing induction (Popper's quest, settling for a trial and error approach of theory testing instead of employing induction)
3. finding justification for the use of probabilistic modelling and/or probabilistic reasoning (statistic's quest)

Gödel's incompleteness theorem also seriously injured the view that one method exists which could completely and coherently capture the process of knowledge creation and the articulation of that knowledge.

This raises the question "*Qua Vadis?*" Do we have any hope of growing knowledge in a disciplined and formalised way? This study argues that the emergence of pluralism as a viable way ahead has already dawned on many more than Flood, but it shattered an implicit assumption that scientific method is monistic of centuries, triggering

1. a lack of discipline as first response (Feyerabend's response was in essence "if there is not one scientific method, then there is no scientific method")

2. a resultant surge in claiming dominance and absorbing all other approaches (imperialism), which led to cluttered and confused terminology (e.g. in the use of terms like "problem", "issues", "dilemmas").

Yet it would be difficult to look at the perspectives described in this study without noticing the emergence of pluralism, in some cases (like the study of scientific method) even with reluctance and confusion as a result of this finding. This happened with a simultaneous shift in focus to areas of scientific study beyond only the natural world.

Kuhn provides the intellectual framework with which this situation can be articulated. According to his view "scientific method" entered a new paradigm. The anomalies of its monistic paradigm have caught up with it, and a new paradigm, namely a pluralistic approach to scientific method, has taken its place. Its development is currently in the emerging phase, where the struggle for dominance by the various "methods of knowledge creation" (which can also be termed "problem solving methodologies") is fierce. As is characteristic of the emergent phase, the underlying assumptions of this paradigm are still poorly understood, which leaves much room for a lack of discipline and confused terminology. Asserting dominance by claiming to be able to solve "more" problems, especially problems which were previously unsolvable, than another (opposing) methodology for problem solving, is also very obviously present in current literature.

Flood captured the consequence of the finding of pluralism by noting " ... *and accepting the challenges which that brings*". What are these challenges? How can they be organised? How can we make sense out of the confused and exclusive language used in the struggle for dominance? To approach these questions we need to understand the essence of science rather than its methodology (i.e. the reason(s) why a specific method can be seen as a *valid* scientific approach rather than to describe one *valid* scientific method in detail).

3.3   The essence of scientific enquiry

3.3.1 What is the goal of science?

Although both Bacon and Descartes started to define science in a methodological way, they were unable to move beyond the Aristotelian search for "causes". Hume's work was also very much involved in the struggle to move beyond Aristotle, although he started to raise serious questions about the acceptability of reasoning by induction in scientific endeavour due to inconsistency in the object being studied. The tradition started by Copernicus, and which culminated in Newton, became the new focus of science, and proved very successful: The development of ever more accurate experimental tools facilitated the unprecedented success of science. "Successful in achieving what?" is a valid question. What were these people looking for, and under what circumstances (or by which methods) did they conclude that they have achieved

their goals? The answer to these questions will provide insight into the value system underlying scientific enquiry.

It was taken for granted from the very outset by all observers of nature that one method existed which could be employed to study nature. The problem is that however hard the best thinkers tried, they could not come to an agreement of what this one method was. That highlighted the underlying issues: "What is the essence of scientific enquiry?" and "What are the properties of scientific enquiry?" The following points are a summary taken from the reading of all sources studied on scientific method, but they were found to be articulated particularly well by Alexander. [Alexander, 2001, 242-273] They provide a "common set of values" for the goal of all scientific endeavours.

Critical Realism – Currently scientists believe almost without exception that science aims to tell something about the real world. In this way they are realists. At the same time they are critical in that every piece of new information is tested and carefully studied often by the wider body of science before it is incorporated into the "body of knowledge" of the specific discipline. Even then its acceptance is only tentative, and new information would cause re-evaluation if necessary. In this way knowledge grows through constantly being scanned and re-evaluated in the light of new knowledge. Any inconsistencies point to incomplete knowledge or wrong interpretations of results, and are documented carefully for further study.

Coherence – Scientific theories provide the framework that explains facts that would otherwise seem to be unrelated in a coherent way. It also provides for explaining the nature of the relation of phenomena which are obviously inter-related. This is one of the main reasons why Darwin's theory of evolution was accepted with so much enthusiasm and became so successful in the field of biology. Since Quine pointed out that science is under determined [Cryan et al, 2001, 138], completeness cannot be seen as a viable aim of science. That makes coherence a valid objective, according to Gödel's work.

Objectivity – The aim of scientific work is to increase objective knowledge about nature. One of the ways in which this is achieved is by describing all experiments in sufficient detail so that they can be reproduced by others, whose results must confirm

the initial claims. Science does not accept any results that carry with it the possibility of subjectivity or prejudice.   This does not mean that individual scientists are objective, but rather that because of the acceptance of the inherent subjectivity of all individuals, methods and procedures are put in place to ensure objectivity of results and the interpretation of results.

Refutation and Commitment – The tension between these two realities in science (i.e. refutation and commitment) is one of the main reasons why progress is either advanced or sometimes stifled. Scientific theories are always open to refutation, and in fact should ideally state clearly under what circumstances they would be refuted, often by stating which facts would disprove them, or else by predicating certain phenomena not yet observed. If these phenomena are then excluded due to later scientific work, the theory is no longer viable. On the other hand, commitment to the theories are often required from scientists in that they have to defend their results to a body of scientists who by nature are "critical realists".   Another reason why commitment is required is that results are often only obtained after many years of work, which require that the scientists doing the work have to believe in the theory to persevere.   It is often the tension between these two, knowing when to accept criticism against a theory as a refutation that calls for much careful consideration. For this reason a certain amount of "building up of evidence" against a theory is necessary before it is overthrown by a new theory which provides more coherence, also including the evidence against the "previously accepted theory".   In this way scientific theories are never the final truth, only the best presentation of current knowledge.

Common Sense and Lateral Thinking – Often the results of scientific work, once produced, seem to be "common sense". With hindsight it seems almost trivial to have arrived at such a conclusion, yet without careful scientific study these "trivialities" are not uncovered.   At the same time it is often lateral thinking that brings about completely new (and often counter-intuitive) theories that change the scientific world completely.   Examples of the latter include the work of Newton, Darwin, and Einstein.

3.3.1.1   What approaches are available to science?

The different approaches in science which developed over the centuries vary considerably, including

1. Mental experiments
2. Modelling from first principles
3. Logic
4. Mathematical modelling
5. Empirical Methods
6. Probabilistic Methods

The two ways in which one can argue from some starting point to a conclusion can be either deductive (i.e. from premise to conclusion, from general to specific), or inductive (i.e. from the specific to the general).

Which combination of approaches, in what order, and by what logic to argue in order to yield a conclusion closest to truth have become the main focus of discussing scientific method over the centuries. This study acknowledges the importance of that focus, but also moves beyond that to ask if all of these approaches are currently still valid, and if so, under what circumstances? Do they provide a sufficient set of approaches for knowledge creation and problem solving? If not, what needs to be added? No conclusive answers are proposed. The landscape which provides the context will rather be explored to gain insight and create new knowledge.

It was to the detriment of development and application of science that the approaches introduced by Aristotle (1,2 and to a certain extent also 3 above) were neglected because empiricism became dominant at the same time that many of the conclusions of Aristotle were dethroned after a reign of about 2000 years. In practical problem-solving the full scope of approaches are useful. This can be seen as one of the reasons why science is currently far more adept in providing detailed answers in probing the limits of nature than in providing realistic answers to everyday problems.

Systems Thinking is arguably one of the modern ways in which methods beyond mathematical modelling and experimentation are sought. It points to the power of mental conceptions and their manipulation in order to understand the real world better: Mental experiments are slowly moving into focus again, dressed up in a

current fashion. Modelling from first principles, but starting with a mental concept as basis rather than a single factual assumption, is in development again. The "proof theory" for this approach is unclear. We are now experiencing the opposite of the days when Aristotle was dethroned – "the scientific method" (i.e. empiricism) is now dethroned and alternatives sought: In the quest to add value to the disciplined progression in knowledge creation, what is known as the classical *scientific method* is seen to be relevant only to a small number of problem spaces where there are "closed systems" and the problems are "not complex", and other alternatives are sought for "open systems" and "complex" problems.

In the discussion of systems thinking, the seeds were found of convergence of the stated "holistic" goal (in reaction to the reductionist approach of mechanistic classical so-called *Newtonian* scientific method) to a migration towards an approach championing the organisation of thought in "systems", introducing a *reduction* to bounded action areas, being studied in *formalised* ways. It is an argument of this study that this convergence points to a very healthy phenomenon of rebuilding a fuller picture of the approaches available for scientific enquiry by not only returning to some neglected approaches, but also by probing new possibilities. These new approaches could in time be seen as the pride of the contribution of the twentieth century to the disciplined growth of knowledge (which has been the hallmark of science for centuries) if disciplined, critical thinking is found to be their *method* and formalised growth of knowledge is found to be their *goal*.

3.4   Practicing science with a pluralist scientific method

In this section a list of salient issues to be addressed if scientific method is indeed pluralist, are given. These issues provide a minimum set for what needs to be taken into account during the design of a scientific decision support capability at IMT.

3.4.1 Problem categorisation

If scientific method is indeed pluralist, then it speaks for itself that different problem types will be best evaluated by using different approaches. This brings to the surface the requirement to formalise problem types. It is interesting that frameworks for problem categorisation already exist, two of which are described in this study.

3.4.1.1 Frameworks for problem categorisation

Literature does provide frameworks for problem categorisation. The awareness that not all problems share the same attributes, has caused various authors to offer different (but related) ways on how to be relevant when solving problems. In this study two frameworks are given and discussed, namely one from Systems Thinking and one from Complexity Theory (sense-making).

3.4.1.1.1 *From Systems Thinking: System of Systems Methodology*

Flood [Flood & Jackson, 2002] provides a framework for problem categorisation, also taking its context into account. He proposes the framework to serve as a pointer towards using the correct methodology to solve problems suited for that methodology. He does provide a list of methodologies, but discussion of those falls outside of the scope of this document.

The focus here is to describe the parameters he identifies to differentiate between problem context types. He proposes two axes, namely "The Participants are…" and "The System is…". Each of these is discussed briefly:

<u>The Participants are…</u>

Unitary:

Participants are Unitary if

  1. they share the same common interests
  2. their values and beliefs are highly compatible
  3. they largely agree upon ends and means
  4. they all participate in decision making
  5. they act in accordance with agreed objectives

Pluralist:

Participants are Pluralist if

  1. they have a basic compatibility of interest
  2. their values and interest diverge to some extent
  3. they do not necessarily agree upon ends and means, but compromise is possible
  4. they all participate in decision making
  5. they act in accordance with agreed objectives

Coercive:

Participants are Coercive if

1. they do not share the same common interests
2. their values and beliefs are likely to conflict
3. they do not agree upon ends and means and genuine compromise is not possible
4. some coerce others to accept decisions
5. no agreement over objectives is possible given present systemic arrangements

The System is …

Simple:

Simple systems have the following characteristics:

1. A small number of elements
2. Few interactions between the elements
3. Attributes of the elements are pre-determined
4. Interaction between the elements is highly organised
5. Well-defined laws govern behaviour
6. The "system" does not evolve over time
7. "Sub-systems" do not pursue their own goals
8. The "system" is unaffected by behavioural influences
9. The "system" is largely closed to the environment.

Complex:

Complex Systems have the following characteristics (these were already listed in the discussion of un-deterministic complexity):

10. It has a large number of elements
11. It has many interactions between the elements
12. The attributes of the elements are not pre-determined
13. The interaction between the elements are loosely organised
14. The interaction between the elements are probabilistic in behaviour
15. The system evolves over time
16. Sub-systems are purposeful and create their own goals
17. The system is subject to behavioural influences
18. The system is largely open to the environment (exhibits a weak boundary)

From the two axes "The Participants are…" and "The System is…", the following framework is defined by Flood:

	UNITARY	PLURALIST	COERCIVE
SIMPLE	Simple-Unitary	Simple-Pluralist	Simple-Coercive
COMPLEX	Complex-Unitary	Complex-Pluralist	Complex-Coercive

Table 3-1 System of Systems Context Categorisation Framework

Each combination is then discussed and its characteristics listed. For each combination Flood provides those methodologies which are suitable, with motivation.

3.4.1.1.2 From Complexity: Cynefin Framework

The Cynefin Framework is presented in "The New Dynamics of Strategy: Sense-making in a complex and complicated world" [Kurtz & Snowden, 2003] The basic principles underpinning the Cynefin Framework is discussed in Chapter Two in the section on Complexity[17]   where Snowden's views of *contextual complexity* is discussed

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[17] See § 2.2.3.3

COMPLEX	KNOWABLE
Cause and effect are only coherent in retrospect and do not repeat	Cause and effect separated over time and space
Pattern management	Analytical/Reductionist
Perspective filters	Scenario planning
Complex adaptive systems	Systems thinking
Probe-Sense-Respond	Sense-Analyze-Respond
CHAOS	**KNOWN**
No cause and effect relationships perceivable	Cause and effect relations repeatable, perceivable and predictable
Stability-focused intervention	Legitimate best practice
Enactment tools	Standard operating procedures
Crisis management	Process reengineering
Act-Sense-Respond	Sense-Categorize-Respond

Figure 3-2 Cynefin Problem/Context Categorisation Framework

The Cynefin framework uses the problem type as the differentiator, arguing that different types of problems require approaches appropriate to their nature to solve the problem satisfactorily. The Cynefin framework does not give as much explicit attention to the participants, but when a study of the methodology is done it is clear that it pre-supposes a pluralist group of participants. It does differentiate between simple and complex problems in much more detail than Flood's model. The Cynefin Framework is given in Figure 3-2. It shows that the problem space is divided into 5 distinct groups. They are grouped into Ordered, Unordered and the Disorder:

1. Ordered: Known and Knowable Domain
2. Unordered: Complex and Chaos Domain
3. Disorder: The domain in the middle.

Each of these domains is discussed in more detail.

Ordered: Known Domain

Cause and effect relationships are linear (consistency can be guaranteed) and empirical in nature. Repeatability allows for predictive models to be built. Data is categorized and then responded to, according to a pre-determined best practice or model. Structured techniques are not only allowed, but mandatory for the best results in problem-solving and decision-making in this domain.

Ordered: Knowable Domain

While stable cause and effect relationships exist in this domain, they may not be fully understood due to the distance in time and space between them. Everything in this domain can be moved to the known domain if enough resources are made available to analyse and understand the systems fully. The best method of modeling is to analyse data and then to respond in accordance to expert advice or expert interpretation of the analysis.

Un-ordered: Complex Domain

Understanding any system requires that we gain multiple perspectives on the nature of the system. The methods, tools and techniques of the Known and Knowable domains do not work here.

The description of complexity as assumed for this domain is already described in Chapter Two[18] where Snowden's view of complexity is given. What is important here is to note his view that in this domain problems are solved through pattern management: Patterns are perceived by defining and approaching the problem via "perspective filters".

This dissertation is following this methodology as an illustration of the value added by utilising perspective filters when dealing with complex problems.

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[18] See § 2.2.3.3.

Un-ordered: Chaos Domain

In the chaotic domain there are no perceivable relationships between cause and effect. The system is turbulent, and applying best practice will not help; there is nothing stable or repeatable enough to analyse; and no emergent patterns will become visible in time. None of the methods of the other three domains will be successful in this domain.   The decision model in this domain is to act in order to decrease the turbulence and to monitor the effect of the action. The trajectory of an intervention will differ depending on the nature of the system, so that learning from experience is excluded.

We may use authoritarian intervention to impose order and move the system into the known or knowable domain, but success will depend on how closely we can stay to the actual chaotic nature of the system in doing so. We may also use multiple interventions to try and create new patterns, and in doing so move the problem-space to the complex domain. All these interventions carry the risk of un-sustainability of the resultant system though, and the more explicit the order is that is imposed, the higher the risk of collapse of the created system if the actual underlying system is chaotic in nature.

Snowden claims that chaos is also the domain that we may enter deliberately in order to open new possibilities or to encourage innovation. In essence it would mean removing order and allowing the resultant system to free-fall for a period of time, before intervening only to decrease the turbulence again.

Disorder Domain

The centre domain is called the disorder domain. In this domain order is resisted even if it does exist inherently in the system, often due to conflict between decision-makers. Disorder differs from chaos in that chaotic systems inherently do not have order, while disorderly systems resist order until the cause of the disorder is removed.

3.4.1.1.3 Integration of the two frameworks

Even a casual observation of the two frameworks renders similarities between them. The two main observations relevant to this study is that Flood focuses on both the type of problem and the type of participant, while Snowden seems to assume

pluralism as the only type of participant and gives attention to a finer grouping of problem type. The only exceptions are when Snowden proposes that taking strong authority is the best way to deal with Chaos (which could indicate a coercive approach). He also mentions that chaos is often caused wilfully by those who want to take control and advance their goals (his disorder domain). In this way he incorporates the coercive type of participant for these two types of problem contexts. It is taken in this study that Snowden's method would not work well though where participants are unitary, since there won't be enough tension to provide enough difference for multiple clusters.

Taking these assumptions into account, the following combined framework is produced. It provides a richer framework which can be used for problem categorisation.

One other observation that is relevant to a combined framework is the fact that Flood's description of "complex" does not indicate all the attributes that Cilliers, for instance, give. It is clear from Flood's reference to an aeroplane which can mistakenly be labelled a "complex" system (while its behaviour, complicated as it might be, is clearly governed by well-defined laws) that he adheres to an un-deterministic view of complexity. This would make his "complex" at least compatible with Snowden's view. The problem is that Snowden does not provide a clearly defined list of attributes of what he calls "complex", and the additional complication is that Cilliers' description of complexity is clearly describing more attributes than Flood. It could be that Flood merely ignores the other attributes, but then his classification of problem types and the resultant mapping of relevant methodologies would not be sufficiently described for a combined framework where the exact description of "complex" is not well-defined.

For this reason IMT proposes a combined model where complexity is broken into two, namely deterministic and un-deterministic complexity. Un-deterministic complexity is taken to be in accordance with Cilliers' description. Deterministic complexity is taken to have Gribbin's description. In this way the "Knowable" domain of Snowden is also refined in that the time-factor is taken into account: Even though something might be knowable in principle (e.g. deterministic complexity), changes in the environment might be faster than any results which could be obtained

from an analysis.   This would render analysis unproductive and produce only *retrospective coherence* (an attribute of complexity according to Snowden's categories).   So Snowden's definition of Knowable is refined by removing deterministic complexity from the knowable domain and creating a new category where only retrospective coherence can be obtained, but the nature of the system is still deterministic. The combined framework then becomes:

	UNITARY	PLURALIST	COERCIVE
SIMPLE/KNOWN			
KNOWABLE			
DETERMINISTIC COMPLEX			
UN-DETERMINISTIC COMPLEX			
CHAOS			
DISORDER			

Table 3-2 Proposed Combined Problem/Context Categorisation Framework

Snowden's Ordered Domains would include the Simple/Known and Knowable categories in the combined framework, while the Deterministic Complex, Un-deterministic Complex and Chaos would be included in the Unordered Domain. The Disorder Domain could by nature be any of the above, but would always have coercive as the definition of the participants due to the fact that any inherent or created order is wilfully resisted and broken by the decision maker(s).

This combined framework is proposed in order to illustrate the best current understanding from literature about possible categories of problem contexts.   The combined model provides well-defined definitions of all categories of participants and system types.   The combined framework includes both Flood's and Snowden's frameworks, but supersedes both of them.

3.4.2 Theory choice and pluralistic approach to scientific method

The problem of theory choice in the philosophy of science, while it is mainly an academic problem, can be overcome in practice by employing frameworks of problem categorisation as a first approximation to limit the candidates among the infinite number of possible theories to use. This also shows that while Popper struggled to provide a way to choose which theories to evaluate without using induction (as possible candidate to test for *verisimilitute*), this implication of a pluralistic approach will make the practical application of Popper's method much simpler, because the theory can be chosen using the problem type as starting point.

3.4.3 Recognising common ground (Sorting out terminology)

The rejection of what is termed "*reductionism*" and the restrictions of "*Newtonian*" scientific method, which became the commonality between systems thinking, chaos theory and complexity theory in the social sciences led to a search for new terminology to avoid any resemblance of similarity with *Newtonian scientific method* (e.g. Ackoff does not speak of "solving" problems, but rather of "treating" problems. Later the word "problem" itself became an issue [Flood, 2000, 84-88]).   This phenomenon, while addressing a legitimate requirement in the search for relevance in knowledge creation, is also a cause of confusion, obscuring similarities.

A further cause of confusion is the fact that the same word is sometimes used to describe inherently different phenomena. An example is the use of 'chaos' and 'complexity' in natural sciences and its use in social sciences, as already described.

Another factor that causes different disciplines to use different terminology for the same aspect of scientific method is that there are actual differences in approach. Yet the same underlying goal is pursued. It is necessary to revisit the common value system identified in the section "What is the Goal of Science?"[19]: How do these feature in a pluralist definition of scientific method? Are they still valid?

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[19] See § 3.3.1

3.4.3.1   Critical Realism

Although systems thinking describes a system as an abstraction from reality, it serves the purpose of informing us about reality. All the perspectives discussed in this study share this common goal – to describe the reality of the action space they are studying. Natural science describes reality in different terms: Materialism (e.g. logical positivism) describes it in terms of the physical world only, while another description is "according to fact".   Social science often describes it in terms of an inclusive view of stakeholders. Yet there is broad agreement across scientific disciplines in practice that the goal is to be as close as possible to reality, however that is seen to be achieved.   A pluralistic scientific method therefore should confirm this goal of science. (The view that realism is the goal of science is also contested currently, but that is not discussed in detail in this study due to the requirement for a "fact-based" service[20])

3.4.3.2   Objectivity

There is general agreement that science's goal to be objective does not mean that the practitioner of science is totally objective, but rather that because the practitioner is known not to be objective, procedures and tests should be built into scientific method to ensure that the methods used and the results produced are objective.

In natural science objectivity is achieved by the requirement of *reproducibility*. Flood states the counterpart of this in systems thinking to be *recoverability* [Flood, 2000, 149-150]. This strongly resembles Popper's view that for objectivity to be achieved in science, it is a prerequisite that the articulation of any theory must be such that it is fully understood by the readers – *objectivity is seen as a fully articulated theory (subjectively constructed and/or chosen), which opens the theory for criticism*. It shows once again how Popper moved towards building a bridge over the chasm between the natural and social sciences, thus providing an articulation of objectivity which can be used in a pluralist scientific method.

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[20] See § 5.1.2.1.3 and § 5.1.2.1.4 for a discussion on pluralism in the context of realism.

3.4.3.3   Refutation and commitment

Popper's views on refutation as a requirement for scientific work drew much response, especially because commitment to theories seems to be so prevalent in science. Yet Popper pointed out that the commitment to theories when they should have been taken into reconsideration already, often stifles scientific development. Regardless whether justification or refutation is seen as the goal of theory testing, this is a weak point in both systems thinking and complexity science in its social application as currently practiced.   While boundaries of the "action space" have become an accepted requirement for practical work, inclusiveness of the views of all stakeholders remains a first priority for acceptance of the results of systems thinking and complexity modelling. There often does not seem to be a major concern about the acceptability of the results from any disciplinary perspective, as long as there is enough "buy-in" from all stakeholders defined by the action area.

Popper's requirement that any theory should state explicitly how it can be refuted is a discipline to be pursued.   This would require critical thinking and call for accountability. Stating upfront how ongoing validity can be monitored and what would indicate a requirement for revisiting the problem would increase the quality of the results of scientific work. This is arguably the best value that can be added to evaluate the quality of scientific results specifically where they lead to decisions which have far reaching impact over long periods of time. This discipline is equally valid in all scientific approaches, so that it should be an important goal to be pursued in a pluralist scientific method.

3.4.3.4   Common sense and lateral thinking

Both of these are always present in scientific work. Natural science does not have a formal approach to lateral thinking, although it is often illustrated in that lateral thinking breaks out of the deadlock of one theory and provides a more productive theory in its place (e.g. the work of Einstein). Social science gives more explicit attention to this. One example of lateral thinking is Flood's concept of prismatic thinking, which has the objective to "create new ideas" in order to "learn in the unknowable" [Flood, 2000, 96]. The productiveness of lateral thinking is illustrated across scientific disciplines, making it a valid goal to pursue in a pluralist scientific

method. It should always be guided by the discipline of scientific endeavour and not leave room for speculation and subjectivity.

3.4.4 Boundary

3.4.4.1   Defining the boundary

Isolating the problem from its environment, and even idealising it by experimenting with simplistic models, has been part of the study of nature since Newton and Galileo. The controlled experiments in scientific laboratories also serve to isolate a specific feature from its environment so that it can be studied without the impact of the environment. Natural science never assumed that nature was a closed system, but devised ways in which "closed boundaries" could be drawn for experimentation whenever possible (although disciplines like astronomy are mainly observational). This was largely the reason why experimentation could be so successful in natural sciences.   Providing "correction terms" to ideal models through empirical work bridged the gap to the real world – thus dealing with the "open system" which nature actually is, in a manageable way.

Social and human sciences find this more difficult to achieve, or even undesirable. They assume "open systems" and perform their studies including the impact of the environment and other aspects of the system from the start. Yet they need to "make boundary judgements" as they "draw the boundary" around the loosely linked elements of the system – a practice that "extracts" the problem space (i.e. "action area") from its environment in a different way. Defining perspective filters (thus implicitly drawing a boundary around the action space if not around the problem area) is another recent way in which both systems thinking and complexity theory search to "draw the boundary" so that the "action area" (e.g. Flood, 2000, 92-94] can be identified and studied.

It is necessary to state the obvious, namely that the definition of the boundary always depends on the work of the analyst / experimenter, so that boundaries are arbitrary in that sense. Finding ways to define "good" boundaries (i.e. boundaries that would enable appropriate evaluation of the problem case) remains one of the tasks of problem solving methodologies, whether in the natural or in the social / human

sciences. In this way boundary judgements are important to both natural and social sciences, but often defined with more scientific discipline in the natural sciences.

3.4.4.2   Relaxing the boundary

Literature is mostly silent about methodologies to relax the boundary and the dynamics involved in managing that, while monitoring the impact of implementation at the end of the investigation. The model which is used by IMT for problem solving gives specific attention to the synthesis between the real world context and the solution offered by the scientific enquiry. The same frameworks which were used to extract the problem from the real world (as discussed already), then matching it with an appropriate scientific approach, can also be used to ensure that the boundary is relaxed in a way that would optimise the synthesis of the adapted action space with its context. Careful attention also needs to be given to ensure that the assumptions made during the analysis phase are true in the context where the solution of the problem is implemented. Any mismatches must be articulated and the effect of such mismatches monitored during and after the relaxing of the boundaries.

3.4.5 Assumptions

In this study a distinction is made between assumption types. This is done to highlight the importance of giving explicit attention to this very important aspect of problem-solving, but also to point to the various different assumptions at stake.

3.4.5.1   Implicit assumptions

Literature does not distinguish between what is called implicit assumptions and underlying assumptions in this study. Yet it is seen to be important enough to make a distinction.

An example of an implicit assumption would be the century-long unspoken acceptance that there is such a thing as THE scientific method, i.e. one method to solve all problems, to approach all scientific work. When that implicit assumption, which was never articulated explicitly, but universally accepted, was finally challenged in the twentieth century, it caused much turbulence and confusion initially.

Uncovering the unspoken, implicit assumptions, assumed because they are accepted universally, should be the ongoing concern of scientific work, even though this is a challenging pursuit.

3.4.5.2   Underlying assumptions

Due to the design of any methodology, it contains certain underlying assumptions. These would describe its weak and strong points, and would also identify for which problem types it is suitable. The underlying assumptions about the methodology in use should be documented explicitly.

Every problem under evaluation also requires that assumptions are made about its nature, stakeholders, variables, etc. These assumptions should also be documented explicitly.

3.4.5.3   Practical assumptions

These are assumptions made during the analysis of the problem for practical reasons. Data might not be available, or the methodology in use might require that choices of certain variables be made in order to be relevant to the practical problem being evaluated. All the assumptions made during this process need to be documented with motivation and their possible impact on the practical usefulness of the solutions obtained after having made those assumptions.

3.4.6 Initial values

Natural science has already realised the most important role of initial values when non-linear relationships between elements of systems exist[21]. This importance has to do with the nature of non-linearity, not with whether or not the model is seen to be deterministic. Even small changes in the choice of initial values for variables could lead to vast differences in the further path of the emerging patterns.

This area needs to be studied in the application of complexity in the social sciences and systems thinking. Very little, if any, attention is given to it in the current literature, because it is often taken to be irrelevant by the proponents of un-deterministic complexity.

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[21] See discussion of deterministic complexity in § 2.2.3.4.

3.4.7 Reduction

While the developments of alternative approaches to problem solving (i.e. alternatives to THE scientific method) tried every possible avenue to get rid of reduction, their quest served to reinforce the practical requirement for reduction in problem solving.

It is generally true that the reduction imposed on the problem analysis has a decisive impact on the solution produced. The use of reduction should therefore not be taken lightly. Modelling cannot be done without some form of reduction, and the practice of not explicitly articulating which reduction is employed, its impact on the problem case, as well as its resultant practical restriction in the light of the context, is unacceptable and should be avoided even where closed systems are analysed. Reduction and its impact on the practical validity of the proposed solution should always be articulated.

In developing the perspectives, especially in following how reduction was frowned upon and the resultant expansionist approaches which proved to be unproductive, some very important issues around reduction were uncovered:

1. There are different ways to induce reduction, each with its own strong and weak points (this has been discussed in the section on complexity and systems thinking in Chapter Two).

2. Where problem-solving cannot be done without taking the context into account (e.g. in open systems and complexity), the context is a major driver in deciding which form of reduction would be least restrictive for the problem to be solved.

3. The kind of reduction that was used and its impact should be monitored and articulated carefully during the implementation of the solution and the relaxation of the boundaries.

3.4.8 Recognising   common   ground   (Exploring   concept fusion)

One of the most important synergistic insights that the perspectives provide is that there is a migration towards a more formalised approach, albeit articulated very

differently from the traditional debate about scientific method. The additional insight which becomes visible as the developments of the twentieth century in all the perspectives are compared, is that the underlying issues remain the same for all areas which strive to create new knowledge and solve practical problems, although the articulation of those issues vary considerably between the disciplines. There seems to be little mutual understanding of their similarities. The imperialistic culture which currently prevails causes the various disciplines to rather make a concerted effort to identify and focus on the differences between them and other disciplines having a similar focus (i.e. the growth of knowledge, or problem-solving).

For the purposes of this study, the emphasis is placed on similarities, so that the specific strengths of all disciplines can be utilised without being negatively influenced by their respective weaknesses. The pluralistic approach to scientific method, coupled with the acceptance that different scientific approaches are better suited for different problem types, provide the incentive to search for a meta-methodology where similarities rather than differences are highlighted. This is not an easy task, due to the confusion in terminology and the concerted effort rather to focus on
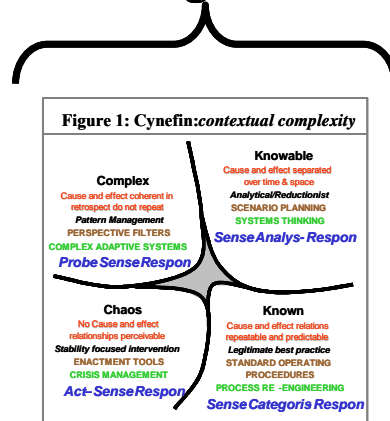
Figure 3-3 Example of possible concept fusion among scientific approaches

differences. However, if methodological similarities can be identified and compared between the different disciplines, their respective weak and strong points can be better understood. Figure 3-3 provides a view of one such a similarity which comes to the surface. This fusion of concepts could provide valuable insights in order to exploit the pluralistic nature of scientific method.

Flood [Flood & Jackson, 2002, 7] alludes to an analogy between systems thinking and natural science when he discusses the 'different levels of resolution' in systems (which obviously will require different levels of sensitivity and fault tolerance in any measuring instrument, but he does not mention that). Kuhn develops the implicit assumptions made by the choice of measuring instrument the furthest by not only agreeing with Popper and others that any design of experiment presupposes some theoretical assumptions already, but by also pointing out that the choice of measuring instrument also presupposes some underlying assumptions about what needs to be measured, how it needs to be measured and to what level of accuracy. While the underlying assumptions about theory choice are only rarely explicitly stated in the design of an experiment or choice of observations to be made, the impact of the choice of instrument is hardly ever mentioned. Yet Crump showed how the development of natural science was shaped, and in fact driven by, the development of ever more accurate measuring instruments.

Studying the exact nature of the pluralistic scientific method falls outside of the scope of this study, but the example above highlights the importance of proper tooling for any discipline as one immediate benefit from such a study. The criteria to evaluate possible tools in the social sciences can be simplified by the analogy proposed by, for instance, using "measuring instrument" as a metaphor for a "perspective filter". In this sense the choice of instruments is part of the boundary definition in conjunction with identifying weaker links and stakeholders, an issue neglected by Flood. [Flood, 2000] The only other example given in this study is the Cynefin Framework, which provides a categorisation tool (i.e. measuring tool) which is poorer in the area of "The participants are...", but richer in the area of "The system is ...", the two axes of Flood & Jackson's framework.

For practical problem solving it therefore makes sense to search for similarities by categorising terminology and finding analogies in the methodologies rather than to highlight differences and search for terminology which would discriminate. Care needs to be taken, however, that actual differences are not overlooked in the process. This could point to weaknesses and strengths of specific theories, techniques and tools which would otherwise remain hidden. This is not pursued any further in this dissertation.

3.5   Conclusions

The following main points emerge from the development and interpretation of the perspectives:

1. There is an emergence in the "soft" sciences, especially noticeable in knowledge management and systems thinking, of practices and methodologies which strive to achieve the same goals as traditional scientific method, even though those goals are articulated in somewhat different terminology.

2. Popper provides a description of scientific method which has proven its usefulness in both natural and social applications. His views provide the disciplined approach necessary to identify commonalties across scientific disciplinary boundaries, and also between natural sciences and other sciences. His main weak point remains that he prefers a view that "theory choice" (i.e. which theories to consider) is done in a trial and error fashion rather than to concede to the use of induction.

3. The awareness that different approaches are necessary to solve the wide scope of problems already brought about frameworks for problem categorisation. This can assist in a practical way to guide the "trial and error" process of theory choice which Popper proposes. It also adds much value to increasing the quality of a scientific problem-solving capability seeking to solve real life problems.

4. Practical problem solving, using pluralist scientific method, requires careful consideration and explicit articulation of a number of issues which used to be taken for granted in problem solving in closed systems when using the classical *scientific method*. These issues are discussed in § 3.4.

These insights provide the backbone of the development of a decision support process in IMT, which is described in the next chapter.

Chapter 4: A Generic Pluralist Scientific Problem Solving Process (Decision Support Process)

Criteria for Choosing Perspectives

P1	P2	P3	P4	P5

Conclusions from synthesis of Perspectives

Finding Commonality in Pluralism

Framework(s) for problem Categorisation

Process of Scientific Problem Solving

Case Study: Creating Knowledge through Complexity Methods
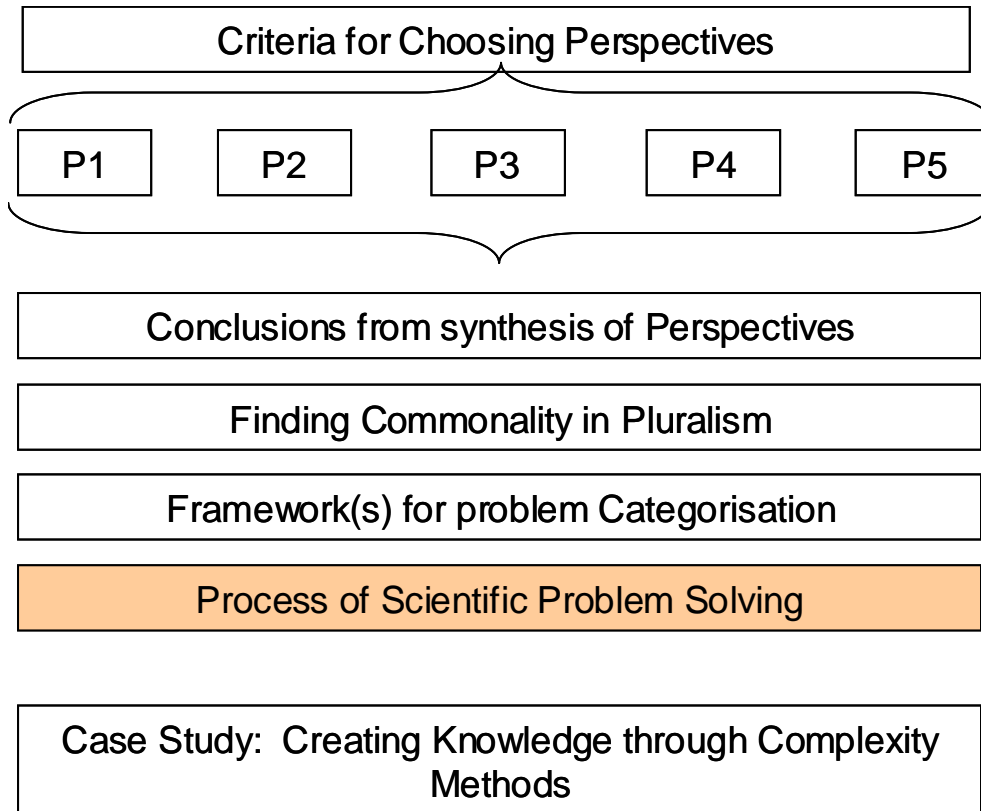
Figure 4-1 Dissertation Road Map

4.1 The process described

Having observed the commonalities in the various problem solving disciplines as they grow knowledge, and having had to cope with the complexity of the problem at hand (i.e. defining a scientific problem solving capability at IMT), it becomes possible to escape from the complexity by abstraction. Following the well-documented fact that abstraction allows us to conceptually escape from the complexity at hand, it is possible to move to the meta-level of abstraction where the complexity is contained and given meaning and direction through a generic process. Following Boisot [Boisot, 1999, 6], abstraction is taken to mean

"an act of cognitive simplification which spares us the need to deal with the complexities that surround us. Conversely, an ability to handle complexity at an intuitive level spares us the painful rigours imposed by abstract thought processes."

Defining a capability where the decision support practitioners can develop this "intuitive level" to assist them to deal with the complexity of the competency they need to effectively service client requirements, the process is articulated in order to be understood and internalised by these practitioners.

Pluralist Scientific Problem Solving Capability
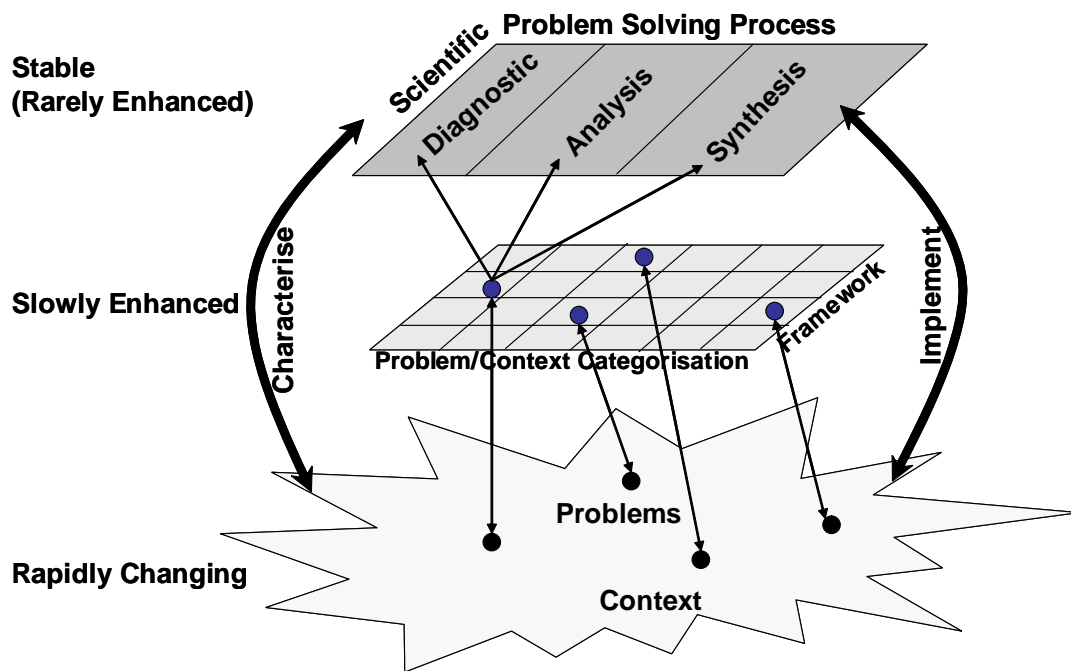
Figure 4-2 Proposed Pluralist Scientific Problem Solving Capability

Figure 4-2 shows the two levels of abstraction of the complexity of the context and the problems which present themselves in the context. The Problem Solving Framework represents the first level of abstraction. In itself it is a reduction of the context, and only valid to the extent that it is appropriate for the context, i.e. it is able to categorise all problem types which present themselves in the context. This framework becomes a way to approach practical problem solving and is used during the proposed scientific problem solving process for practical problem solving. The Framework(s) currently in use by IMT is described is Chapter Three. The aim of this chapter is to describe the proposed Scientific Problem Solving Process (second level of abstraction in Figure 4-2).

4.1.1 The objective of the process

The aim of IMT is to build a scientific capability for decision support to the SA Navy (and other DOD clients). The mandate is that such a capability should provide a scientific support service to decision makers in the SA Navy and other DOD clients.

In order to best serve the client's requirements, it is important that IMT remains aware of the latest developments in the field of scientific thinking which could be relevant to such a capability. The five perspectives (P1 to P5) developed in this study represents the current fields identified by IMT which best represent the underpinning areas of scientific study for such a capability.

Using these insights in practice for the wide variety of problems that IMT are confronted with by its clients, is the reason why this process is proposed. The process does not prescribe an algorithmic (or procedural) approach, but rather describes a process with multiple inter-relationships and feedback loops to ensure that

1. The problem is correctly understood and documented from the perspective of the client, and translated into an appropriate scientific articulation.

2. All aspects relevant to a balanced scientific enquiry are visited during the process at the appropriate phase of the process.

3. All limitations and strengths of the scientific enquiry utilised are understood, documented and its impact on the practical solution of the problem articulated.

4. The insight (and new knowledge) created by the enquiry has practical relevance to the client for real life decision making.

Taking these things into account the process can be understood as a grouping of aspects to visit during the various phases of the investigation, giving prominence to specific aspects when necessary. It is understood that the process is interactive and that new insights can at any point necessitate an earlier aspect (and even an earlier phase) to be revisited and reconsidered. In this way the process progresses slowly through all its phases, retracing its steps as necessary, until it is completed. The feedback loops are therefore loosely connected and dynamic in nature.

The content and exact description of how to go about the execution of a specific aspect is

1. sensitive to the context within which the problem is found, as well as

2. sensitive to the actual problem to be solved, and

3. sensitive to the different scientific approaches which could be used for such types of problems and their respective strong and weak points.

The actual activities performed during a specific scientific enquiry are therefore performed taking into account what will be suitable in the light of these three. The aim of the process is not to be prescriptive on how to execute each aspect or phase, but rather to ensure that all aspects are given appropriate attention at an appropriate phase of the problem solving exercise. In this way it describes a generic process equally suitable for all problem types (and all scientific approaches), regardless of the context within which the problem presents itself.

4.1.2 The phases of the process

Three broad phases are defined, namely

1. Diagnostic Phase. This phase extracts the problem from its context (or understands it in the light of its context)

2. The Analysis Phase. This phase studies the problem and proposes some (alternative) solution(s).

3. Synthesis Phase. This phase places the solution back into the context and implements it in order to remove (or dissolve) the problem.

The argument is that all scientific problem solving has these three phases, but their importance and dominance might differ from problem to problem. Notably, the "softer" the boundary, the more interaction there will be between the phases at all times, even during the study of the problem (analysis phase). In some cases the problem would never be extracted from its context (or no attempt made to understand it as a whole), but it would be treated by interactive multiple processes of intervention and observation in order to bring about change. This represents a very "open" system.

On the other end of the scale the problem might be isolated from its context (the boundary is taken as "hard") and analysed in isolation, with the solution then introduced back into the context. The generic process described here caters for both of these and everything in between.

A description of each phase follows:

4.1.2.1 Diagnostic Phase

4.1.2.1.1 Goal of the diagnostic phase

The goal of the diagnostic phase is to understand the problem and articulate that understanding from the decision maker's perspective, as well as to translate that into an appropriate scientific articulation of the problem (but stopping short of making any recommendations of how to go about analysing the problem).

4.1.2.1.2 Aspects to be taken into account

1. Context Characterisation

The context needs to be understood and described in enough detail to serve as sufficient background against which the problem can be articulated and the boundaries, assumptions and appropriate reduction can be identified and tested for validity.   A narrative description of the context needs to be produced which include at least the following important attributes:

a. A description of the problem from the decision maker's perspective, clarifying concepts specific to the decision maker and/or the context.

b. the rate at which changes occur which might impact on the problem definition and approach used to solve the problem.

c. the kinds/number etc of participants and stakeholders in the context which might influence the implementation of the solution or the understanding of the problem

2. Problem Description (Client Articulation)

A narrative of the problem needs to be produced which fully articulates the problem from the client's perspective. This is a working document to be updated during the execution of the diagnostic phase until it contains the content required for the work in the analysis phase of the scientific enquiry, as well as a description of the context which is agreed upon with the client.

3. Defining and documenting appropriate

a. Boundaries

Defining appropriate boundaries are very important, since the boundaries not only define the "action space" to be taken into account during the analysis phase, but it also implicitly defines what is not taken into account, which is very important to understand. Not giving sufficient attention to the best possible definition of boundaries might cause serious problems during the synthesis phase.

It needs to be decided whether the boundaries are taken as closed or open (i.e. whether influences from the context will be taken into account in the construction of the model and/or execution of the analysis phase).

b. Implicit Assumptions

Every decision maker does have implicit assumptions about the problem he/she is experiencing, and articulates the problem taking those for granted. It is a constant challenge for the kind of capability developed at IMT to be sensitive to this fact and try to uncover as many as possible of the implicit assumptions. This is not a trivial objective, since implicit assumptions are embedded in unarticulated common values and views, and they are often invisible due to their wide acceptance. (One example uncovered in this study is the implicit assumption through the centuries that there is such a thing as "the scientific method" which can solve all scientific problems – monism – and the work of philosophy of science is to describe this one method.)

c. Reduction

Although there was a strong movement away from the "reductionist" methods of classical scientific method in the first part of the twentieth century by the proponents of fields such as systems thinking and complexity science, the latter part of the twentieth century shows a return to "reduction" (albeit not articulated as "reduction", but nevertheless having the very same nature and purpose) in order to overcome the unproductive nature of the expansionist views of these disciplines. The kind of reduction which would be appropriate for the context and type of problem needs to be given specific attention during this phase. The goal is to make enough use of reduction in order to be productive in the pursuit to solve the problem (i.e. create new knowledge and insight), but not to the extent where the answer (knowledge/insight) produced by the scientific enquiry is so restrictive due to the imposed reduction that it has only limited value in real life application. The understanding of what reduction would be fitting for the problem under investigation, taking into account the context of the problem as well, contribute to the decision on which type of scientific approach would be appropriate during the next phase of the process (the analysis phase).

4. Populating the Problem Categorisation Framework (Context and Problem Type Aspects)

All information necessary to be able to map the problem to be analysed on the Problem Categorisation Framework has to be obtained and documented, with the problem placed on the Framework with documented motivation. Any gaps in the available data to categorise the problem on the framework must also be documented. This is an important output of the Diagnostic Phase of the problem solving process.

4.1.2.1.3 Deliverables (to be passed on to the analytical phase):

1. Populated Problem Categorisation Framework (In terms of the Problem Type and the Context) with motivation for categorisation choice.

2. Context and Problem Descriptions from the decision maker's perspective.

3. Documented and motivated implicit assumptions, appropriate boundaries (also describing the kind of boundaries, i.e. closed or open) and appropriate reduction as derived from the context and type of problem.

4.1.2.2 Analysis Phase

4.1.2.2.1 Goal of the analysis phase

The goal of this phase is to create new knowledge/insight from a scientific perspective by providing possible solutions/alternatives by which the problem can be addressed. Ideally the results would highlight alternative options of decisions to the decision maker, showing the possible impact of each of those options on the context. The goal of this phase is not to advise the decision maker on what to decide.

4.1.2.2.2 Inputs into the analysis phase

1. All Deliverables from Diagnostic Phase

2. Additional data/facts necessary to make analysis of the problem possible.

4.1.2.2.3 Aspects to be taken into account

1. Update the Framework in terms of Appropriate Scientific Approaches

Once the Framework (i.e. the Problem Categorisation Framework) has been populated in terms of Context and Problem Type, it can be updated to also contain the scientific approaches best suited for that combination of context and problem type. These approaches need further investigation to narrow down the choice by taking into account

    a. Available data which could serve as initial values or test data, also noting crucial data which would be necessary for the analysis but for which actual data does not exist, or is inaccessible.

    b. Practical constraints (of time or resources) which could disqualify some approaches.

c. Specific outputs required by the decision maker, which might not be provided by some of the approaches available, or provided for better by specific approaches.

The final decision on which approach(es) to use for the analysis can only be done after all of aspects 2, 3 and 4 are conducted for the remaining approaches which are still possibilities after this step.

2. Defining initial values

Each scientific approach/technique requires specific initial values in order to be useful in practice. This could be single values, or data sets (or facts and statements taken as valid). It must be ascertained which of these are available and their correctness must be validated. The impact of not being able to source any of these might disqualify a specific approach, or might lead to practical assumptions (of which the impact must be understood and documented).

3. Making and motivating additional assumptions

a. Underlying assumptions

Each scientific approach/technique has underlying assumptions embedded in its design and philosophy. These need to be articulated and their impact on the specific problem and context must be evaluated. Those techniques of which the underlying assumptions cannot be married to the context, or the problem, have to be disqualified.

b. Practical Assumptions

The initial values required, but not available, might lead to some practical assumptions which need to be articulated and validated. The impact of such assumptions on the practical usefulness of results from the analysis needs to be studied and articulated. Should such assumptions lead to unacceptable low levels of practical usefulness/confidence of the results, the approach requiring these initial values must be disqualified.

Practical assumptions might also be required to overcome mismatches between the underlying assumptions of the technique/approach and reality of the context and problem to be solved. Once again the impact on the validity and usefulness of the results in the specific context and for the specific problem need to be investigated and articulated. Any assumptions which lead to unacceptably low confidence levels of possible results of the technique/approach, lead to the technique being disqualified as a possible candidate for the analysis phase.

4.   Describing additional reductions

 Each scientific approach/technique has embedded reductions stemming from implicit/underlying assumptions, or from the nature of the technique and/or how measurements are made. These need to be investigated and validated against the reduction described to be appropriate during the diagnostic phase in terms of the problem and context.   Unacceptable mismatches lead to the specific technique/approach being disqualified. Those mismatches that are deemed to be acceptable need to be documented with motivation while they are accepted.

5.   Motivated Choice of Scientific Approach

Taking into account the results of the analysis phase aspects 1 to 4, as well as the results from the Framework as received from the Diagnostic phase, the best options of scientific approach(es)/technique(s) to use are identified. At this point a final evaluation between the strengths and weaknesses of these final set of possible techniques need to be weighed against each other and a final choice needs to be made. Any impact on the possible results to be obtained by the analysis using the chosen technique(s) needs to be documented.

6.   Conduct analysis, ensuring goals of scientific inquiry are followed.

Applying the technique/approach for the analysis of the problem needs to be conducted, taking into account the value system for scientific enquiry. At this stage additional practical assumptions, not foreseen before, might be required. Should this happen, it could indicate that the investigation to narrow down the choice of scientific approach during the Analysis Phase needs to be repeated. This

needs to be monitored and a rework of technique choice needs to be conducted should the additional practical assumptions cause unacceptable restrictions on the practical usefulness of results to be obtained from the analysis.

4.1.2.2.4 Deliverables of the analysis phase

1. Documented insights from the scientific enquiry

2. Populated Framework (Context, Problem Type and valid scientific approaches indicated)

3. All work done to choose the final technique(s) to use, also highlighting the resultant restrictions on the practical validity of the results.

4. The results need to be articulated and documented in such a way that indication is given of

    a. For which (future) changes (in the context) the results would lose their validity.

    b. For which (future) changes (in the context) the investigation of the problem needs to be re-validated.

    c. All restrictions to the practical usefulness of the results due to assumptions, boundaries, initial values or reductions of the technique(s) used need to be articulated as part of the results.

4.1.2.3 Synthesis Phase

4.1.2.3.1 The Goal of the synthesis phase

The goal of scientific problem solving of this kind is to make a practical difference in the context where the problem exists, so that the problem will no longer exist. New knowledge and insight for the decision makers potentially lead to better decisions to bring about changes that would solve the problem. Providing this new insight in an objective way which provides practical utility is the goal of the scientific enquiry. The capability developed in IMT is focused on providing such a service.

The synthesis phase translates the results of the analysis phase into utility for the user.

4.1.2.3.2 Inputs into the synthesis phase

1. All deliverables of the Diagnostic Phase

2. All deliverables of the Analysis Phase

3. All additional data/facts from Context relevant for Synthesis Phase

4.1.2.3.3 Aspects to be taken into account

1. Contextualising the proposed solution

The impact of all reduction and all assumptions during previous phases, as well as the inherent weaknesses (and strengths) of the scientific approach/technique used during the analysis phase need to be taken into account for the phase of studying the possible impacts of alternative solutions on the context. These need to be articulated. If any significant mismatches, or any significant possible negative impacts are identified, a rework of the previous phases is necessary, taking into account these findings.

Once the contextualising of alternatives proposed by the analysis phase has been studied and the results indicate that practical implementation would be feasible, the work of the previous two phases is completed. The remaining effort of the synthesis phase can then proceed.

2. Translating new knowledge/insight into practical utility.

In some cases the new knowledge (or insight) created by the analysis phase provides enough utility in itself to the decision maker. The norm is, however, that it would be necessary to provide tools, structures, infrastructure and processes which would embed the new knowledge into the context. In this way problem solving tools might have to be developed, new or changed organisational processes might be required, training might be required, etc. In order to define and develop these, all the results from the diagnostic and analysis phases need to be taken into account. This cannot be completed before the rest of the synthesis phase is conducted – it is conducted while the rest of the synthesis phase is executed, and interacts with all the aspects mentioned below.

3.   Relaxing of Boundaries

The boundaries defined during the process of problem solving brings about a superficial isolation between the problem and the context within which it is encountered.   The harder the boundaries are (i.e. closed systems), the more pronounced is this isolation.   Soft boundaries (i.e. open systems) require less effort during the relaxing of the boundary, i.e. removing this superficial isolation.

It is important to note that in some of the soft techniques (of systems thinking for instance), the distinction between the analysis phase and the synthesis phase fades due to the constant interaction with work groups and interim changes in the context brought about as part of the analysis phase.   For such techniques the analysis and synthesis phases run concurrently and might influence each other strongly.   Each time something resulting from the analysis is embedded into the context, the impact of the relaxing of the boundaries between the problem space (action space) and the context needs to be considered, and the context characterised again.   Changes which are significant enough might require revisiting all phases of this process of problem solving before further work is done.   In some cases the initial problem might be dissolved by these changes and new problems emerge which require investigation.

The following needs to be done during the process of relaxing the boundaries.

a.   Monitor Implementation

It is important that the manner the proposed solution is implemented, is done in a way which takes into account the limitations of the technique used during the analysis phase.   It might also be necessary to do make an effort to specifically overcome the weaknesses imposed by reductions and assumptions embedded in the proposed solution.   Training might be required to properly understand the results obtained, and processes/infrastructures might have to be designed to provide input data, for proper use of the technique, and also for reporting of the results produced from the implemented solution in order to embed the proposed solution into its context.

b. Monitor impact of Implementation

It needs to be part of the synthesis phase to monitor the changes brought about by the implementation of the proposed solution. This is not trivial, due to the fact that there might be a significant time lapse between the implementation and its impact, making it difficult to see any causal link. The softer the technique which was used, the more pronounced this difficulty. It is however important that changes in the context which can be identified as a result of the implementation be monitored and measured against the changes in the context which might invalidate the results of the proposed solution. This needs to be articulated should they occur, so that possible reworking of relevant aspects can be identified and executed.

c. Monitor changes in the Context

Some changes in the context might occur independently from the implemented solution, but might still bring about changes in the context which were shown during the analysis phase to be pivotal in the validity of the results of the analysis phase. This needs to be noted and articulated as well. Should these changes indicate that the process, or aspects of the process, require reworking, it needs to be articulated and executed.

4.2 The process motivated from the theoretical study

In this section the theoretical study is visited and used as motivation for the process described in the previous section. The emergent properties which resulted from the theoretical study are of specific importance, with the understanding of the generic features of valid manifestations of scientific method used as guiding principles.

4.2.1 Process follows Popper's views in broad terms

It is not of primary importance to IMT to follow a specific school of academic thought. The aim is to extract as much value as possible from the academic discourse for practical problem solving. For this reason no specific school of thought is chosen with a purpose of excluding any others. Noting that Popper's views are followed in broad terms therefore does not exclude the use of induction where appropriate for practical problem solving. Rather, the statement indicates that Popper's views of

scientific method is seen as the most productive for a trans-disciplinary (and multi-disciplinary) capability such as is found at IMT. This statement needs to be qualified:

1. Popper's view of scientific method has value across disciplinary boundaries. He demonstrated it himself by using it to evaluate political theories (e.g. Marx) and psychological theories (Jung). He also applied his views to study society and the salient features of society with good results. He developed his view from observing natural scientists, which indicates that it is also meant to be productive in the natural sciences. In fact, he argued successfully that his view is more productive in the natural sciences than other competing views (e.g. in his debate with the Vienna Circle and also with Kuhn).

    The value of this philosophy, which tries to describe the growth of scientific knowledge as the pursuit of moving ever closer to the truth for all scientific work, makes it applicable to the very practical (realistic) capability which is required at IMT. It makes integration with actual reality not only possible, but necessary. That allows for the addition of the two phases (diagnostic and synthesis) in the process which are heavily influenced by the actual context.

2. Popper's focus on falsifiability is productive in practical terms in that it supplies the decision makers (and analysts) with a way by which ongoing validity of results can be evaluated. It also provides a useful way to incorporate the impact of contextual changes in the scientific enquiry, which is especially prevalent where boundaries are softer.

    The requirements stated in the process described in the previous section to articulate all assumptions, reductions and the definition of the boundaries, opens the process for criticism. In addition, the requirement to indicate which (future) changes in the context could invalidate the results of the investigation opens the technique used and the results produced for criticism. This adds much value to the capability at IMT, since it provides for client interpretation of the results, as well as protecting the client from using results produced by past studies in a context where the technique, or its results, might no longer be valid because of changes in the context since the study was done.

3. Popper's definition of objectivity provides a more realistic approach (i.e. more realistic than the prevalent definition in natural science during the twentieth century – the definition championed by *logical positivism*) to scientific problem solving for decision makers. Objectivity is no longer seen as of necessity "context-free" with an objective analyst and decision maker, but rather as objective because it is articulated in such a way that it can be criticised. This makes his views more accessible to problem solving where human decision making, and human judgements, are part of the process of problem solving. Scientific rational decision making becomes practically viable in such contexts due to Popper's view of objectivity.

Much of decision support contains value judgements. Popper opens the door for objectivity to be seen as "subjectivity articulated in such a way that it can be criticised". This view of objectivity, which Popper claims to be at the root of ALL scientific enquiry, facilitates a smooth integration between natural, social and human sciences, maintaining rational scientific enquiry which is objective. It makes it possible to have one generic process for all scientific problem solving work at IMT rather than different processes where the context cannot be eliminated in the process of analysis (i.e. where the boundaries are soft).

4. Popper's view that "Science starts with a problem", i.e. that knowledge grows primarily from solving one problem after another, recognising that solving one problem brings others into focus, is also appealing in the kind of service provided by IMT. Problem solving is seen not only as a decision support function, but as a vehicle of growing knowledge. This articulates the stated goal of the capability at IMT, namely to provide a service and to be a repository of ever increasing knowledge, fusing military and technical expertise.

This illustrates how Popper's views are embedded into the process of scientific problem solving at IMT, and in fact underpins that process. IMT does not follow Popper to the extent of excluding all induction, but cautions that where it is used it has to be shown as a valid approach given the attributes of the context and problem type. This caution is articulated by the requirement to articulate all underlying assumptions.

This means that where induction is used, its basic underlying assumption that consistency is found in the context (i.e. no change over time and from place to place) needs to be shown to be an appropriate description of the specific context in order for induction to produce results which are of practical value.

4.2.2 Process facilitates a disciplined pluralist practice

One of the most prominent emergent properties of scientific method in the twentieth century is the fact that it is pluralist, not monist. During the discussion of both complexity and systems thinking this fact is further highlighted. Both these approaches to problem solving migrated to a framework for problem categorisation as a way to cope with the pluralist nature of scientific problem solving, as described by the frameworks of Flood and Snowden. This property is built into the process of scientific problem solving practiced at IMT by using such a framework as guideline in both the Diagnostic and Analysis phases. It is not prescribed here which framework should be used, but only that the framework which is used is an appropriate one for the context and problem (i.e. able to handle all problem types which are encountered in the context).

A lack of discipline presented itself in the latter part of the twentieth century as a result of the awareness that scientific method is pluralist (or, if the view that it is monist is retained, then systems thinking and complexity correctly indicates that such a manifestation of scientific method does not cater for solving all problems which presents itself in reality). This is highlighted in the interpretation of the theoretical study as one of the main handicaps still besetting the various approaches to problem solving. The process used at IMT recognises and caters for the pluralist nature of scientific problem solving while it also insists on maintaining the discipline inherent in scientific endeavour through the centuries.

The pluralist view of scientific method is adhered to by describing a generic process, which is not procedural or sequentially methodological in nature, but rather contains a description of the generic aspects to be taken into account to ensure thorough and objective scientific investigation. This process is optionally informed by, and impacted upon, by the context, thus catering for the requirements of complex problems and problems with soft boundaries.

The discipline is enforced by insisting on articulating the various assumptions, reductions and boundary choices (also with the resultant boundary conditions to be taken into account during the Analysis phase and the relaxation of the boundaries in the Synthesis phase). It is further promoted by following the common value system of all scientific problem solving approaches which were identified from the various perspectives developed in the theoretical study and documented in chapter three. In this way room is made in the process for constant critical realism, objectivity, refutation and commitment, and both lateral thinking and common sense.

4.2.3 Process is generic and valid for all contexts and problem types

The process does not prescribe specific methods to address the aspects of the phases. It rather leaves room for this to be done for each problem that is to be solved, taking into account the nature of the context and the problem type. The only requirement of the process is that any decisions made regarding the specific ways to address these aspects be articulated, and investigated for their impact on the validity of the results of the problem in its context. For example, should any of the aspects in any specific phase be deemed very important for a specific problem, requiring special attention, it needs to be motivated and the required detailed attention given to that aspect. Similarly, should a specific problem not require some of the aspects described in the phases of the process, they can be left out with the necessary documented motivation. This leaves room for Popper's requirement of falsifiability while it gives the analyst(s) the freedom to adapt to attributes specific to the problem to be solved and its context.

4.2.4 Process is coherent and takes into account the dominant features of scientific problem solving

The aim of the process is not to be a complete description of all aspects to be addressed during scientific problem solving. Room is left for the analyst(s) to adapt the required aspects to also include other aspects when necessitated by a specific problem. The process provides for a coherent approach which would indicate check points, guiding the analyst(s) in their evaluation when to rework previous aspects, and when to proceed to the next aspects to be addressed. Any specific problem needs to

be addressed in a coherent way, not leaving room for any gaps in progressive understanding. In this way a coherent audit trail of thought and decisions is produced during the process of problem solving. This corresponds with Flood's requirement of *recoverability* of the evaluation and of results obtained from systems thinking practices – just another articulation of Popper's view of objectivity and refutability (falsifiability).

While the process does not strive to be complete, it does require that at least all the dominant features of scientific problem solving are addressed (or their role evaluated in the light of the specific problem to be solved and its context). These dominant features are obtained from the commonalities identified from the perspectives developed in the theoretical study and documented in chapter three.

4.2.5 Process can be implemented and managed like any other technology (process) product

The observation from the discussion of the technology perspective in Chapter Two (§ 2.6.3) describes how a "process product" can be seen as a new technology itself, and implemented and managed accordingly. The process described in Chapter Four is such a process product, designed to create new knowledge scientifically. Different from other processes described in knowledge management for the purpose of knowledge creation, the process described here is generic and can be applied to any field of application, not only organisational knowledge creation. It is even a valid description of classical scientific method if the correct assumptions, initial values, boundary conditions, etc. are chosen.

This observation provides a vehicle to implement the process described here in any organisation, and for any field of knowledge creation (scientific problem solving). It is described in chapter five how IMT uses this fact to implement the process described here in the decision support domain.

4.3 Conclusions

The process described in this chapter is one articulation which provides for a pluralist practice of scientific problem solving. It does not describe the scientific endeavour in methodological terms (like philosophy of science tried for many centuries), also not in

sociological terms (like Kuhn proposed). It is a description of the three phases in problem solving and the dominant aspects of each phase. Its aim is not to provide a theoretical framework, but rather to guide practical problem solving in the light of the best possible insights from current scientific problem solving theories, obtained from the perspectives developed in the theoretical study.

The process also enhances the practical implementation of team work in scientific problem solving which is an important feature of the capability developed in IMT. Team work is the only way to cater for the unavoidable multi-disciplinary nature of such a capability. The process described in this chapter provides the team with a common road map and common terminology to facilitate coherent progress in the problem solving process among team members.

In a knowledge society "knowledge" itself can be treated as a technology. The process described in this chapter represents a proposed "process product" for knowledge creation (i.e. scientific problem solving). That makes knowledge creation manageable, which is the goal of the third generation knowledge management as described in the theoretical study. This potentially further enhances the development of the capability at IMT – it paves the way for a culture among the team members where the individual and collective competence to create new knowledge becomes an integral part of the capability at IMT (see Figure 2-14, Chapter Two). The productiveness of this process to facilitate the creation of new knowledge is illustrated in the case study of the next chapter.

Chapter 5:   Case study – Defining an appropriate scientific problem solving capability for IMT

Criteria for Choosing Perspectives

P1	P2	P3	P4	P5

Conclusions from synthesis of Perspectives

Finding Commonality in Pluralism

Framework(s) for problem Categorisation

Process of Scientific Problem Solving

Case Study: Creating Knowledge through Complexity Methods
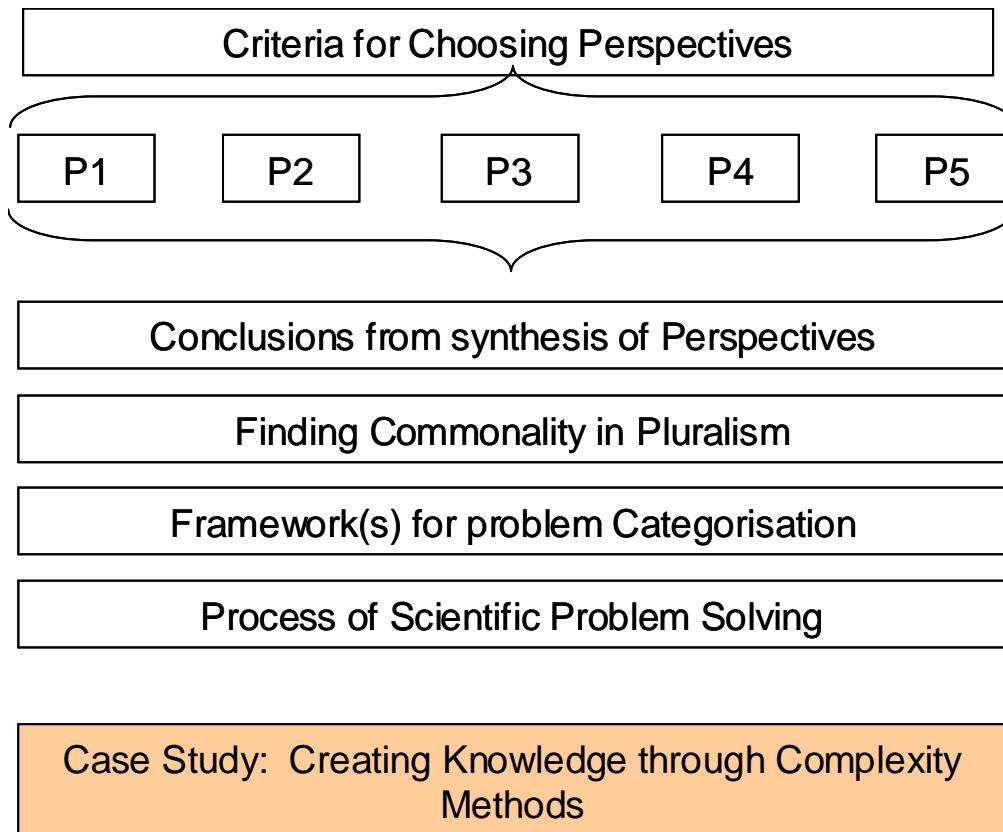
Figure 5-1 Dissertation Road Map

5.1 Describing the approach

The structure and content of this dissertation is the main focus of the case study. It illustrates a practical implementation of the process described in the previous chapter. In this way it shows the productiveness of

1. Taking pluralism as an implicit assumption for scientific method, which is argued to be one of the major accomplishments of the study of scientific method in the twentieth century in this dissertation.

2. Taking scientific problem solving as a productive way of describing the development of new knowledge and increased understanding (which has been the goal of scientific endeavour through the centuries).

3. Knowledge treated as a technology, a view which is argued to be a practical approach uniquely suitable for understanding how to manage the creation of knowledge in a knowledge society.

4. Treating a problem in accordance with its nature, and the nature of its context, rather than to enforce one approach on all problems. In the case of defining the required capability at IMT, this dissertation illustrates the productiveness of approaching a complex problem, using the techniques of complexity (in this case "Perspective Filters"). This was done after having experienced the unacceptable restrictions resulting from choosing an approach which ignores the fact that the problem at hand is complex, during the first attempt to define the capability.

The approach followed in this dissertation challenges stereotypes regarding science which prevails in literature and in doing so provides a more productive way of thinking about scientific method. In this way the underlying discipline and goals which has always underpinned scientific method become available for problem solving in areas where the classical scientific method did not prove to be very productive in providing answers for practical application. In changing the focus from methodological descriptions of scientific method, or even sociological descriptions, to the meta-level of those goals and principles embedded in the pursuit of new understanding and new knowledge (which has been the guiding principle of scientific work through the centuries), commonality is found which is trans-disciplinary and provides for being pluralistic in scientific work without resorting to speculation or subjectivity. This is seen to be of much value in defining a scientific problem solving capability.

5.1.1 Making the classical mistake

The initial attempt to define a scientific decision support capability at IMT, did not give consideration to the implicit assumptions of the prevalent views of the classical scientific method. It was taken for granted that the scientific method was monistic, and the philosophers through the ages provided an audit trail of learned thought about the resultant view(s) of scientific method. *As a result of this oversight it was taken that the proper thing to do for any capability which claims to be scientific, would be*

to know all the arguments and to be able to justify any particular choice of allegiance in the light of those arguments.

The persistent anomalies and disagreements articulated in these historical debates (with the resultant circular reasoning over many centuries) provided a landscape of fragmented thought, highlighting the fact that science, which champions objectivity and rationality, is fraught with its own internal inconsistencies and lack of coherence. This fact made it very difficult to define the boundaries of a scientific service from a *scientific* perspective – Which approaches should be included? Which excluded? And why?

The wide scope of the kind of problems which IMT could realistically expect to be confronted with, added to the problem of defining the boundaries (scope) of the capability – which areas of *application* should be included in developing the capability and which should be excluded, and why?

In order to tame this problem of the required scope of such a capability in terms of both scientific and application perspectives, IMT developed a Technology Income Statement TIS by mapping the areas of application to the underlying scientific disciplines historically understood to be of value for such a capability. It was found that the aspects to be taken into account were too numerous to map onto the TIS as described by De Wet [De Wet, 1996], so it was enhanced to incorporate more of the most prominent aspects. A copy of the last version of this work is included for illustrative purposes as Appendix D. This provided some focus, but it was open to the constant change in the context within which IMT finds itself. This posed an additional problem: It takes considerable effort and resources to develop any specific part of the capability, and there was the real risk that the context could already have changed during the time it took to develop the relevant part of the capability, so that when the capability becomes operational, it might not be the optimal capability any more. In this way the development of the capability at IMT proved itself to be a moving target. This was an unacceptable state of affairs, and IMT decided to rethink the approach of defining such a scientific capability to be more robust and cost-effective. This dissertation describes the resultant work.

5.1.2 The dissertation as a case study

By the time IMT decided to rethink how to define the capability for a scientific support service, much reading and study had already been conducted in terms of scientific method. The initial TIS also provided one possible manifestation of such a definition in terms of both underlying scientific disciplines and client requirements for areas of application (which were current at the time). These provided the first input for the renewed effort.

5.1.2.1 Rethinking the problem

5.1.2.1.1 Is a scattered landscape the only option for a scientific capability?

The scattered landscape which characterised the debate about scientific method was already known at the time of retracing the steps of defining the capability at IMT. This provided a considerable challenge in itself for defining a coherent, inter-disciplinary capability at IMT. Our concern is with practical problem solving for the purposes of decision support, not academic debate. The different schools of thought in science provide exclusive views on how science is to be conducted. These schools of thought are not only mutually exclusive, they often represent strong commitments to specific views (even to the point of Pythagoras having a student of his drowned when the student presented results which proved Pythagoras' view wrong!) How does one find one's way amongst these strongholds, in order to develop a balanced scientific capability which can be used for practical problem solving, utilising the best that science offers?

During the twentieth century this situation was further complicated by the development of new fields (disciplines) which claimed to be more productive than THE "scientific method" in solving practical problems in some areas of application. These include cybernetics, systems thinking, knowledge management, complexity science, etc. Are these of any relevance to the capability to be defined and developed at IMT? And if they are (evidence from past practice in IMT pointed to an affirmative answer for at least some of them), how are they to be incorporated in a *scientific* capability?

5.1.2.1.2 *Does a changing environment make for a capability which always has a high risk of becoming sub-optimal?*

The Decision Support Domain at IMT has a wide client base, with its clients functioning in a wide variety of contexts within the SA Navy (and other parts of the DOD). This poses a considerable challenge for the definition of a capability which could service such a wide variety of clients, having different contexts, given the constraints in resources available to IMT for this capability. One option would be to limit the scope of the capability to a sub-set of these contexts, but that would limit the usefulness of the service to the SA Navy at large, considerably. Can the resources made available by the SA Navy for such a capability at IMT be spent more effectively? If it is unavoidable to limit the scope of the capability, what would be the best possible choice of areas to include? (The previous work on the TIS focused on this area, so that its complexity was already well known.)

Apart from the problems posed by the wide scope of the potential client base, the reality is also that the context within which each of these clients functions, as well as the bigger context within which the SA Navy finds itself, are constantly changing. This indicates that even if a sub-set of areas to include in the development of a capability could be defined with sufficient certainty at any given time, there was no guarantee that it would remain valid for a long enough time to warrant the effort and resources spent to develop it. Is it possible to define a capability not so completely open to changes in its environment? Are there those aspects of the capability which would remain constant regardless of changes in the context? If there are, what are they?

5.1.2.1.3 *Rethinking the implicit assumption of science and the resultant lack of consistency and coherence in scientific method.*

The centuries-long debate about the *nature* of scientific method which could not converge to a coherent and consistent *description* of scientific method, indicates that there might be some implicit assumptions which cause this inability to finding a solution. The question is, if there are some unproductive implicit assumptions causing this deadlock in the debate, what are they?

The developments of the scientific method debate in the twentieth century provide a cue. Specifically two thinkers about scientific method provide the necessary background to uncover one possible unproductive assumption – the work of Popper and Feyerabend. While Popper spent his life describing a deductive scientific method (removing the inconsistencies of induction), he was unable to describe such a method completely in all its aspects. Yet he was able to apply his method (which he derived from observing natural scientists like Einstein) across disciplinary boundaries to also be productive in the social sciences. Popper was a monist. Feyerabend, on the other hand, saw that knowledge could be created in various ways, and started to argue "against method" [Lakatos et al, 2001], especially in his debate with Lakatos about scientific method. Feyerabend provided the key to uncover the implicit assumption which ruled the debate about scientific method for all the centuries: *The unarticulated assumption that there is such a thing as ONE scientific method by which all scientific knowledge advances.*

While Kuhn provides the framework to justify his view that scientific method does change (i.e. is pluralist), his focus on the behaviour of scientists as a point of departure is unproductive, since it links the objectivity of science to the objectivity of scientists (something which was never an assumption in science). Kuhn described his understanding of pluralism in terms of the level of maturity of development of the scientific paradigms. Laudan [Nola et al, 2001, 216] holds to pluralism because he rejects the realist aim of science, holding that scientists may pursue a multiplicity of aims, which lead to a pluralist (relativistic) view of scientific method. Can pluralism be described in terms of something else? Are there other (valid) reasons to believe that scientific method is of necessity *pluralist* without compromising its aim to seek for truth?

The work of the mathematician Gödel provided the first formal proof of the fact that no one method can be expected to completely and coherently describe all knowledge. While the full implications of Gödel's work has yet to be understood in depth for other contexts (his work was focused on Hilbert spaces), no one has been able yet to show that his findings do not apply for other contexts.

Another cue for a possible reason for pluralism in scientific method is provided by the insights created by both Systems Thinking and Complexity Theory, namely the

insight that not all problems have the same nature, and that the contexts within which problems present, also do not have the same nature. The frameworks of problem categorisation in terms of the nature of the context (including the nature of the participants), and the nature of the problem as described by Flood and Snowden provides *a valid reason for proposing that various valid manifestations of scientific method could be found - depending on the nature of the problems to be solved and their contexts*.

This finding is also confirmed by the developments in logic in the twentieth century. It points to the same fact – *not all contexts function according to the same logic*, and the development of logic in the twentieth century not only points to that, but also articulates the nature of some of these differences.

It speaks for itself that if the findings of Gödel, the observations of Systems Thinking and Complexity Theory regarding problem types, and the developments of Logic all point to pluralism for scientific method, then an implicit assumption that scientific method is monistic would of necessity be restrictive and unproductive (explaining the reason why no single method could be defined through the centuries despite the success of science). So IMT decided not to adhere to the implicit assumption that scientific method is monistic, but to rather assume that scientific method is of necessity pluralistic.

This assumption is not based on the behaviour or preference of scientists (like both Kuhn and Laudan propose), but rather on the *realistic observation* that not all contexts (and problems) function the same, their underlying nature (and the logic within which they function) might require a different approach – so IMT is able to assume a pluralist view without compromising on the realist view of science, thus upholding the requirement for a "fact-based" scientific service with truth as the regulating ideal.

Armed with this new assumption that scientific method is not monistic, but rather pluralistic, IMT set out to redefine the capability to be developed at IMT. The variety to be developed no longer depended on changes in the context, but on changes in context type (nature of context). Can a set of representative natures of contexts (and also natures of problems) be described? If so, then the scope to be defined for a capability at IMT could be stable and representative enough to *be insensitive to the*

relatively fast rate of changes in the context. The Frameworks of problem and context categorisation (of which the two frameworks of Flood and Snowden respectively are examples) provided such a relatively stable definition of the types of contexts as well as problem types. IMT used these as basis for the development of a scientific capability which could service changing client requirements in changing contexts, while the capability remains valid and relatively stable. The way in which they have been incorporated is described in the process for scientific problem solving in chapter four.

5.1.2.1.4 *Defining a pluralistic scientific method*

During the twentieth century the realisation that scientific method is pluralistic had the following two (taken in this dissertation to be negative) consequences:

1. A breakdown in discipline in what is taken as valid methods of knowledge creation (e.g. the arguments of Feyerabend against scientific method, as well as the initial expansionist views of for instance Systems Thinking).

2. An acceptance of Kuhn's model where scientific endeavour is described in terms of political lobbying and even in pseudo-religious "conversion" among scientists as the essence of science. While the history of science does provide ample examples of such activities, they invariably describe stages where growth in knowledge was stifled because of these activities. Instead of describing scientific method appropriately, it describes their role as major stumbling blocks to the goal of objectivity in scientific work.

How can scientific method be described in pluralistic terms so that the discipline is maintained, and the goals of scientific work are maintained, doing justice to the unparalleled success of science in knowledge creation? Chapter Three of this dissertation describes the elements to be taken into account in this pursuit. It is important to state here that it is not the goal of Chapter Three to fully describe scientific method in pluralistic form, but rather to define the minimum set of requirements to do justice to science in a pluralist definition of scientific method. This is done because the aim of IMT is not academic theorising, but rather the definition of a practical problem solving capability which is scientific in nature.

5.2   The scientific problem solving process in action

From the results obtained in the theoretical study (described in Chapter Two) and its interpretation (described in Chapter Three), the process of scientific problem solving was designed (as described in Chapter Four). The rest of Chapter Five is dedicated to describe and illustrate the definition and application of this process in defining the capability at IMT. (The recursive nature of this statement is immediately apparent, something which is inherent in the process: The process is used to describe the process and illustrate its application). This is used as an illustration of the productiveness of treating a problem according to its problem type.

5.2.1 The diagnostic phase

The Diagnostic phase of the process is described in § 4.1.2.1. Its implementation for the development of the definition of a scientific problem solving capability for IMT is described here.

IMT's initial work to describe the capability, when scientific method was taken as monistic without even realising it, represents a first pass of the phase. The restrictions posed by this implicit assumption forced IMT to retrace its steps and start from the beginning again. Restating the implicit assumption about scientific method to be that scientific method is pluralist therefore introduces the second pass through the diagnostic phase.

5.2.1.1   Restating the problem

The initial understanding of the problem to be solved was purely to identify a productive match between aspects of technology, scientific disciplines and the required fields of application where clients might experience problems. The problem was mainly to define how to ensure a scientific approach in the capability, servicing the wide scope of possible fields of application. This proved to be unsatisfactory because of the high cost in time and resources to develop a capability in a context where the developed capability could be outdated by the time it becomes operational due to changes in the context. Rethinking the situation, taking into account what was learned during the first pass of the diagnostic phase, led to only one change: <u>reversing the implicit assumption that scientific method was monistic to rather assume that</u>

scientific method is pluralist. This seemingly simple change proved to be very productive in that

1. It provided generic parameters to define the capability by which it would remain stable in all contexts.

2. It provided a set of parameters to take into account to ensure that the capability is scientific which proved to be trans-disciplinary (facilitating easy implementation of the inter-disciplinary nature of the capability to be developed).

The restated problem then became

"Which process of enquiry needs to be defined which will ensure a scientific problem solving capability at IMT which could be used for all problem types and in all types of contexts with equal productivity and value for all clients, taking into account the limited resources available to IMT to develop and maintain such a service?"

5.2.1.2   Characterising the context

Since the SA Navy is a hierarchical organisation, systemic positioning of problems is an important part of context characterisation. IMT has developed a model to describe this in more detail, but it falls outside of the scope of this dissertation. *This fact is mentioned in § 2.1.2 where cognisance is taken of the importance of this aspect of context characterisation, but that it is not taken as part of the perspectives to be developed.*

Following the methodology proposed by Flood & Jackson [Flood & Jackson, 2002] for context characterisation, the following discussion is given:

5.2.1.2.1 The Participants are…

Using Flood's framework, the kinds of participants were evaluated. Are they typically unitary, pluralist or coercive? While it would be fair to make an overall statement that in the military, decision making is mostly coercive, the fact is that the decision support domain services all areas of the SA Navy, also those which concern themselves with normal management practices. In these areas decision makers could

be either unitary or pluralist. It would therefore not be wise to limit the definition of such a capability to a coercive setting. All possibilities need to be taken into account.

5.2.1.2.2 The System is …

The decision support domain at IMT is very open to changes in its environment. This was in fact one of the major reasons why the first attempt to define the capability proved to be unproductive. In constructing the initial TIS it became clear that there were many interrelationships between the context, possible fields of application and that a variety of scientific disciplines could be applicable to solving a specific problem. The fact that the system evolves over time was also a major driver to abandon the first attempt to define the capability. Due to the fact that the clients of the decision support domain create their own goals and are subject to behavioural influences, there was even less stability in the context. From the perspective of Flood's framework, the system was definitely not simple, but rather complex.

Cilliers' definition of complexity was also tested in the light of the understanding gained from the first attempt to define the capability. They were found to be

1. *Complex systems consist of a large number of elements.* The TIS showed that there were a large number of possible candidates on all axes of the TIS. Defining a sub-set always proved to be too restrictive to be acceptable.

2. *The elements in a complex system interact dynamically.* The interplay between changes in decision makers, changes in the relevant contexts and changes in the development of science made for too fluid an environment to be able to define a capability which does not carry an unacceptably high risk to become outdated (or at least sub-optimal) by the time, or even before, it is fully developed.

3. *The level of interaction is fairly rich.* The interactions which bring about the problems to be serviced by IMT are rich, unpredictable, with changes in the context which could dissolve the specific problem even before IMT is able to complete the study of the problem and come up with possible solutions.

4. *Interactions are non-linear.* Since decision making takes place in a social system, it is inherently non-linear, so that a decision support capability should cater for the resultant complexity of such a system. It is never true in the

decision support domain that a problem poses itself without any human judgement or interpretation built into its nature, its articulation and even its perceived impact on the context.

5. *Interactions have a fairly short range.* Not all decisions have equal range, and some of the problems might lead to solutions which might have far-reaching implications. Yet for the most the full impact of any individual decision is not understood (and cannot be understood) before it is made. Since the SA Navy consists of many layers of decision makers, there is very little coherence in their goals and viewpoints regarding practical matters. Any understanding what "the Navy's view" is on any subject often depends on who you interact with in the Navy.

6. *There are loops in the interconnections.* There are often loops in interactions. The context, as well as the decision makers, are influenced by multiple feedback loops of which some are so complicated that they are not immediately apparent. Understanding this is a major requirement for decision support work, since the discourse about any given problem would almost without exception change even during the investigation of the problem. This is well understood at IMT, so that constant client interaction is imperative for all decision support work.

7. *Complex systems are open systems.* The reality of the fact that the decision support domain is so open to its environment and the resultant impact on the definition of the capability at IMT has already been mentioned as an important driver to abandon the first attempt to define such a capability.

8. *Complex systems operate in conditions far from equilibrium.* Due to the fact that decision support requires much interaction with the client, has to cope with constant changes in requirements, and yet provide a coherent scientific service, leads to the understanding that the process to be defined is not sequential, but rather a description of a set of activities which could be repeated as necessary, slowly progressing to its conclusion. The capability cannot be described in terms of a methodology, but only in terms of a process which is not necessarily sequential, having its own internal feedback loops. These feedback loops are implicit in the process described in Chapter Four.

This reality requires ongoing effort and much energy in order to remain relevant in the pursuit to solve any specific problem. In the case of decision support it is never true that the service is rendered in a state in equilibrium – there are almost always a variety of views, a variety of influences, a variety of possible outcomes. Equilibrium would often make the problem go away, so that the decision support capability has to be able to function in contexts far from equilibrium.

9. *Complex systems have histories.* The historical development of IMT provides the seedbed for the definition of the required capability. The way the client articulates his requirement for such a capability is heavily influenced by his experience and interpretation of what can be expected from IMT due to the past service rendered by IMT. Defining a capability is therefore an intricate interplay between the expectations created by the history and new possibilities due to developments in science and changes in the contexts.

10. *Individual elements are ignorant of the behaviour of the whole system in which they are embedded.* This is an important underlying truth of all decision support work. Any decision maker is concerned with his/her own priorities and mandate, not necessarily evaluating the impact of any of their decisions on the whole system. Even when they are concerned about such an impact, it is impossible to fully understand it in advance.

From this description and application of Cilliers' definition of complexity, it becomes clear that it would make sense to define the capability to be developed by taking into account the strong possibility that it is inherently complex in nature. It would be unwise to restrict the understanding of the complexity as being a "lack of understanding" or being so complicated that it cannot be modelled in time before change invalidates it in defining the capability (i.e. the deterministic view of complexity).

5.2.1.3   Defining the problem type

Without entering into the debate as to whether or not there is a difference between the two views of complexity (i.e. the deterministic and the un-deterministic views), the decision is made to use a technique developed by the proponents of the un-deterministic view of complexity. This is done because of the fact that the context,

and the problem, presents itself with the attributes of complexity as described by Cilliers, who is a proponent of the un-deterministic view of complexity.

It might be argued that there was no distinction made between the context and the problem in defining the type (of context and problem). This was done because the context of the capability need not be distinguished from the nature of the capability in this case – the primary client for whom the capability is to be defined is IMT. The primary client who will make use of the capability is the SA Navy, but a distinction is made between the definition of the capability and the application of the capability. For this reason the nature of the problem type (i.e. the type of the capability required in IMT) becomes dominant against the background of the nature of the client context (i.e. the SA Navy). It is assumed that a capability which is well defined in scientific terms will provide the best possible practical scientific problem solving service to the SA Navy client, given the unparalleled success of scientific method in the field of scientific problem solving (and the resultant growth of knowledge).

5.2.1.4   Assumptions, Boundaries, Reductions

5.2.1.4.1 *Implicit assumptions*

The difficulty with uncovering the implicit assumption of monism in scientific method has been articulated already. When that implicit assumption was found and shown to be unproductive, the new assumption of implicitly assuming that scientific method is pluralist required a rework from the very beginning, due to the fact that it is redefining the view of what the problem is, not only of how to analyse the problem (which would have required a rework of the analysis phase only).

Another implicit assumption is described above: It is assumed that a scientifically well-defined capability will prove to be the most productive capability for scientific problem solving. This is assumed because of the track record of success of scientific method in this field. No other approach proved to be as productive in problem solving and the creation of knowledge – and those who tried to propose an alternative migrated in time to follow the same disciplines found in traditional scientific method. This is an important observation from the literature study identified in the interpretation of the perspectives, and underpinning the proposed implementation of the insights obtained from the emerging patterns of the perspectives.

5.2.1.4.1 Boundaries

Once the decision was made to approach the problem as an un-deterministic complex problem type, coupled with the fact that the first attempt highlighted the extreme sensitivity of the problem to its environment, it became clear that defining good boundaries would be imperative for the productivity (i.e. practical usefulness) of the results of the process.

It was decided to include all dominant disciplines which lay claim to problem solving and knowledge creation during the twentieth century in the study. This decision is articulated in § 2.1.1 of the dissertation. The following disciplines were accepted for inclusion:

Perspective 1: Operations Research, Cybernetics, Systems Thinking and Complexity Theory.

Perspective 2: Scientific Method (This is the dominant perspective).

Perspective 3: Knowledge Management.

Perspective 4: Research and Development

Perspective 5: Technology Development.

5.2.1.4.2 Reductions

Once the perspectives to be studied were identified, the decision needed to be taken what aspects of those perspectives needed to be focus on. Each one is a field in its own right with a rich body of knowledge associated with it. It would be impossible to study each one in sufficient depth to claim to have an in depth understanding of each one of them individually.

The decision was made to study each perspective from the viewpoint of "The development of …". This was done because of the interest in development of the notional understanding of each field. This narrowed the area of enquiry to

Perspective 1: *The development of* Operations Research, Cybernetics, Systems Thinking and Complexity Theory.

Perspective 2: *The development of* Scientific Method (This is the dominant perspective).

Perspective 3: *The development of* Knowledge Management.

Perspective 4: *The development of* Research and Development
Perspective 5: *The development of* Technology Development.

In this way the historical development comes into focus, as well as the development of dominant themes which steer the main debates as understanding of the relevant subject matter grows. This additional reduction facilitates a focused rework of the literature study: It creates clearer boundaries of what to include in the reading, and what to scan for during the literature study. The description of these perspectives using this reduction is found in Chapter Two.

5.2.2   The analysis phase

Having taken the problem type to be un-deterministic complexity, Snowden's framework guided to the decision of taking the technique of choice as "Perspective Filters".   In this way various perspectives are developed in order to observe the patterns which emerge from them, taking the insights created by these patterns as the outcome of the study. These patterns are identified by observing what Snowden calls *retrospective coherence*.

5.2.2.1 Assumptions, Boundaries, Reductions

The only additional reduction which was defined for analysis purposes (in addition to those already defined during the diagnostic phase), is the decision of which perspectives not to develop. This is documented in § 2.1.2. For clarity the two additional criteria of exclusion are repeated here:

3. The perspective adds value to the <u>application</u> of the decision support capability rather than to the <u>definition</u> of the decision support capability

4. The perspective adds value to aspects of the decision support capability not directly of importance to the <u>decision support process</u> to be described and evaluated in this study.

These two additional criteria facilitated a further refinement of the definition of the boundaries, i.e. it provided an even more consistent way to decide whether or not a specific subject would be included as a perspective to develop as part of the study.

5.2.2.2 Surprising productivity

The emergent patterns and properties of the perspective filters which are developed in chapter two are described in chapter three. The main reason for the surprising productivity of what insights presented themselves, is two-fold:

1. The ease with which stability is found in what needs to be developed at IMT to provide a generic capability (insensitive to the ever-changing and interacting contexts, and the wide variety of problems which could be presented to the decision support domain for evaluation)

2. The ease with which emerging properties were found during the development of the perspectives, presenting almost effortlessly the minimum set of generic features of a pluralist manifestation of scientific method.

The description of these emergent properties as found in Chapter Three is clearly present in all of the individual perspectives developed, but would not have presented themselves with equal force if an in-depth study of any individual perspective was pursued instead. This illustrates the value of "pattern management" and the use of "perspective filters" when problems of a complex nature are studied.

The second attempt to understand what capability needed to be defined at IMT proved to be very productive. This illustrates the productivity of accepting that scientific method is pluralist, and then following the minimum set of requirements as described in Chapter Three.

5.2.2.3 Restrictions of the results of the analysis

The following future findings would invalidate the results of this dissertation:

1. If it is shown in future that scientific method (i.e. scientific problem solving in order to create new knowledge) is indeed monistic for all branches of science, the process described in Chapter Four would not be necessary any more.

2. If it is found in future that it is impossible to identify a sufficient set of problem types (and context types), so that a finite set of problem/context types cannot be constructed through frameworks such as those presented in this study, then the claim of providing a stable capability which is insensitive to

changes in context would not be true any more. Such frameworks would then only provide more stability than no categorisation at all, but not sufficient stability to ensure a completely stable capability.

As is common to all investigations of complex problems, the definition of the action space (i.e boundaries) have a decided impact on the results obtained.   If other perspectives were chosen, other variants of emergent properties would have presented themselves. Should the choice of perspectives in this study become too restrictive due to future developments in scientific approaches to problem solving and knowledge creation, the results of this study will become outdated.

The reduction of looking at "The development of …" for each perspective brought specific facts to the forefront. This reduction was taken as an appropriate reduction for the problem at hand, because an understanding of how to define a scientific problem solving capability was sought. However, should subsequent work prove that this reduction is too restrictive, because it excludes other facts which might prove to be of value in defining such a capability, the results of this study might be deemed too restrictive in the light of the new findings and require a rework taking that into account.

Should new developments in problem categorisation frameworks in future indicate additional/other categories of problems which prove to be more productive, this study might need to be repeated to enhance its productivity in the field of practical scientific problem solving and knowledge creation.   These frameworks will provide the backbone for stability as long as they are sufficiently complete to categorise all possible problems/contexts.

5.2.3   The Synthesis Phase

Having designed a process as the product of this dissertation, the focus changed into implementing it at IMT. At this point the perspective of looking at knowledge as a technology becomes prominent. Figure 2-14 in Chapter Two (§ 2.6.3) provides the necessary background to implement this new product (which is a "process product") at IMT. It provides the way to translate the results of the analysis phase into practical utility – i.e. a fully operational capability for pluralist scientific problem solving.

Since the scientific problem solving work for which the capability is defined is conducted in the Decision Support Domain at IMT, the field of Decision Making Theory is of interest. Keeping up with the developments of this field of study would enable the decision support practitioners to be more relevant during the synthesis phase of problem solving. *Decision Theory is mentioned in § 2.1.2, where it is mentioned that it is not included as part of the perspectives to develop, but is rather of interest during the synthesis phase of the decision support process.*

5.2.3.1 Relaxing the boundaries

Relaxing the boundaries is not difficult, since the defined boundaries, reductions and assumptions provide a much richer definition of capability than was previously the case at IMT. In this way the current experience of relaxing the boundaries is one of enhancement of capability in comparison with its previous definition, rather than one of restriction.   The focus therefore becomes how to best articulate the new possibilities to users of the capability rather than to ensure that the restrictions of the results do not impact negatively on the environment and value of service provided by the capability. The first round of articulating the possibilities of the new capability to the client was done during the recent long term planning session with the SA Navy. The complete document is included as Appendix C, but only those recommendations made to the SA Navy to identify for them what service they could realistically expect from IMT is repeated here:

1. "Translate the results *(i.e. of the study presented in this dissertation)* into the minimum definition of "expertise toolkit" which we need to develop at IMT. The minimum is defined as having an in-house expertise which could

   a. <u>Categorise problems</u> so that we can advise the SA Navy which scientific approaches/methodologies would best suit which problem types (for both in-house use and to advise the SA Navy when other institutions are contracted for the actual Decision Support work).

   b. <u>Integrate and synthesize</u> scientific methodologies and tools as well as maritime warfare systems to provide practical utility to the SA Navy for specific requirements.

    c. Have the ability to <u>evaluate results from Decision Support</u> work from the perspective of its scientific validity.

    d. Have the ability to serve the problem-solving requirements for decision-making of the SA Navy by providing an in-house service which can <u>deliver utility timeously on an acceptably high percentage of requests for work</u>.

    e. Have the ability to identify with the SA Navy any external expertise required for specific requests for work and assist the SA Navy in <u>ensuring quality results</u> from such work.”

From this articulation it becomes apparent that the capability at IMT can also be utilised by the SA Navy as a “Scientific Quality Assurance Service” and no longer only as a “Scientific Problem Solving Service”. This is a direct result of having formalised a process which is valid for scientific problem solving for all problem types and all contexts. It enables IMT to also evaluate all scientific problem solving work in the light of this process.

5.2.3.2 Developing the capability

Having defined the capability, its development becomes the focus. This is both time consuming as new skills and new understanding need to be developed in the decision support practitioners, but also because new tools, processes and (infra-)structures need to be defined and implemented in IMT. Each of these is discussed briefly:

1. The study indicates the existence of problem types (and the resultant scientific techniques) which were not previously given specific recognition in any decision support service to the SA Navy (or the rest of the DOD). This requires the acquisition of new expertise with the resultant tools to utilise that expertise in practical problem solving. IMT is pursuing a combination of developing new areas of expertise, developing in-house new decision support tools, and acquiring commercial tools which focus on these “new” problem types.

2. Scientists are usually proficient in what is termed the Analysis Phase of the process. These scientists need to be sensitised and trained to also become

proficient in the other two phases.   For this purpose a "Diagnostic Workgroup" meets once a month to discuss the issues and aspects relevant to the Diagnostic Phase.   This is an ongoing process in the Decision Support Domain.

3. The model as described in Figure 2-14 (Chapter Two) is populated for the proposed "process product" and given in Figure 5-2. It was used to illustrate the progress of the implementation of the process described in Chapter Four during a planning session to report to the group of scientists in the domain. Due to the steep learning curve regarding the definition of the capability and the aspects of the Diagnostic Phase the requirements of the Synthesis Phase is not actively incorporated into the processes of the Decision Support Domain yet. The illustrative power of the model as described by Figure 2-14, Chapter Two, has become a common language in the decision support domain to evaluate progress of technology implementation in certain projects in the domain. This is seen as a major step ahead already. Formal implementation of this model as a vehicle for the Synthesis Phase is postponed until the Diagnostic Phase is sufficiently understood and implemented by all practitioners in the domain. At that time the "Diagnostic Workgroup" will cease to exist and a "Synthesis Workgroup" will become part of the processes in the decision support domain. It is foreseen that this will happen within the next eighteen months.
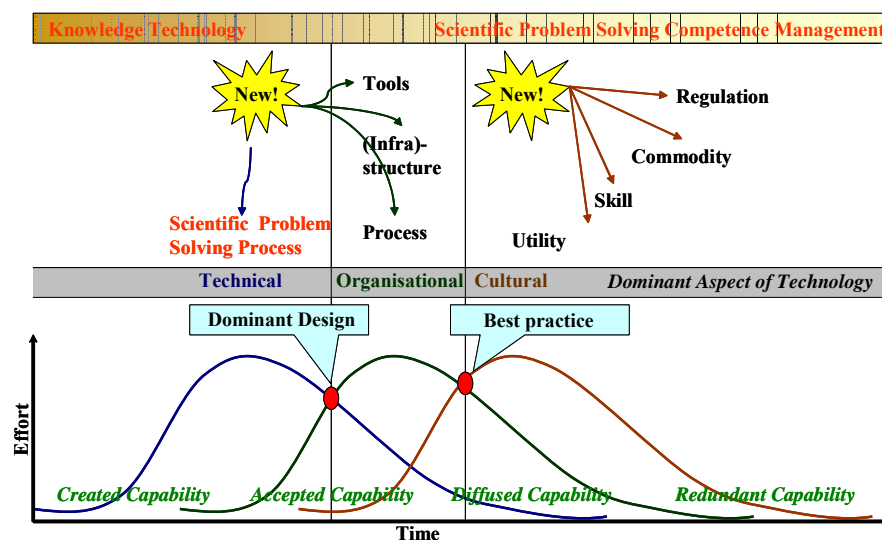

Figure 5-2 Process Product for Scientific Problem Solving

According to Figure 2-14 (Chapter Two), the implementation of the capability at IMT has reached the point of "dominant design" (i.e. the process as described in Chapter Four), but the necessary processes, tools, infrastructures and structures to embed that process into the practice of individual practitioners, as well as in the practice of group activities in the execution of projects, are ongoing. Looking at the implementation of the process in this way focuses the effort to be relevant, and provide a common picture of the progress made, so that it can be monitored in a meaningful way.

The Decision Support Domain does not foresee that it would have enough resources to develop all necessary expertise in-house. For this reason part of its infrastructure would include a network of relevant experts available for contracting in cases where problems requiring their specific expertise are encountered. The scientific quality assurance aspect of the capability provided by the decision support process becomes dominant for in-house development in the light of this reality. *The model developed at IMT to regulate this aspect of the Decision Support Infrastructure is mentioned in §* *2.1.2 in this context as an explanation why it is not given direct relevance in the* *choice of the perspectives to develop.*

The practice of pursuing simultaneously what appears to be mutually exclusive scientific approaches in IMT, utilising each where it is most productive, is a new culture which is only beginning to be accepted in the decision support domain. Its productiveness is illustrated by this dissertation, which highlights the productiveness of treating a complex problem with due respect (i.e. with appropriate boundaries, reductions, assumptions and initial values, and then using appropriate techniques to analyse the problem).

The process as described in Chapter Four does not only provide a common language for practitioners, or even an improved definition of scientific work, it also serves the very important purpose of enabling the identification of gaps in expertise, processes, tools and structures which need to be identified and implemented in an ongoing development and implementation of the process at IMT.

5.3   Conclusions

5.3.1 A change of culture pursued

Having understood the impact of Gödel's conclusions, IMT does not search for a complete description of the scientific problem solving capability to be developed at IMT, but rather for <u>a coherent way of approaching problem solving in a scientific manner, making the best use of the pluralistic nature of scientific method</u>. This change is a direct result of the study as articulated in this dissertation, which is in contrast with the goal pursued initially during the construction of the TIS. It also articulates an insight into scientific method (i.e. what to take as minimum requirements to ensure the goals of science are upheld) which would not have become known if the complexity of the problem at hand was not recognised and pattern management pursued (via the vehicle of perspective filters) in the pursuit of the definition of the capability, rather than a monistic description of scientific method and its application to decision support.

5.3.2 Suitable for knowledge creation as well as the articulation of new knowledge

The results of the theoretical study as described in Chapter Three, highlights the productivity of the proposed process in the field of scientific problem solving. This is of particular interest because it utilises a technique developed by social sciences (i.e perspective filters) to provide answers for what was traditionally a capability pursuing the techniques of natural sciences. The trans-disciplinary value of the proposed process is illustrated in this way.

The proposed process, and resultant methodology used during the Analysis Phase also provides a productive way to articulate the findings of the study. This would otherwise be difficult, because there is no single line of argument leading to the results. There is also no apparent convergence in the study of the various perspectives from literature (quite the contrary, they often compete and try to prove themselves to be superior in comparison) – yet they come to convergent conclusions, articulating the conclusions differently but describing enough of the attributes of their conclusions for commonality to emerge.

5.3.3 Taming the demands of an ever-changing context

The process described in Chapter Four provides the definition of a stable capability in an ever changing context. In this way the weaknesses inherent in the first attempt to define the capability, are overcome. The definition which came about after the second attempt to define such a capability (which is described in this dissertation) is insensitive to changes in the context. As long as the frameworks for problem categorisation remain valid and a sufficiently complete description of current understanding of problem categorisation in future, the capability will not need redefinition.

The fact that a stable capability is defined does not remove the reality that the Decision Support Domain is very sensitive to changes in its environment. These changes will still necessitate constant changes in application areas to be serviced by the Decision Support Capability. The definition of the Process described in Chapter Four, together with the framework(s) of problem categorisation, provide the background knowledge to identify for each new application field to become proficient in the minimum set of techniques (i.e. a representative set of techniques which would cover all problem types according to the problem categorisation framework) which needs to be understood in order to service the new area of application. This does not remove the requirement of constantly learning new techniques, but it does provide a vehicle to do so in a structured and planned manner to become proficient in servicing an ever increasing set of application areas relevant to the SA Navy.

In this way the process described in Chapter Four provides the backbone of a stable capability, with the framework(s) for problem categorisation serving as a window through which to observe the ever-changing environment. All requirements for studying a new field of application can now be managed in terms of the categorisation framework(s) – to ensure that a representative sub-set of techniques (covering the problem types relevant to the field of application) is studied rather than to focus the effort on one (or a few) problem types. This leads to a revisit of the TIS.

5.3.4 A new Technology Income Statement
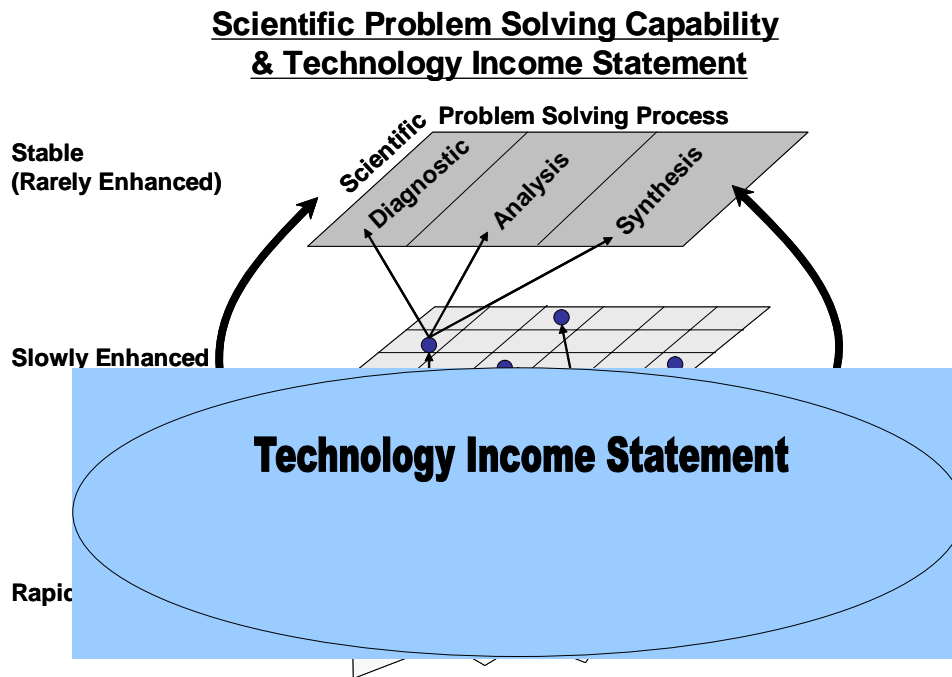
Figure 5-3 Role of the Technology Income Statement

The TIS which IMT developed for the envisaged capability initially could not serve the purpose of defining the capability sufficiently. Rather, it highlighted the adverse impact of the openness of the decision support domain to changes in its environment in the light of long lead time to develop any aspect the of the capability required for application areas (historically shown to be at least three years from no capability to a capability which is operationally able to provide a timeous service in problem solving). It was therefore instrumental in highlighting the need for another approach, which led IMT to conduct the study documented in this dissertation. Having completed that process, other TIS, using the Problem (and context) categorisation framework has been developed. It serves to ensure that for each field of application for which techniques need to be studied, a representative set of techniques can be defined so as to optimise the effort in ongoing learning of the decision support practitioners. A schematic presentation of the scope of the TIS as part of the complete capability is given in Figure 5-3. An example of the resultant structure of the new TIS is given in Appendix E.

Chapter 6: Final remarks and recommendations

6.1 Summary of results of the dissertation

This dissertation illustrates how the observation embedded in the growth of knowledge about scientific method during the twentieth century, namely that it is pluralist in nature, can be applied to enhance the growth of knowledge in a disciplined manner.

Having failed to provide a solution to the problem of defining a scientific problem solving capability at IMT, which can be developed with relative low risk of becoming sub-optimal due to the time and effort investment required for such a development at first, the recognition that the problem is complex in nature, caused IMT to rework it using a technique of complexity theory.

Using a technique which suited the problem type proved to be surprisingly productive. Insights emerged from the simultaneous study of the five perspectives which eluded those who studied specific disciplines in depth. These insights are documented in Chapter Three. The centuries-long debate about scientific method, brought to a climax in the twentieth century again, also made sense in the light of this approach:

- changing the implicit assumption of monism to that of pluralism overcomes the problems embedded in the traditional debate about scientific method by dissolving it (a typical way to deal with problems in complexity techniques)

- Gödel's work points to a formal mathematical reason for pluralism

- The developments in logic illustrates the fact that various contexts function according to different logic (thus pointing to pluralism in scientific method)

- Empirical results of systems thinking, operational research, cybernetics and complexity points to pluralism, also providing a mechanism for problem categorisation.

The emergent properties as documented in chapter three provided the backbone for the problem solving process as described in Chapter Four, together with the following insights from Popper's work on scientific method:

-   Scientific <u>objectivity</u> is in essence subjectivity, articulated sufficiently to facilitate for it to be open to criticism, especially articulating under what circumstances the theory/results will be falsified.

-   Refocusing science to pursue absolute truth as a guiding ideal, thus bringing the search for new knowledge and moving ever closer to the truth (i.e. <u>reality – defined as "according to true fact"</u>) back as a central goal of science.

-   Stating that "science starts with a problem", thus indicating the success of science as a vehicle of <u>knowledge creation through solving problems</u>.

These results are used to define a stable scientific problem solving capability, which can be developed in an ever changing environment, without the risk of becoming sub-optimal before it becomes operational. This capability also provides all the necessary elements of a scientific quality assurance capability – to ensure that scientific work is done in a way that does justice to the problem at hand, analysed using appropriate techniques, and that results are implemented in a scientifically justifiable manner.

The dissertation itself becomes a case study of the approach promoted by this study, namely to use a pluralist process of problem solving to grow scientific knowledge. In this way the "process product" is a "knowledge technology" which can be used to grow knowledge across scientific disciplines, illustrated by its use in this dissertation.

6.1.1 The limits of understanding when dealing with complex problems

Cilliers and others state clearly that it is impossible to model complex problems. Conversely, they state that a complex problem can only be modelled by a model which is at least as complex as the problem itself. This result of complexity theory leads to the observation that only partial understanding of a complex problem is possible. That partial understanding is highly dependent on choosing appropriate reduction (i.e. appropriate for the context within which the problem presents) and then looking at the problem from various perspectives (according to Snowden), or through

various windows (according to Flood). This provides partial insight into the problem, but, as is illustrated by this dissertation, also provides insight which cannot be obtained otherwise (i.e. by traditional analytical methods).

Complex problems can therefore only be studied with coherent understanding as a goal, not with complete understanding as a goal (according to Gödel again). This is a humbling result of complexity theory, making partial knowledge the best we can achieve in the study of complex problems. This partial understanding is highly dependent on the choice of perspectives (i.e. the choice of action space by drawing boundaries), the choice of what reduction(s) to use, and the appropriateness of the techniques used during the analysis. It also needs to take into account that any such coherence can only be obtained with hindsight.

6.2 *Pluralist scientific problem solving capability at IMT*

Against this background the proposed scientific problem solving process as defined for the capability at IMT is a partial (albeit coherent and sufficient) description of the required capability, which needs to be upgraded and revisited constantly as new knowledge becomes available.

The capability as defined in chapter four, with its underlying weaknesses and strengths due to the assumptions, reductions and boundaries, is more complete than any predecessor at IMT, able to provide a far more versatile capability – i.e. able to solve a much wider range of problems with a higher quality of output. This is potentially a significant upgrade of IMT's service to the client.

The definition of a pluralist scientific method proposed in this study differs from other prominent current views of pluralism in that it upholds the realist aim of science (i.e. science has the pursuit of truth as a regulating ideal). The proposed reason for accepting a pluralist view of science in this study rests on the observation from developments in the twentieth century which indicate that not all problem types are the same, and that not all contexts function with the same logic. Gödel's result is also taken as formal indication that monism is not a realistic goal to pursue.

6.3 Knowledge technology

The definition of the scientific problem solving capability is a "process product" which can be managed and implemented like any other technology. It is a technology for knowledge growth which is scientifically justifiable. As such it becomes a tool for the knowledge society (and the knowledge industry) in its wider context, even more so because it is applicable trans-disciplinary. It is especially useful for the third phase of knowledge management.

It also provides the attributes for quality assurance standards for scientific work. Thus far all quality assurance in IMT has been done according to the standards applicable to "hardware products". The results of this dissertation make it possible to define the quality standards for "knowledge products" like the process defined and described in chapter four.

This process does not only serve as the definition of a capability to develop, it also serves as a *research management* tool in that it provides managers with the parameters by which to evaluate research results, as well as with the definition of what kinds of capabilities to develop for such a capability. It needs to be stressed that the process can only be utilised in group/team context, it requires too wide a definition of capability to develop all its aspects in an individual.

6.4 Recommendations for further investigations

The process as described in chapter four can be used as a scientific quality assurance capability, i.e. providing a service to the client to ensure scientific work of a high quality by contractors. As mentioned in the previous paragraph, additional work can be done to formalise quality assurance standards and procedures for this kind of "knowledge technology", but it falls outside the scope of this study.

The criteria defined in chapter two for choosing the perspectives to include in the investigation leave room for the inclusion of "*The d*evelopment of Innovation" as an additional perspective. This requires a study of the historical development of innovation, as well as the development of notional understanding of innovation. It is uncertain whether that perspective will add new insights, and if so, what insights would be created. For the purposes of this study it was not included, because of the

strong focus on problem solving and its interplay with knowledge creation. Future work might include an investigation of this perspective.

A pluralist scientific method requires a mechanism to decide on which scientific approach to use under what circumstances. Literature provides such "Problem Categorisation Framework(s)". In this dissertation the Cynefin Framework (of Snowden) and the Total Systems Intervention Framework (developed by Flood) are described. They are used in chapter three to define a combined problem solving framework for illustrative purposes, but no population of such a combined framework is pursued. More work to refine the definition of such combined framework(s), and how to use them, is necessary, since problem solving framework(s) become pivotal in providing high quality practical problem solving. That is not pursued in this dissertation.

The three phases of the problem solving process as described in chapter four are well-known. The aspects as embedded in each of them are described conceptually only in this dissertation. Much value can be added by studying these aspects in more depth and identifying theories and techniques which would enable appropriate utilisation in all known context/problem types. This work is not pursued as part of this dissertation.

Recent work in cognitive psychology and cybernetics provide the knowledge base to indicate that there is a possibility that certain people would be more proficient in solving certain kinds of problems. If these problem solving profiles can be identified and quantified, the investment to train decision makers and utilise them in contexts where they would thrive rather than struggle (due to the types of problems they are confronted with) could add much value to any organisation. This is not pursued any further in this dissertation.

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Appendix A: Descriptions of scientific method from history

A.1 A few thinkers who shaped the philosophy of science

The descriptions of scientific method provided here can be grouped together in terms of development of thought as shown below.   The descriptions are provided as examples of some of the most prominent views influencing the development of scientific method, and not as an exhaustive account in any way. In giving a summary of their respective contributions, only that which is relevant to this study is noted, and again not covering all the aspects of their work. The list will include at least a short summary of the contributions and insights of

1. Galileo, Newton   (Importance of testing hypotheses arrived at through deduction by subsequent experimentation)

2. Descartes, Kant   (Deduction (logical justification), combined with a priori knowledge)

3. Bacon, Hume (Induction and psychological justification)

4. Leibniz, the Bernoulli's, Bayes (Induction and Probability)

The groupings above indicate those who pursued similar goals, which are given in parentheses.   The first two groups pursued absolute certainty, while the last two groups (except for Bacon) conceded that absolute certainty could not be obtained through their methods. A more detailed discussion follows:

A.1.1 Francis Bacon (1561 – 1626)

Still very much searching for the 'cause' of observation as the true goal of science to provide new knowledge, he placed more emphasis on experimentation (passive observation of properties through the senses) in finding such knowledge. His views were shared by many members of the Royal Society in Paris, establishing the school representing *classical empiricism*. Bacon accepted that his method could not provide complete certainty of the cause identified. He was also the first one to propose that

science should be employed in service of humankind and not just be an endeavour to gain more knowledge.

Bacon tried to find the 'cause' by elimination from tables of similarities and opposites found in nature to the subject being studied. These tables were empirically constructed. Only those properties which withstood this test, were then taken as the underlying 'cause'. Although Bacon's method is no longer in use today, his emphasis on method, specifically elimination, was a valid addition to scientific method. Bacon embarked on a progressive inductive ascent up the pyramid, reasoning from observations to generalisations.

A.1.2 René Descartes (1596 – 1650)

Still very much seeing the goal of science as finding the 'cause' in the way Aristotle prescribed, he nevertheless placed emphasis on mathematics and human intellect in finding such knowledge. His views were shared by Hobbes in England, establishing the school of thought which is called *classical rationalism* or intellectualism. Descartes is famous for "I think, therefore I am". Although Descartes tried to get away from the unfounded hypothesising based on mere opinion, or speculation, which prevailed at the time, and therefore focused on the correct method, he nevertheless criticised Harvey (who correctly identified the heart as a pump through experimentation) for not being able to find the cause of the heart pumping, as well as Galilei, who was able to explain the movement of the planets mathematically, but could not explain the cause of such movements. Yet Descartes' focus on method to get real knowledge and his focus on mathematics furthered the development of scientific method. Descartes accepted that his method of employing the human intellect could not provide complete certainty of the cause identified.

He started his "systematic and methodological doubt" (i.e. methodological scepticism) from the apex of the pyramid and moved down through a deductive procedure. He realised that one cannot move down from the apex very far without requiring empirical data, and his passion for generalisations (often from hypotheses suggested through analogies) often led him astray.

He was a foundationalist in that he believed that knowledge must be justified in order to be rational, and in order to justify knowledge it must be derived from an infallible source. He believed the God-given intellect was such a source, therefore using a priori intuition as his source of truth.

He described two methodological principles, namely "methodological Scepticism" and what can be called "French Epistimology" [Notturno, 77-79]. These two are now described in some detail.

Methodological Scepticism:

"Methodological Scepticism says that we should question any statement that has not been shown to be true, and that we should always remember that a belief that has not been shown to be true may turn out to be false no matter how familiar or obvious it may seem." [Notturno, 79]

In this way methodological scepticism tells us how to arrive at the truth, or how to respond to statements that cannot for certain shown to be true.

French Epistemology:

"French Epistemology says that we should regard a statement as false, or at least that we should not accept it as true, unless or until it has been shown to be true." [Notturno, 79]

In this way French epistemology tells us how to avoid mistakes. (This principle has been implemented in the French judicial system as the principle whereby in cases of *reasonable doubt* the assumption of *innocent until proven guilty* may be reversed. The person's previous convictions, family history, observations, etc. may then be used in the trial in order to convict the person. This is in contrast with the Anglo-American judicial systems.)

A.1.3 Galileo Galilei (1564 – 1642)

Galilei searched for absolute certainty in the answers science provided, but did not see the goal of science, like Atistotle did, in finding the 'cause' any more. For Galilei

" ... the book of nature is written in the language of mathematics, and consequently a mathematical demonstration of the facts of motion from accepted principles does provide real knowledge of nature" [Gower, 67].

A.1.4 William Harvey (1578 – 1657)

Galilei's contemporary, William Harvey, was the first to identify the flow of blood as being due to the pumping action of the heart. Much to Descartes' dismay, he made no effort to explain why the heart was pumping! He also did not see the goal of science as finding the cause any more, but his emphasis was on experimentation to find real knowledge from nature. Harvey was Bacon's physician.

A.1.5 Isaac Newton (1642 – 1727)

Newton must have been aware of the work of Descartes (emphasising mathematics in finding the 'cause'), and of Bacon (emphasising experimentation to find the 'cause'), but he did not give any explicit indication of having been influenced by any of these. Instead, he continued in the tradition of Copenicus, Brahe, Kepler and Galilei where he no longer searched for "cause", but rather to describe nature through mathematics and experiment. He shared the view of avoiding "hypothetical reasoning" (i.e. reasoning that a hypothesis must be true because it is able to explain certain phenomena – Aristotle's "saving the phenomena" principle) from which both Descartes and Bacon tried to get away by describing their respective methods. It was the success of Newton's work that finally caused the views contrary to those of Aristotle (in looking for the 'cause') to prevail. Newton was searching for practical (or 'moral') certainty in the answers his method provided, but did not claim absolute certainty, i.e. his method can establish certainty beyond reasonable doubt.

Although he did not give much explicit attention to documenting his method, it can be found by studying his writings. His success and the way in which he transformed science make his method an important part of this study.

"While Galilei and Descartes, and Harvey and Bacon, supposed that both mathematics and experimentation have important roles in scientific method, Newton showed by precept and example how it was possible for them to have such roles." [Gower, 79]

Initially Newton documented two rules for reasoning, and later he added the last two rules (about the role of induction) because of criticism of his method. They are

"Rule 1: We are to admit no more causes of natural things as are both true and sufficient to explain their appearances.

Rule 2: Therefore to the same natural effects we must, as far as possible, assign the same causes.

Rule 3: The qualities of bodies, which admit neither intensification nor remission of degrees, and which are found to belong to all bodies within the reach of our experiments, are to be esteemed the universal qualities of bodies whatsoever.

Rule 4: In experimental philosophy we are to look upon propositions inferred by general induction from phenomena as accurately or very near true, notwithstanding any contrary hypotheses that might be imagined, till such time as other phenomena occur, by which they may either be made more accurate, or liable to exceptions" [Gower, 69-70]

These four rules were given by Newton, as was his choice of how he presented his results in his publications, in the first place to make his theory and results acceptable to his critics and to place it in the context of his readers more than anything else. His method is called the _Hypothetico-Deductive method_. He opposed the use of hypothesis in the inductive way it was done in his day. His ability to devise experiments which tested his hypotheses sufficiently, provided him with the toolkit to arrive at "practical certainty" of his results. He went far beyond being a passive observer of nature, employing instruments both for more accurate measurements (like the telescope) and to probe properties of phenomena in experiments (like the prism). Induction for him was therefore controlled by careful experimentation and modelling, utilised to test his hypotheses.

Some commentators of scientific method, e.g. Gower, who wish to promote inductive inference as the primary method of science, hold that although Newton did not acknowledge to it, in retrospect it is clear that he derived some of his hypotheses from the results of his previous experiments, and did not employ experiments solely to test his hypotheses. While such an observation is possible in retrospect, it is by no means

necessary. Any scientist who ever designed an experiment can answer that an experiment is designed for a specific purpose (i.e. with a priori theory) rather than just blindly to "see what happens". New insights do come from experiments, but then as surprises (therefore as disproving our prior theory, or showing it as incomplete), and not by design. We continue to test these new insights by making hypotheses as to what could have caused the surprising results and by testing those hypotheses by further experimentation. This explains Newton's apparent "learning from his experiments" rather than only testing his hypotheses. This is very familiar to the practice of scientists even to this day. However, the role of experimentation and observation in science (as a valid vehicle for inference as well as to test hypotheses, or only as a vehicle for testing a priori hypotheses) remains a watershed argument in the discussion of scientific method.

A.1.6 David Hume (1711 – 1776)

Hume noted that "all reasoning concerning matter of fact seems to be founded on relation to cause and effect" [Gower, 102]. He raised serious concerns about the use of probability in scientific reasoning when for the relevant subject matter there could be any doubt that the course will change, so that complete consistency would not hold in space and time. He also objected to the validity of inductive inference.

Due to the success of the empirical methods of Newton and others, philosophers became increasingly convinced that not a priori knowledge or intuition, but sense experience (stemming from empirical work) is the proper criterion for truth. They concluded that scientific theories must be derived by inductive inference from experience. This developed into the rejection of beliefs that could not be grounded in sense experience alone. It was in this context that Hume then objected by saying that relying on sense experience only leads to irrationalism. He pointed out that there is no valid way to infer from past experiences what would take place in future. Such inference leads to "psychological justification" through custom and habit rather than to rational justification. Although Hume saw that inductive inference from observation leads to irrationalism, he did not object to this irrationalism, because he maintained that "the reason is and ought to be the slave of the passions".

Hume's empiricism can be explained by looking at his theory of the origin of ideas. [Notturno, 153-155]. Hume's theory of meaning held that the meaning of a term is an idea, and that a term is meaningful only if that idea is a copy of an impression or a combination of impressions (with "impression" coming from sense observation only). He therefore argued that our idea of causality is derived from our feeling of expectation that one event will follow another. This expectation comes from repeated prior observation of the conjunction of those two events. Unless we had such experiences of conjunction, we cannot have an idea of causality for any combination of events. It is important to note that he found it necessary to state this because of the way he saw ideas, and because he had to explain our obvious awareness of causality in a way that could be linked to sense observation only for his empiricism to be valid. He had to do this, because otherwise causality would fall into the non-observable category of e.g. forces, the meta-physical and the self, which Hume claimed was meaningless and could be discarded. If truth can be defined in terms of sense observation only, then nothing that cannot be observed by our senses exists.

So Hume did not argue that we *should not* have an idea of causality other than what we have due to prior sense experience of repeated conjunction of events, his argument was rather that we *do not* have such an idea. But if we really cannot have ideas of causality, force and the self (other than from previous experience), the question is why this "matter of fact" statement of the theory of the meaning of ideas can be regarded as controversial or even as interesting, since we would have nothing else to compare it to. The mere fact that it is seen as either interesting or controversial and open for further investigation shows that other possibilities exist – which points to the fact that such *a matter-of-fact position regarding sense-experience-only could be interesting only if it was false*. If it were true it would not be interesting at all. If on the other hand Hume's argument was that we *should not* have ideas of causality etc. other than what we had through sense observation, it would be interesting whether or not it was false.

By going to great lengths to explain our idea of causality in the way he did, Hume therefore did science the service of exposing the weakness of an experience-only criterion of truth. He could not deny that we had an idea of causality (it was in fact a

very important ingredient of scientific enquiry from early ages), but had to define it as a sense-experience-only idea.

A.1.7 Emmanuel Kant (1724 – 1804)

Kant disagreed with Hume, arguing that there is a priori synthetical knowledge.   He used Newtonian physics to show that causality is expressed in the law of inertia, substance is expressed in the law that matter is conserved, and community is expressed in the law that action and reaction are equal and opposite. [Gower, 135] He argued that we impose a conceptual structure upon our experience and thought, so that we observe and think according to an a priori synthetical knowledge. He based many of his views and arguments on Newtonian science. It was therefore inevitable that when Einstein's theories overthrew Newton's theories, Kant's philosophy was discredited at the same time. In this way foundationalism was challenged to its core, with the result that a sense-experience-only view of science prevailed in the first part of the twentieth century, as well as a widespread abandoning of the quest for truth (or "certain knowledge") as goal among both philosophers and scientists.

Kant believed that knowledge is infallible, and that errors occur because of madness. He based his view of rationality on the infallibility of the a priory knowledge that we have and believed with other rationalists that our theories can be justified.

A.2 Probability and (un)certainty

As induction gained ground in scientific method, the issues about certainty and probability also became more pressing. This section gives a short overview of the development of thought around the issues regarding probability.

Newton introduced his concept of "practical certainty" instead of absolute certainty. This emphasised the problem of when to know with absolute certainty, when to accept a conclusion reached. Degree of certainty had to be defined for any conclusions reached where there was no absolute certainty. His contemporary, Leibniz (1647 – 1716) criticised him on his acceptance of "practical certainty" while he excluded hypothetical reasoning. At the same time the Bernoulli's were doing work on probability as well, trying to find mathematical ways to quantify degrees of belief. But a degree of belief contains psychological elements, and cannot just be calculated.

D'Alembert (1717 – 1783) tried to prove this point and argued against the results of the Bernoulli's. It was during this time that Hume also expressed his concerns about probability (as already stated).

Thomas Bayes (1702 – 1761) used "the doctrine of chances" to explore the problem from a perspective of '*Given* the number of times in which an unknown event has happened and failed: *Required* the chance that the probability of its happening in a single trial lies somewhere between any two degrees of probability that can be named.' Bayes was able to derive ways to calculate these, but took the following things for granted, namely:

1. The equi-possibility of all causes of the event, and

2. that his work is also applicable when no prior knowledge of the event is available.

3. that the unknown chance of an event occurring does not change over time or from place to place. (He ignored Hume's objection to the assumption of consistency in induction, so that he can also only at best work on "psychological justification".)

These things, however, cannot be assumed in actual events.

Laplace (1747 – 1827) continued work on this subject, and claimed that degrees of certainty could be quantified in a number of contexts where scientists used such probable arguments. He was able to determine the probability of an event to happen under certain circumstance, given the number of times the event happened and did not happen in the past under those circumstances. His results also assumed certain things, namely

1. Prior to any evidence being available, the unknown chance of an event taking place could take any value, and

2. That no value was more likely to be true than any other value.

These were exactly what Leibniz and the Bernoulli's already noted, and why Leibniz concluded that probable reasoning in practical science cannot take this for granted.

All the work of Bernoulli's, Bayes and Laplace assumed that <u>probability was a degree of belief</u>.

Venn (1834 – 1923) defined <u>probability in terms of frequency</u> in a quest to overcome the problems experienced by the earlier work. He pointed out that Laplace's formula gives a 0.5 probability for any event that has never occurred, and concluded that this was unacceptable. He was one of the first ones to propose the frequency definition of probability.

Peirce (1839 – 1914) agreed with Venn about the definition of probability in terms of frequency, and distinguished three different kinds of <u>probable reasoning</u>, namely

1. Inferring a particular conclusion from a general statistical claim (e.g. if only 2 percent of people wounded in the liver recover, then there is a 1/50 chance of any individual so wounded will recover). This conclusion will of course be better the bigger the sample from which the statistical claim was made.

2. inversion of probable deduction (quantitative inductive reasoning), e.g. if we take a handful of beans from a bag, and 90 percent is perfect, we conclude that 90 percent of the beans in the bag is perfect. This result will obviously become better the bigger sample we take from the bag (i.e. taking ten handfuls instead of only one).

3. Hypothetical inference (qualitative induction). A possible world in which a certain hypothesis is true will have certain characteristics (which we can derive from the hypothesis). When we observe that our world has a certain proportion of those qualities, we conclude that our world has a certain degree of likeness to that hypothetical world.

Both 2) and 3) are contentious when probability is understood the way Venn and Peirce proposed, i.e. in terms of frequency of occurrence. However, Peirce pointed out that quantitative induction is self-corrective in that the bigger the sample, the closer the conclusion to the actual value. In the same way hypothetical inference can be seen as the hypothesis scientists will eventually accept. In this way the logic we use in scientific method is self-corrective in the sense that persistent recourse to it will bring us closer to the truth. This seems to be an appropriate description of the

anomalies in scientific method, since in many ways this was at the heart of debates about scientific method since the seventeenth century – some proposed what Pierce called quantitative inductive reasoning, while others proposed what Peirce called hypothetical inference.

Appendix B: Logical Grounds for Deduction and Induction

A short description of the inherent difference between deductive reasoning and inductive reasoning follows [Notturno, 2000, Chapter 5]:

Compare the valid modus tollens:

$P \rightarrow Q$ (ïf P then Q)

$\sim Q$ (not Q)

$\therefore$ $\sim P$ (therefore not P)   (Argument 1)

with the invalid affirmation of consequent

$P \rightarrow Q$ (if P then Q)

Q (Q)

$\therefore$ P   (therefore P)   (Argument 2)

The conditional for argument (1) is

$[(P \rightarrow Q) \& \sim Q] \rightarrow \sim P$ (P therefore Q, not Q, therefore not P) (Conditional 1)

The conditional for Argument (2) is

$[(P \rightarrow Q) \& Q] \rightarrow P$ (P therefore Q, Q, therefore P) (Conditional 2)

An argument is valid if and only if its corresponding conditional is a tautology (i.e. true under all circumstances).

But since $P \rightarrow Q$ is equivalent to $(\sim P \text{ V } Q)$, each of the above conditionals has the equivalent correspondent disjunction

$\sim [(P \rightarrow Q) \& \sim Q]$ V $\sim P$ (Argument 3)

and

$\sim [(P \rightarrow Q) \& Q]$ V P. (Argument 4)

This illustrates the important fact that an argument presents us with a choice instead of a justification. Disjunctions corresponding to valid modus tollens are tautologies, and disjunctions that correspond to invalid modus tollens are not. It means that we are free to deny both alternatives provided by the affirmation of consequence (i.e. formula 4 in the example), but we are not free to deny both of the alternatives offered by a valid modus tollens (i.e. formula 3 in the example). By "free to deny" is meant free to deny without contradicting ourselves. This is explained as follows:

For (3):

Table 1

P	Q	~[(P → Q) & ~Q]	~P
T	T	T	F
T	F	T	F
F	T	T	T
F	F	F	T

From Truth Table 1 it is clear that if I want to deny the conclusion of (1) and assert that ~P is false, then ~[(P → Q) & ~Q] will always be true. Similarly, if I want to assert the ~[(P → Q) & ~Q] is false, then Truth Table 1 shows that ~P is true. There is therefore a logical relationship between the alternatives that a modus tollens offers. Notice, however, that it does not supply us with a justification, but rather with a logical consequence of a choice we make. We are also not free to deny both of the statements ~P and ~[(P → Q) & ~Q].

For (4):

Table 2

P	Q	~[(P → Q) & Q]	P
T	T	F	T
T	F	T	T
F	T	F	F
F	F	T	F

Suppose I want to assert that the conclusion P is false, from Table 2 it is clear that ~[(P → Q) & Q] can be either true or false, so that (4) is not a tautology. Suppose, on

the other hand, I want to assert ~[(P → Q) & Q] is false, then Truth Table 2 once again shows that P can be either true or false. This means that, contrary to the modus tollens, we are in this case free to assert and deny BOTH the alternatives offered by the affirmation of consequent (4).

This shows that affirmation of consequent (4) is useless both for justification and criticism. However, the affirmation of consequent offers, according to Notturno, most closely the general form of inductive arguments. This shows therefore that inductive arguments give us neither grounds for justification, nor critical control. At best then, inductive arguments induce us to believe that our guesses are better than guesses. This, Notturno argues, shows the real problem with inductive arguments.

Note that this is a problem with inductive inference. The great difference between inductive inference and deductive inference is that the inferences may be false even if the conclusions are true. This is why Popper turned away from induction as a valid method in science, and not in the first place because it causes un-productivity. This is also why inductive inference is as useless for criticism as it is for justification.

Some philosophers hold that even though inductive inference has this weakness, it is still possible to hold on the 'principle of induction'. It must be noted that such a principle could only be valid in science if it does not make use of inductive inference, but rather of deductive inference.

Note also that not even deductive arguments affirm the truth (and therefore are useful for justification), they only present us with a choice that would lead to logically valid conclusions. We can only assert the truth of a conclusion if all the premises are true. In order to further understand Popper's insistence on deductively valid arguments, it is important to also note that, with the exception of contradictions, only logic can show that a statement is false, and falsification is Popper's way of testing theories.

Appendix C: Copy of a motivation to the SA Navy to explain the process followed in IMT to define and start to develop the decision support capability described in this dissertation.

This is a copy of the document provided to the SA Navy as part of the Synthesis Phase of the capability at IMT. Its aim is to articulate realistic timescales and areas of service which the SA navy can expect from the capability at IMT.

IMT lost a significant part of the expertise it had at the time in Decision Support with the departure of two of its senior members. IMT then had to rebuild this capability, which incurred a greater than usual requirement for capability development in the Decision Support domain.

It takes about three years to build expertise in any given area of relevance for Decision Support to a level where utility can be provided timeously.

C.1 Development of expertise for decision suppport

IMT started about three years ago to redefine and rebuild a relevant capability in order to be able to provide the scientific support service to the SA Navy. This situation was used to reconfirm the definition of the required capability for a scientific problem-solving service to the SA Navy. IMT embarked on a process of investigation where areas of relevance were studied and interpreted to ensure the best possible definition of such a service.

Defining a service of this nature is not trivial due to the following parameters stemming from a client perspective:

1. The scope of problems which the SA Navy could pose to the Decision Support domain stretches across all system levels.

2. The scope of problems which the SA Navy could pose to the Decision Support domain comes from a wide variety of possible fields of application (e.g. combat systems, support functions, management & organizational problems).

3. Resources available to the Decision Support domain does not leave room to cover the whole area of possible problems from client application areas. Identifying the best possible toolkit of expertise to cover as wide a scope as possible is therefore necessary.

Defining a service of this nature is furthermore also not trivial due to the following parameters stemming from the perspective of the technological and scientific fields relevant to such a service:

1. Problem-solving of this nature requires a multi-disciplinary approach, which means that pure academic training needs to be supplemented by in-house hands-on expertise development.

2. There are many academic disciplines relevant to Decision Support work, each with its own expertise base and respective strong and weak points.

3. New developments in Research and Development, Technology, Scientific Method and Knowledge Management make it possible to provide a better service now than was possible before. This requires that IMT develops expertise which was not part of its past expertise base.

C.2 Process followed in defining the service

Recognising the complexity of the situation as described above, IMT embarked on an investigation of which service would best serve the requirements of the client.

It was recognized that

1. Core expertise which has to be developed in-house needs to be defined carefully, since the investment to develop the expertise to an operational level for utility to the client is considerable (as mentioned it takes at least three years to develop to a point of adding sufficient value to the client to be called "utility").

2. A network of experts and their skill profiles need to be defined and maintained which could be contracted as required to serve the client's requirement on demand. Defining the expertise "developed" in this way depends both on the

gap between in-house expertise and the understanding of the scope of problem-types which could be encountered, and the availability of expertise in other institutions.

Both these realities were pursued simultaneously in the design of the IMT expertise base. The following were also taken into account and studied over a period of three years in order to understand the necessary expertise base to serve a reasonable number of requests from the client on demand timeously:

1. The historical types of problems that the client brought to IMT to be solved by the Decision Support domain.

2. Types of problems which could not be solved previously (or which could not be solved satisfactorily before), but for which the client expressed a requirement, and for which new developments in the science and technology exist which could be used to increase the quality of the service to the SA Navy.

3. Projected new types of problems, as seen from the perspective of the changed environment of the client, as well as new developments in technology and science, which could be brought to IMT in future.

4. The systemic nature of the required service to the SA Navy.

The Decision Support domain embarked on the following process to define the required expertise-base:

2. Articulate the process and dynamics used for problem-solving and define its elements in order to understand which implicit capabilities are required for Decision Support work. This was done in the first year of inquiry.

3. Articulate from the results of (1) the required capabilities on each system level taking into account all the above-mentioned parameters. This involved a scan of expertise at other institutions (this is an ongoing activity) as well as literature studies on new developments which could be useful for the service at IMT.

4. Map the results of (2) above on the prioritized problem-solving requirements of the SAN(DF) as extracted from past projects, current discussions with clients, foresight discussions in IMT and in discussions with clients and other experts in the field. Fields of client application were defined and allocated to the various Decision Support practitioners as a result.

5. Construct a model for Decision Support work at IMT which would serve the requirement of the SA Navy, formalize the complete problem-solving life-cycle, provide framework(s) for Decision Support practitioners to map practical problems to relevant scientific approaches.

6. Identify priorities from the result of (4)

    a. In terms of the types of problems we anticipate having to solve

    b. In terms of the minimum viable service to build in-house

    c. In terms of available expertise in other institutions.

7. Translate the results into the minimum definition of "expertise toolkit" which we need to develop at IMT. The minimum is defined as having an in-house expertise which could

    a. Categorise problems so that we can advise the SA Navy which scientific approaches/methodologies would best suit which problem types (for both in-house use and to advise the SA Navy when other institutions are contracted for the actual Decision Support work).

    b. Integrate and synthesize scientific methodologies and tools as well as maritime warfare systems to provide practical utility to the SA Navy for specific requirements.

    c. Have the ability to evaluate results from Decision Support work from the perspective of its scientific validity.

    d. Have the ability to serve the problem-solving requirements for decision-making of the SA Navy by providing an in-house service

which can <u>deliver utility timeously on an acceptably high percentage of requests for work</u>.

e. Have the ability to identify with the SA Navy any external expertise required for specific requests for work and assist the SA Navy in <u>ensuring quality results</u> from such work.

In order to achieve the goal as stated in (6) above, a working knowledge of representative scientific techniques need to be developed at IMT. After two years of study the four subjects defined in the IMT plan under the title **MODELLING TOOLKIT FOR DECISION SUPPORT (02.06.02)** were defined. They represent the minimum set of scientific modelling expertise to be able to understand the wide scope of problems which we anticipate to encounter. If we keep these to a level of sufficient capability that we can do a sub-set of the problem types relevant to each of these in-house, we'll also have the expertise to ensure quality results on those techniques we currently envisage to contract as required rather than to develop in-house.

Some of the results leading up to the conclusion found in the IMT long term plan was documented in IMT document P0076-000014-730 with the Title "Strategic Decision Support – An Appraisal". That document applies the results to strategic Decision Support, but the principles are relevant on all system levels. Other results are documented in the Decision Support domain in terms of internal documents and presentations to the team of Decision Support practitioners. These can be discussed with the client on request.

C.3 Conclusion and recommendation

While IMT makes every effort to ensure a relevant and streamlined service to the client, the following needs to be noted:

1. We cannot guarantee that we can maintain a state of readiness to serve the client's requirement timeously in <u>all</u> requests of work, even with the external network in place. Where we are confronted with problems for which we do not have expertise (in-house or in our external network), capability development will have to take place as part of the project work. This will impact on the time scale within which we can serve the client requirement.

This is unfortunately true due to the wide scope of work that could come to the Decision Support domain, coupled with the limited resources in the Decision Support domain.

2. Developing a new area of expertise to a level of readiness for service takes time. The areas currently defined constitute a minimum footprint of expertise in order to have a viable service. Any specific requirements from the client which would require the Decision Support domain to develop specialist expertise for specific fields of Decision Support need to be added to this as and when required in future.

3. The process we have followed in arriving at the current definition of the expertise toolkit needs to continue, due to the dynamic nature of the scientific fields underpinning the service, as well as the changing environment of the SAN(DF).

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Appendix D: Initial Technology Income Statement for the decision support capability at IMT

The initial Technology Income Statement (TIS) is given in this Appendix. It serves to highlight the inter-relatedness of all its aspects (a change in any one of "Products" or "Technology" requires a change in the whole TIS. It is the effort to compile this TIS, together with its lack of stability (sensitivity to changes in the environment) that identified the need to conduct the study documented in this dissertation in order to define a more robust capability.

Initial TIS developed by IMT for the Decision Support Domain.

PRODUCTS

Provide New Insight

Clients

| SAN Office |
| SAN Fleet |
| IMT |
| SANDF |
| JOPS |
| DoD |
| IGDoD |
| Defence R&D |
| Industry |
| Other |

CORE COMPETENCIES

To conduct Def Research, exploiting relevant Decision-making science and technology in order to provide DS to the DoD and SANDF in the following areas:

1. Maritime warfare management functions and management models
2. Maritime Warfare Paradigms and Concepts of Operation
3. Maritime Warfare Operations modelling and analysis
4. Maritime Warfare Systems Integration and Systemic Modelling

Decision-making Technology

Model in following basic areas

Basic Disciplines

Capabilities

Cap Application

Skill Level: 4 3 2 1 0

| Technology Scan |
| Networking |
| Fact-based DS |
| Exp.-based DS |
| Utilising Tools |
| Utilising Facilities |
| Team Work |
| Marketing |

Cap Development

| Planning |
| Literature Study |
| Partnering |
| Facility Development |
| Expertise Development |
| Team Development |
| Process Development |
| Tool Development |
| Tool Evaluation |

System Level

| Technical |
| Tactical |
| Operational |
| Strategic |

Product LC

| Research |
| Development |
| Production |
| Operational |

Technology LC

| Emerging |
| Growth |
| Mature |
| Decline |

Technique Type

| Empirical |
| Numerical |
| Analytical |
| Conceptual |

Appendix E: Technology Income Statement for decision support domain from the problem categorisationTTTTTTTTTTTTTTTTTTTTTTTTTTTT framework.

The Combined Problem Categorisation Framework (as described in Capter 3) is used as the underlying structure of the new TIS. The purpose of this technology statement is to manage the fluid part of the capability, namely to remain relevant to the changing context of the client as well as the changing context of the scientific approaches relevant to scientific problem solving. Its sole purpose is to manage a balanced capability in fields of application, covering as wide a scope of problem types with the minimum required effort. For illustrative purposes no changes are made to the "Products" and "Basic Disciplines" aspects – they are left as they were in the original TIS. The only changes occur on the "Problem Solving Types" (called "Decision making Technologies" in the previous TIS) and "Capabilities" axes.

New TIS taking into account the Problem Solving Process developed in this dissertation – for illustrative purposes only.